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Zootechnologies: Swarming as a Cultural Technique

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Abstract

This contribution examines the media history of swarm research and the significance of swarming techniques to current socio-technological processes. It explores how the procedures of swarm intelligence should be understood in relation to the concept of cultural techniques. This brings the concept into proximity with recent debates in posthuman (media) theory, animal studies and software studies. Swarms are conceptualized as *zootechnologies* that resist methods of analytical investigation. Synthetic swarms first emerged as operational collective structures by means of the reciprocal computerization of biology and biologization of computer science. In a recursive loop, swarms inspired agent-based modelling, which in turn provided biological researchers with enduring knowledge about dynamic collectives. This conglomerate led to the development of advanced, software-based 'particle systems'. Swarm intelligence has become a fundamental cultural technique related to dynamic processes and an effective metaphor for the collaborative efforts of society.

Keywords

agents, computer simulation, cultural techniques, media, scientific visualization, social swarming, swarms

I. Fish and Chips

In his *Guide to the Study of Fishes*, an expansive reference work published in 1905, the ichthyologist David Starr Jordan posed the following question: 'What is a fish?' A fish, he answered, 'is a back-boned animal which lives in the water and cannot ever live very long anywhere else. Its ancestors have always dwelt in the water, and most likely its descendants will forever follow their example' (1905: 3). At first glance it would be difficult even today to refute this definition, so long as a few obscure exceptions

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are set aside. The ambitions of the seemingly hydrophobic mudskipper *periophthalmus barbarus*, an amphibious goby, come to mind in this regard. A second glance, however, reveals that fish have been seizing dry territory rather energetically for some time. Such land grabs, of course, have not been the result of baffling leaps in evolutionary biology. They rather owe their occurrence to a co-evolution that has taken place in the fields of biology and computer science. Fish, or more precisely schools of fish, have been a source of inspiration to a branch of computer science since the middle of the 1990s. Along with other biological collectives, such as flocks of birds and colonies of insects, schools of fish have inspired a field of research that has come to be known as computational swarm intelligence.

Computer applications of swarm intelligence make use of the effects that are observable in animal collectives. On a global level, the multiple and localized interactions among large numbers of relatively simply constructed 'agents' have yielded interesting potentialities of self-organization. Collectives possess certain abilities that are lacking in their component parts. Whereas an individual member of a swarm commands only a limited understanding of its environment, the collective as a whole is able to adapt nearly flawlessly to the changing conditions of its surroundings. Without recourse to an overriding authority or hierarchy, such collectives organize themselves quickly, adaptively, and uniquely with the help of their distributed control logic. Within swarms, the quantity of local data transmission is converted into new collective qualities.

It is thus possible to conceive of an initial way in which swarming has developed into a novel cultural technique. Swarm intelligence helps to configure an environment that is increasingly confronted with the task of organizing highly engineered and interconnected systems and also with the task of modelling complex correlations. It can be applied wherever there are 'disturbed conditions', wherever imprecisely defined problems present themselves, wherever system parameters are constantly in flux, and wherever solution strategies become blindingly complex. Swarm intelligence, according to one standard work, 'offers an alternative way of designing "intelligent" systems, in which autonomy, emergence, and distributed functioning replace control, preprogramming, and centralization' (Bonabeau et al., 1999: xi). To borrow an often-repeated notion from bionics, humans would do well in this case to learn something from the 'inventiveness' of nature.

There is yet another way in which swarming can be viewed as a burgeoning cultural technique. Since the year 2000, swarms have entered a growing discourse in the form of such expressions as 'smart majorities' (Fisher, 2010; Miller, 2010), 'smart mobs' (Rheingold, 2002), 'swarming in the battlefield' (Arquila and Ronfeldt, 2000), 'the wisdom of crowds' (Surowiecki, 2004), and simply 'multitude' (Hardt and Negri, 2004) – and this is not to mention their role in recent thrillers by Michael Crichton

(2002) and Frank Schätzing (2006). They have become a metaphor for the coordination processes of an engineered present, a present in which the flexible adaptation to ever-changing conditions can be associated with the alleged potential for freedom inherent in ‘autonomous individuals’.

With the help of ever more dynamic forms of interconnectedness, as the swarm metaphor suggests, we are able to use an instantaneous infrastructure of decision-making to our own advantage. To achieve certain goals, it is thought, we are thereby able to coordinate temporarily with those of the same mind. This ephemeral and apparently ‘grass-roots democratic’ conception of collectivity has promised to uncouple political, economic, and social behaviour from the structures of entrenched systems and social organizations such as nations, political parties, and labour unions. Swarming, as a sort of ‘network 2.0’, has come to be used as a celebrated catchword – for political demonstrations arranged by means of mobile media, for the type of communication that takes place in online collectives, and for the organization and availability of information or ‘knowledge’. Over the last 15 years, it seems, swarming has established itself both technologically and socially as a means of collaboration that is far superior to traditional forms of collective organization.

These recent developments are complicated, however, by a closer investigation into the genealogy of swarming intelligence. When, in what follows, I describe swarming as a cultural technique, I will attempt to approach the phenomenon by means of exemplary scenes from the media history of swarm research. It is worth clarifying, in general, the conditions under which swarms had been able to develop into productively deployable figures of knowledge, for traditionally they were associated either with an aura of the chaotic, escalatory, and uncanny (Tarde, 1901; Le Bon, 1896), or with a ‘miraculous’ and ‘divine’ power to fascinate (Maeterlinck, 1901). My approach below rests upon three theses, each of which problematizes and adjusts the paths of development, outlined above, that the concept of the swarm has undergone to become a cultural technique.

First, it can be maintained that the media history of swarm research has been based on a fundamental and gradual *withdrawal from naturalness* that has taken place within engineered environments of observation and experimentation. Analytic approaches and (media-technological) methods of observation have, for decades, been mired in a ‘technological morass’ (Parrish et al., 1997: 9), because swarms are problematic objects of knowledge: they disrupt the scientific processes of objectification by means of their dynamics in space and time. The only way to overcome this obstacle is to resort to synthetic methods of acquiring knowledge. Such methods are based on the recursive intertwinement of certain processes, namely those of the biologization of computer science, on the one hand, and those of the computerization of biological research on the other. In this way, swarm-inspired agent-based computer simulation models and the applications of computer graphic imaging, which originated in different places for different purposes, have ultimately gained entry into the field of biological swarm research. Over the course of this development, swarms have become both an object and a principle of agent-based models and their methods of computer graphic imaging. A sociobiological understanding of animal swarms, or of bionic transferences, falls short in its description of the dynamic relations among humans, animals, and machines.

In the case of swarms, it is no longer animals that serve as a model for mankind and its *technē*. What is noteworthy is rather the reciprocal interference of biological principles and the processes of information technology. Swarms should be understood as *zootechnologies*. In contrast to biotechnologies or biomedia (Thacker, 2004a), they derive less from *bios*, the concept of 'animated' life, than they do from *zoē*, the unanimated life of the swarm. *Zoē* manifests itself as a particular type of 'vivacity', for instance as the dynamic flurry of swarming individuals. It is a vivacity that lends itself to technological implementation, for it can be rendered just as well into ordered or disorderly movement. This capacity, in turn, is based on rules of motion and interaction that, once programmed and processed by computer technology, can produce seemingly lifelike behaviour among artificial agents. And thus the conditions of knowledge overlap and entangle as well. Swarm research combines this *zoē* with the experimental epistemology of computer simulation.

A sound understanding of swarms will ultimately emerge where self-organizing processes are applied to processes of self-organization. In such a 'media-emergence', or 'becoming-media' (Vogl, 2007), swarms therefore co-create our knowledge of swarms. Without the specific media technologies of swarm research, 'swarms' do not exist as objects of knowledge, and swarming cannot be regarded as a cultural technique. In the media history of swarm research, the concept of media-emergence and that of cultural techniques intertwine; the development of swarming into a cultural technique could not have taken place outside of specific media cultures.

The second thesis concerns a perspective on the relationship among man, animal, and machine that has redirected the discourse of researchers concerned with cultural techniques. It is no longer a matter of debate whether (human) body techniques can be subsumed under the concept of (human) cultural techniques, or whether cultural techniques derive from the body (Maye, 2010: 122). Likewise, the perspective in question avoids the recent call in the field to make a 'media-anthropological turn' (Schüttpelz, 2006). Nor is it restricted to the representation of reciprocal, recursive, and cyclical mediations among signs, persons, and things (and to their significance to the medial extension of humans into their environment). Rather, swarming is thought to include animals into the discourse – here as a multitude, as a collective – and thus to address a *zootechnological* relation. Produced between the fields of biology and computer science, a *systems knowledge* of self-organizing collectives assists us, in a way that anthropology cannot, in our treatment of certain problems and regulatory issues that are normally regarded as opaque. To the question concerning the operative interconnections between body techniques and media techniques, swarms contribute an element of 'dynamic collective bodies'.

In this light, a third thesis can be formulated that is of interest to the study of cultural techniques. For, although descriptions of swarms have existed since antiquity, swarming in the sense of a cultural technique did not originate until the media-emergence of swarms as 'intelligent' zootechnologies. Around the year 1900, swarms were thematized in works of mass psychology to lament the debased treatment of humans as animals. Around the year 2000, however, animal swarms were suddenly serving as models for human 'smart mobs'. What occurred in the meantime is the transformation, based on biological swarm research and new developments in computer science, of swarms into operatively deployable applications. Along with this transformation, however, the concept of swarming was also fundamentally transformed – namely as a consequence of media-technological processes. Only a media-emergence could enable swarming to appear as a cultural technique. As much as possible, moreover, this media-emergence delegated the fundamental cultural techniques of image-making, writing, and calculation to automated and mechanized processes, be it in the form of new object-oriented programming languages or for the sake of presenting transactional data on graphical user interfaces, for example.

Thus, within recursive chains of operation, swarm principles not only participate in their self-description within the field of swarm research but rather they *co-author* processes within our knowledge culture (Vehlken, 2012). They appear in economic simulations and models of financial markets, in simulations of social behaviour, 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, which has deeply permeated the governmentality of the present.

Related below, within the context of these three theses, are scenes from the media history of swarm research that depict the production of swarms as zootechnologies. In light of these scenes I will examine how it has been possible for swarming to evolve from clouds of data drifts into a concept that is essential to social and cultural techniques.

II. Data Drifts

At the beginning of medial relationships, according to Michel Serres, there is noise (1982: 18–19), and thus noise can be understood to mark the beginning of all media theory (Siegert, 2007: 7). It is not an unhindered exchange between two parties that stands at the onset of every societal and cultural relationship, because a third party is always involved. With the concept of the *parasite*, Serres has identified phenomena of interference and interruption that precede any such interaction. It is therefore characteristic of medial relationships, he notes, that their channels of communication have to be constructed and optimized under the assumption that they will be distorted and interrupted by certain factors. In our efforts to exclude parasitic phenomena, the latter are thereby made a part of our every interaction. It is only through the act of suppressing noise, in other words, that mediality comes into being. The result is a tripartite model in which interference is not accidentally grafted onto existing relationships, but rather in which it is constitutive to the formation of the relationships themselves (Serres, 1982: 73). Serres's concept of the parasite is interesting for the study of cultural techniques because it augments this media-theoretical insight with two additional considerations. First, it contributes a cultural-anthropological dimension that arises from the semantics of the concept itself, based as it is on transcending the difference between humans and animals. Second, it contributes an aspect associated with cultural techniques in the older sense of the term, which was laced with economic and agricultural significance (Siegert, 2011: 102).

With respect to swarming, however, the media-theoretical aspect should be pursued even further, for swarms represent an instructive *object* of Serres's concept as well as a particular exception to it. They operate simultaneously as agents of the materialization of noise and interference, on the one hand, and as processes of the productive revaluation of noise on the other. Animal swarms oscillate on the field of tension between interference and organization.[1] From a distance, what appears to be the precise and coherent macro-dynamic of an admittedly diffuse collective begins to look quite different when examined up close, namely like a seemingly unorganized flurry of innumerable micro-interactions. These interactions surpass not only the capacities of human perception but also the analytic capabilities of technological recording devices. As an event, swarming defies perceptual or medial transference by means of its own transformative properties (Vogl, 2004: 147). The very swarming of swarms baffles our view of the 'swarm' as an object of knowledge; as a chaos of spatial, temporal, and interactional information, swarming introduces an ‘inability to experience objects empirically’, something which was captured so well in Alfred Hitchcock’s *The Birds* (Vogl, 2004: 145). At the heart of biological swarm research lies the search for adequate media-technological means of studying the interactions and functions of these dynamic animal collectives.

At the beginning of the 20th century, the first attempts to observe swarms of birds in the wild coincided with the emergence of a new field of research known as behavioural biology (Nyhart, 1996). Long before the establishment of professional scientific research practices, amateur ornithologists such as William J. Long and Edmund Selous simply ‘went out into the field’. There they attempted to trace the secrets of certain flocks of birds that swarmed together in the air like a single being. Equipped with an ornithological recording system – which consisted of little more than their eyes, a telescope, a pen and some paper, a great deal of patience, and some crude shelters for observation – they assiduously took note of everything they could see (Selous, 1901: 173). Yet the speed of the interactions defied the perceptive capabilities of the observers to such an extent that they were forced to base their findings on super-perceptual ‘waves of thought’. For the recording of the latter, unfortunately, no appropriate technology had yet been invented (Selous, 1931). Of course, such ideas have to be situated within their contemporary context. First, they should be evaluated in terms of the popular theories that circulated about the ‘psychic lives’ of animals and humans (Bouvier, 1922); second, they must be seen in light of new wireless media such as radio and radar, and also in light of the various wave theories that were hotly debated among the physicists of the time (Vines, 2004: 48).

Although short-lived, such swarm theories – along with an intensive biological-philosophical discourse concerning emergent evolution and superorganisms (Morgan, 1923; Wheeler, 1911) – smoothed the way for other avenues of explanation. Whereas decades would pass before technological innovations facilitated the study of flocking birds, those studying schools of fish profited from more accessible experimental conditions and from an elaborate infrastructure of aquaria. The latter infrastructure was supported quite substantially – *mirabile dictu* – by the interests of the fishing industry. And yet these developments resulted in new epistemic fissures, which the biologist William Bateson had identified even before the turn of the century. Although it was now possible, Bateson noted, to enjoy the advantages of ‘artificial conditions’ within the laboratory, the abiotic influences of such conditions must always be kept in mind (Bateson, 1890: 225–6). Artificial environments represented the best means of approximating the living conditions of the animals under investigation, but only to the extent that new laboratory findings were informed by a sophisticated understanding of aquaria and their effects (Allen and Harvey, 1928). Even then, however, it remained questionable whether the behaviour observed in aquaria was transferable to schools of fish swimming freely and unobserved in the sea. In addition to peculiar sleeping behaviour – '[a]t night they lie *on the surface* of the water' – Bateson identified three main characteristics of a school of captive grey mullet, namely a tightly-formed collective body (at least during the day), the lack of an explicit leader, and the parallel alignment of individuals in one direction (1890: 249–50).

A good three decades later, researchers such as Albert Parr, Karl von Frisch, and Guy Spooner developed these early observations further, although they conveniently failed to address the issue of sleeping habits. In 1927, Parr conceived of a psycho-mechanical model for schools of fish, according to which the social behaviour of such swarms was neither complicated nor mysterious. According to his theory, this behaviour is rather the result of multiple psycho-mechanical and physio-mechanical reactions within a simple set of rules: an instantaneous attraction among the individuals upon eye contact, a parallel alignment, and the maintenance of equal distance among the individual fish (Parr, 1927). By means of experiments with partitions and mirrors inside aquaria, Spooner (1931) systematically evaluated the extent to which these factors actually came into play during the formations of schools. Frisch investigated the ability of minnows to react to certain repellents and signs of danger. Whereas he boasted of the 'good overview' provided by his aquarium, which allowed for an 'objective execution of protocol [...] with a stopwatch in hand' (Frisch, 1938: 603), Spooner acknowledged the fundamental limitations encountered when dealing with swarms: 'For any given fish it is impossible to predict definitely how it will behave, but it is possible to say how it will most probably behave [...]. But it is not possible to measure this probability [...] accurately' (1931: 444). To Spooner's mind, unambiguous correlations between the reactions of fish and the methods of experimentation were lacking. Yet another difficulty in determining the relevant factors of swarm formation, in other words, involved a level of predictability that could only yield probable correlations. Researchers had to distance themselves from the determined and linear principles of cause and effect. For it was not only the imprecision of physical observation – but also that of the data produced by experimental fumblings, imaginings, and especially *processing* – that led to certain pitfalls.

After the Second World War, the research concerned with schooling fish underwent a media-technological upgrade. D.V. Radakov endeavoured to observe swarms consisting of approximately one hundred individuals, for only swarms of such a critical size could be said to demonstrate any universal patterns of behaviour (1973: 54). To this end he installed a camera above an aquarium, the bottom of which was equipped with a measuring grid. His method also enabled such techniques as replay and slow motion. Radakov determined the interactions of swarming individuals by examining the changes of their position in frame-by-frame projections or stills – adjusting, of course, for changes of scale. Thus were created maps of the activity of fish schools in two dimensions plus time. Yet this method also entailed certain obscurities, especially because it failed to account for the third dimension of space. The fish overlapped one another from the perspective of the camera, so that it was hardly possible to track them with accuracy throughout the sequences of film. Accordingly, all of the data had to be tediously and manually generated and 'saved' in a tabular form. This process was further complicated, moreover, because school formations would often break apart upon reaching the wall of the aquarium and having to turn around.

In anticipation of this problem, doughnut-shaped aquaria were developed during the 1960s (Shaw, 1962: 130); in these, the polarized individuals of a school can swim constantly in one direction. To this development can be added the so-called 'shadow method', which allowed for schools of fish to be studied in three dimensions. The method required a camera to be flanked by a spotlight, and for the latter to be aimed at a particular angle. By such means, each of the fish under observation cast a clear shadow onto the bottom of the aquarium, and the differences in size between the actual fish and their projected shadows, given the angle of the light and the depth of the water, yielded information about the coordinates of the individuals in three-dimensional space (Cullen et al., 1965). Thus it was possible to map the activity of a moving swarm over a long period of time, though the swarms in question were typically restricted to between 20 and 30 individuals.

A comprehensive analysis of this type was undertaken in the middle of the 1970s by a team under the direction of Brian Partridge (Partridge et al., 1980), and the data accumulated by their four-dimensional measurements remained the standard for many years. Even in the present millennium, according to Julia Parrish, their findings have provided a metric of swarming activity that has influenced the design of certain computer simulations (Parrish and Viscido, 2005: 67). However, even though Partridge was able to implement a partially automated recording system – so that positional data could be read by means of a computer program along with graphical user interfaces, optical fuzziness could be filtered out, and the paths of individual fish could be plotted on coordinates – researchers were still left in despair on account of the immense amount of data at their disposal. Even in the case of small schools observed in laboratory settings, there were '[m]ethod sections from several fish schooling papers [. . .] full of agonizing descriptions of the number of frames analyzed [. . .]. The endless hours of data collection were enough to turn anyone away' (Parrish et al., 1997: 10).

Similar observations can be made about the study of flocking birds. In this field, for instance, Peter Major and Laurence Dill conducted experiments in the 1970s with stereo-photographic recordings. In order to ensure a stabile camera perspective and uniform photographic details, however, their experiments were only possible in the case of flocks passing above at a leisurely pace, such as those heading to a feeding ground. Even an attack by a predatory bird, which might itself lead to interesting collective dynamics, would overtax the system of observation (Major and Dill, 1978: 122). Ironically enough, these researchers had their best luck at the Vancouver airport, 'where flocks are a particular hazard to turbine-powered aircraft'. This conflict between technology and swarms is likewise valid in the case of their empirical, optical analysis. The media-technologies of swarm research have encountered the greatest difficulties when trying to dissolve the inter-individual movements of individuals from the collective movement of the whole in efforts to reach conclusions about the dynamics of large collectives in time. Attempts to examine individual details, that is, can obscure our understanding of the whole.

The stubbornness of swarms in the face of media-technological patterning processes also manifests itself in complementary fields of research. With the help of radar (in the case of birds) and sonar (in the case of fish), for instance, attempts have been made to analyse the global activity of animal collectives (Heppner, 1997; Gerlotto et al., 1999; Simmonds and MacLennan, 2005; Paramo et al., 2007). These investigations have brought to light another side of medial 'uncertainty principles', namely where technological media are confronted with 'bodies without surfaces'. The act of (electro-) acoustic scanning – and the visualization processes associated with it – must contend with multiple interferences that frustrate its ability to draw accurate conclusions about the inter-individual relations within a given collective. Far more problematic, however, is the failure of such methods to create reproducible testing conditions and to generate data of long-standing significance. The Cartesian procedure of dissolving problems into sub-problems, and thus of analysing collective movement as the sum of segmented individual movements, necessarily fails to explicate scale-variant phenomena such as swarms.

III. Simple Rules

Because of the complications surveyed above, certain researchers sought other approaches to the problem. In connection with Parr's thesis, namely that the dynamics of fish schools can be ascribed to a few simple rules of interaction, efforts were made to 'calculate' swarms, that is, to develop abstract mathematical models of their activity in space and time. This process did not aim to solve, in an analytic manner, the non-linear dynamics of swarms and the factors responsible for their ability to self-organize, but rather to approximate them numerically. In response to an Aristotelian platitude that is often cited in this context, Heinz von Foerster has related a fitting riposte: 'The whole is greater than the sum of its parts. As one of my colleagues once remarked: "Can't the numbskulls even add?"' (Foerster, 2003: 319). For this is not at all a matter of the summation of parts, but rather of the dynamic relations *among* the component parts of a system. Swarms engender a specific *relational being*, the nature of which has been summarized well by Eugene Thacker: 'The parts are not subservient to the whole – both exist simultaneously and because of each other. [. . .] [A] swarm does not exist at a local or global level, but at a third level, where multiplicity and relation intersect' (Thacker, 2004b).

However, before computer technology enabled the viability of elaborate synthetic approaches, which circumvented the analytic problem of 'fuzzy relations', models of swarming behaviour were at first only possible if the number of variables involved was severely reduced. In the early 1950s, Charles Breder began to calculate the internal relations of swarms by conceptualizing each of its individuals as a physical point of mass with specific powers of attraction and repulsion (Breder, 1954). As far as biology is concerned, models of this sort have been criticized as having little predictive value; however, they do have the advantage of relying on established physical laws and formulas. Geometric models were also developed, the concern of which was either the optimal utilization of space (Breder, 1976) or the formation of aggregates in general (Hamilton, 1971).

Breder and Radakov gradually formulated new concepts, based on information theory, that would supplant the older psychological and psycho-mechanical terminology. They directed their attention, for instance, to the phenomenon of so-called 'waves of agitation'. Radakov described such waves, which are also observable in flocks of birds, as 'a rapidly shifting zone in which the fish react to the actions of their neighbors by changing their position [. . .]. The speed of propagation [. . .] is much higher than the maximum (spurt) speed of forward movement of individual specimens' (Radakov, 1973: 82). They introduced additional environmental factors into their models, which had been overlooked elsewhere, and also filtered out what they considered to be 'unimportant' interference. These adjustments led to significant structural changes and to the optimal reaction of their theoretical swarms to environmental influences. Measured under such influences, swarms came to be understood more and more as infrastructures of information or, more generally, as 'social media' (Schilt and Norris, 1997: 231).

The conceptual informatization and mathematical modelling of biological research may have stimulated the first attempts at individual-based simulation, which were ventured in the 1970s and early 1980s (Kay, 2000). In an article from 1973, Sumiko Sakai provided a mathematical model, based on internal rules, for the behaviour of schooling fish. The novelty of this study was that the paths of motion were calculated by a computer and then, much like the plotted diagrams of empirical laboratory reports, recorded graphically. Tadashi Inagaki et al. (1976) investigated the coherence of fish schools over long periods of time and developed a mathematical model with the following five variables: 'mutual attractive or repulsive force, mean swimming force, random force, force exerted by the change of circumstances and frictional force of swimming motion'. According to their results, the coherence of a given swarm could only be maintained so long as certain combinations of these parameters were in effect.

Of special interest to the potential of computer simulation was the work of Ko Matuda and Nobuo Sannomiya (1980), which enhanced Sakai's model into an application for modelling fish behaviour in relation to fishing nets. Theirs was the first study to address the reciprocal effects of computer simulation and swarm research. Whereas traditional technologies such as underwater cameras and hydro-acoustic sensors were subject to certain restrictions – underwater visibility, marine conditions, and so on – and were only capable of recording small excerpts of data, computer simulations could be relied upon to compensate for these deficiencies (Matuda and Sannomiya, 1980: 689). Increasingly, swarm research began to distance itself from the influences of psychology and behavioural biology, and 'natural behaviour' came to manifest itself as little more than a function of physical, quantified variables. Swarms were modelled as technical systems of multiple components, each with a set of predetermined characteristics. Models of this sort enabled biological swarm research to expand into an operational and far more general means of describing multitudes composed of homogeneous elements. As a result of this development, the actual 'nature' of these collective systems ultimately became a subordinate issue.

The latter authors conducted computer experiments with virtual schools of fish in which they tested, for instance, their behaviour in response to certain obstacles. However, it was Ichiro Aoki's simulation model of schooling fish, published in 1982, that would become foundational to later research in the field of agent-based modelling. Aoki integrated motion parameters into a zone-based model, composed of concentric circles surrounding individuals, that governed the activation of certain behavioural parameters. The model generated reciprocal dynamics among individuals, and these dynamics depended on the presence of such forces as attraction, repulsion, or alignment, on the velocity of the individuals, and on their trajectories in relation to one another. For some time, this understanding of the organization of swarm dynamics remained inapplicable to other disciplines. The realization of its interdisciplinary potential would require another media-emergence of swarms. What had been lacking, to be precise, was the ability to animate this activity with visualization processes, based on the principles of swarming, in which swarms could ultimately appear to be 'written in their own medium'.

More than half a decade passed before the processes of computer graphic imaging, in the form of Craig Reynolds's boids model (1987), would come into play. Ironically, the latter model has often been cited as an *urtext* of computer-assisted *biological* swarm research. Building upon William Reeves's particle system for the animation of fuzzy objects such as dust, clouds, or fire (Reeves, 1983), Reynolds was not at all interested in realistic variables of behaviour but rather in a performance that was only somewhat true to nature. To some extent, his program was born of laziness, for he wanted to avoid the error-prone and Sisyphean task of separately programming the path of each individual boid within a large collective. Such a program was inflexible, too, for the alteration of a single flight path would entail a commensurate alteration in the flight paths of the other swarming individuals. This difficulty was remedied by the application of object-oriented programming methods. For each boid, Reynolds generated a customized geometric orientation and, much like Aoki, he created an individualized and locally applicable algorithm on the basis of three 'traffic rules'.

In test runs, which Reynolds was (innovatively) able to track on a computer monitor, it came to light that realistic swarm activity would only be produced when the boids oriented themselves toward the locally perceived centre of the flock. Spatially limited knowledge, according to the model, was thus fundamental to the universal operation of a collective. Moreover, each individual boid's capacity for decision-making was also temporally limited, such that changes in their course did not become more time-consuming in response to an increase in neighbouring boids, and the coordinate system did not become increasingly complex as the size of a given flock enlarged. The result was a highly realistic representation of collective movement, along with a few surprises for the animator himself. The boids, for instance, were able to negotiate obstacles independently without the addition of further parameters to the model, and they would also change direction suddenly and abruptly. On account of its simplicity and flexibility, the boid model would soon be employed in the field of special effects, especially for the animation of crowd scenes. Swarms, therefore, were reintroduced to the medium of film not simply as a way of distorting images, as in Hitchcock's *Birds*, but also as an organizational principle of image production.

The use of swarming in scientific simulations represents a culmination point in the media history of the concept. Swarms themselves came to be used as a model, as a potential condition. In computer simulations, experiments were conducted with distributed behaviour parameters, which were then regarded as the simple behavioural rules of biology itself. In short:

> 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, as the digital 'corporealizes' the biological. (Thacker, 2004a: 6–7)

Reynolds's dynamic, computer-graphic visualizations evidenced a new epistemic strategy. They introduced a way of understanding according to which swarming individuals localize, organize, and synchronize themselves independently. The misleading view of observational media with a central perspective was replaced by a topological system that creates its own space for itself. Swarms have to be understood as projects of time and space. They function as a self-organizing swarm-space on the basis of local interactions conducted in parallel and *en masse*. By adapting to external influences, this swarm-space also provides information about the nature of the environment surrounding it. And a constitutive element in this regard is the fourth dimension of time, for it is only in time that swarms come to be. With the help of agent-based modelling and its processes of visualization, swarms could finally be understood in four dimensions.

IV. Cultural Techniques, Opaque Spaces, and Agent-based Modelling

Biological swarm research did not begin to implement agent-based models on a broad scale until the 1990s, that is, until advances in animation technology were made in Hollywood (Macavinta, 2002). In correlation with rapidly increasing data processing speeds, larger and larger swarms could be modelled and more and more variables could be introduced (Reuter and Breckling, 1994; Couzin and Krause, 2003). Thus phenomena such as currents, predatory attacks, different body types, and the variant speeds of individuals could be taken into consideration, while integrated stochastic errors could account for imprecise movements and coincidental environmental disturbances. At first, all of this was carried out graphically, for example with two-dimensional cellular automata (Vabø and Nøttestad, 1997), but soon, and to an increasing extent, such models were designed in real-time 3D with the help of suitable visualization software (Couzin et al., 2002).

Computer experiments conducted with agent-based models are not constrained by the physical interferences encountered by researchers in the sea and in the laboratory. They are rather spaces of potential, in which multiple scenarios can be tested and brought into contact with one another. Thus, agent-based models have established an immaterial culture within the sciences – embedded, of course, in the facticity of the hardware and software on which they run. In such representations, swarms lose their optical and acoustic stubbornness, even while they can be simulated as facets of material culture under the most diverse conditions. Intermediary steps and spaces for epistemic and technological things or for the capacity of objects to operate in actor-networks, which have been central ideas in the work of Hans-Jörg Rheinberger (1997, 2010) and Bruno Latour (1987, 2005), shrink or disappear within the spacio-temporality of virtual scenarios. In plain terms, the application of agent-based modelling has led to a simultaneous explosion and implosion of epistemic things, something which is characteristic of computer applications in general: an explosion, because more and more new scenarios are allowed to multiply; an implosion, because thus they lose their solidifying character and become fluid, that is, processable.

To some extent, swarms contain a concentration of certain problems that, when addressed by the experimental epistemology of computer science, expand into something like a culture of intransparency or opacity. Computer graphics enable a visual comparison of various universal structures, both with respect to parameter adjustments within the rule sets of agent-based modelling and also in terms of the sporadic, empirical data collected about schooling fish in laboratories and in the open water. Thus it can be determined 'intuitively' whether a chosen combination of parameters produces results that resemble the behaviour of a biological swarm. The base function of this knowledge is the act of 'seeing in time'. In its state of temporal 'thrownness' (*Zeitgeworfenheit*) – or, better, in its state of having been designed in time (*Zeitentworfenheit*) – computer science is able to animate mathematical models, that is, endow them with life in 'run time'. In this way, it does not exhaust itself into a mere expansion of existing epistemological strategies.

Computer science represents more than simply an improvement of numerical calculation methods by means of the processing speed of computers. It can rather be attributed an entirely unique epistemological status of theoretical experimentation. It is here that pragmatic operationality has supplanted the need for precise theoretical foundations. It is here that categorical truth-claims are replaced by provisional knowledge. Here, in other words, 'the performance on the computer is more important than the model's derivation and its accuracy of calculation' (Küppers and Lenhard, 2004: 271). Unlike the case of theories, computer science is less concerned with what is true or false than it is with pragmatic utility (Sigismundo, 1999: 247). The hypothetical character of knowledge in this field is underscored by the different and competing models of swarm simulation; instead of confirming one another's findings and producing certainties, they have instead generated a spectrum of opinions and viewpoints.

Where computer science focuses its attention is on the *relations* that exist within systems. At this point, swarming as an object of knowledge encounters the epistemology of simulation. The relational being of swarms, with its intersections of the microscopic and macroscopic, can only be adequately captured by a technology that itself bisects the distinction between the epistemic and the technological thing, that is, by a technology that focuses on *knowledge relations*. The knowledge of swarms and that of computer simulation go hand in hand. That which cannot be addressed adequately *in vivo* and *in vitro* can be recorded *in silico*.

The recursive coupling of swarm-inspired agent-based modelling and swarm research, however, entails an even graver consideration. Agent-based models were first implemented by means of object-oriented programming. Both agent-based modelling and object-oriented programming can thus be assigned to the same paradigm, one that Frederick Brooks (1987) subsumed under the concept of 'growing' (in its double sense of 'increase' and 'cultivate'). To a certain extent, control and 'intelligence' are here delegated to a self-regulating system (Parikka, 2010). And within the paradigm of growing, which inclines toward self-organization and procedurality, swarms appear as a digital cultural technique *par excellence*, one that enriches the study of cultural techniques with a zootechnological dimension.

Casey Alt (2011) is even more radical in this regard, for he has identified object-oriented programming to be the material foundation of our entire understanding of computers as media. Alt conceptualizes this medial relation as a 'society of objects' within a computer, the communication of which takes place both among the objects themselves, at the program level, as well as with human users by means of interfaces. Thus the user is likewise conceived of as a programming process, and object-oriented programming begins to structure, more than just metaphorically, our daily lives: 'Object orientation increasingly mediates how we work, play, fight and love' (Alt, 2011: 298) – from video game communities to social networks to the flow of information in modern businesses.

To this list, agent-based modelling contributes the realm of knowledge and science. For, from the media-historical threshold where the epistemic conflation of fish and chips yielded an extensive and novel understanding of the principles of regulation and self-organization that govern swarms, these principles became operable as figures of knowledge in various fields of implementation and for various technological applications. Toward the end of the 1980s, for instance, when experiments were conducted with robot collectives composed of simply designed individuals, the researchers operated according to the following motto: '[U]sing swarms is the same as "getting a bunch of small cheap dumb things to do the same job as an expensive smart thing"' (Corner and Lamont, 2004: 355).

The logic of swarms introduced a new type of economy to technological processes, an economy based on the flexibility of model environments, on a distributed mechanism of control and regulation, on the independent creation of unpredictable solutions, and on high levels of fault tolerance and reliability. Swarms integrated themselves as components of the evolutionary software designs with which mathematical optimizations could be executed – in the form, for instance, of particle swarm optimization (Kennedy and Eberhart, 1995). The latter designs were in turn implemented for problems of multi-objective optimization, that is, for processes involving multitudes of reciprocal and mutually constraining variables. Their field of application has extended from industrial production processes to logistics planning to the optimization of network protocols (Engelbrecht, 2005). Moreover, the interactional intelligence of swarms can play a role wherever there are time-sensitive problems of coordination and transference between numerous particles; such problems present themselves, for instance, in traffic simulations, social simulations, panic simulations, consumer simulations, epidemic simulations, simulations of animal collectives, in the behaviour of aerosol in climate models, and even in the case of organizing building materials. Swarms create information by means of formation.

Swarms and the algorithmics of their relational being can be called ‘intelligent’ whenever a matter concerns the (independent) government and planning of interactions in space and time. Their applicability to agent-based computer modelling and to distributed technological collectives is indicative of their effectiveness as a novel cultural technique. As such, swarming is characterized by the fact that it was produced in the area of tension between biology and computer science. Originally regarded as mere interference phenomena, swarms emerged as operational media technologies. As an addressee of this cultural technique, humans were at first only an unintentional part of the equation. Strictly speaking, swarming did not exist as a cultural technique before its media-technological manifestation, that is, before it became applicable in the field of computer science as a novel epistemic process and as a solution configuration for a multitude of complex problems.[2] Moreover, the influence of the cultural technique expanded even further when the ‘crowd logic’ of its behaviour came to be employed as imitable particles in social simulations. Around the year 2000, at the latest, swarm intelligence and agent-based modelling emerged as a powerful and irreversible element of the current media culture. It is as *zootechnologies* that they have developed into a relevant cultural technique, and as such they have enabled and initiated novel engagements with opaque areas of knowledge, with interference phenomena, and with technological and systemic correlations that otherwise would have been difficult to ascertain.

At the same time, they produce and even demand – like the paradigm of object-oriented programming – a zeitgeist and world view in which cultural processes are characterized more and more by the multiple and dynamic interactions of autonomous and self-optimizing ‘agents’. Once aware of the lasting effects of swarming as a cultural technique on our current media and knowledge cultures, at least as described here, one should be quick to distrust the highly touted potential of social swarming and the grass-roots-democratic ‘nature’ of human techno-collectives. This holds true even despite the elevation of the discourse, in the past few years, to sophisticated media-theoretical levels (see in this regard the work of Tiziana Terranova, Luciana Parisi, Olga Gurionova, Howard Slater, and the recent issue of *Limn* devoted to 'crowds and clouds').

Ultimately, whoever belittles recent revolutions with the journalistic banalities of swarm logic – 'Facebook revolution', 'Twitter revolution', and so on – deliberately overlooks the extent to which the cultural technique of swarming has come to define our situation. Swarms should no longer be understood simply as advanced manifestations of older forms of collective behaviour. It is much rather the case that they have gained relevance as structures of organization and coordination. These structures have become effective against a backdrop of an opaque culture – one defined by the permanent flexibility of various domains of life – and they have become effective namely as optimization strategies and zootechnological solutions *within* these very domains. At the heart of swarming, as a cultural technique, is thus the governmental constitution (*Verfasstheit*) of the present itself, in which operationalized and optimized multitudes have emerged from the uncontrollable data drift of dynamic collectives. From this there can be no escape.

Translated by Valentine A. Pakis

Notes

1. Here I am limiting myself to 'decentralized' animal collectives such as swarms of birds and schools of fish, the dynamics of which are created in three dimensions of space and by constant motion in time. Insect collectives thus remain beyond the scope of the present discussion.
2. As a term used in mass psychology, or as an obsolete element of military tactics, the concept of swarming was chiefly employed to signify the *dissolution* of order, that is, the act of 'swarming all over'. It was not then conceived of as representing the relational, procedural, and structural intermediary domain between the individual and the collective, namely the very domain that, according to Eugene Thacker, defines the dynamics of swarms.

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