Preface

Why Biocommunication of Fungi?

When we consider the biocommunication of fungi, we first must become familiar with the current terms of communication (and with the signalling system, what we would term language or code, which is used to communicate). Therefore, we should consider the results of the pragmatic turn in the philosophy of science in the 1970s and 1980s, which was the result of discourse from 1920 until 1980, and was intended to clarify the conditions for generating correct sentences in science.

Communication is defined as the sign mediated interaction between at least two living agents, which share a repertoire of signs (which represents a kind of natural language) that are combined (according to syntactic rules) in varying contexts (according to pragmatic rules) to transport content (according to semantic rules).

Contrary to former concepts the importance of this result is that these three levels of semiotic rules are complementary parts of any natural language or code. If one level is missing, according to Charles Morris, we cannot seriously speak of language or signal mediated communication. Therefore, the most recent definition of communication is: sign-mediated and rule-governed interactions, i.e. interactions that depend on a shared repertoire of signs and rules. However, these features are lacking in abiotic interactions; no semiotic rules are necessary if water freezes to ice.

Additionally, we know that mathematical and mechanistic theories of language are less helpful in investigating natural language and real-life communication processes, because such theories cannot explain typical features of communication between living entities, which are not formal (i.e. for which no algorithm is available), such as the *de novo* generation of coherent, sentences or sequences. This means that no natural language or code speaks, or codes, itself but requires living agents that are competent in such languages or codes.

In the biology of the twentieth century, the physiology of all manner of cells, tissues, organs and organisms, was the mainstream direction of biological research and experiments. In the 1970s, an increasing use of "communication" as a metaphor also arose in biology. During the last decade of the twentieth century, interest in communication (no longer being used as a metaphor) within, and between, organisms overtook that of the purely physiological understanding of organisms. This was due to concrete communication processes designating varying contexts in real life circumstances. Cell-to-cell communication now dominates contemporary cell biology, including knowledge of a great variety of signalling pathways, serving for both organization and coordination of production, release, uptake, interpretation and processing of context-dependent "information" (content) within and between cells. Context dependency determines the crucial fact that, it is not the syntax (grammar) of a sequence of signs (information) which determines the meaning (semantics), but the context (pragmatics) in which the concrete use of the sequence occurs.

In parallel, the use of "language" as a metaphor has increased since the middle of the twentieth century with the improved knowledge of the genetic code. Most of the processes that evolve, constitute, conserve and rearrange the genetic storage medium (DNA), are terms that were originally used in linguistics. For example: nucleic acid language, genetic code, "code without commas" (F. Crick), coding, copying, translation, transcription, "genetic text" (F. Jacob), sequence homology, etc. Meanwhile, the linguistic approach also lost its metaphorical character, and the similarity between natural languages and codes, and the genetic storage medium of DNA have not only been accepted, but have been adapted in epigenetics, comparative genomics, bioinformatics, biolinguistics, biocommunication theory and biosemiotics.

The advantage of a methodical adaptation of communication and linguistic terminology is that it provides appropriate tools for differentiation at specific levels, which is otherwise difficult to describe in non-reductive terms by pure physiology. The result of this is that language like structures and communication processes occur at the simplest levels of nature. Language and communication are not the evolutionary inventions of humans, nor are they anthropomorphic adaptations to describe nonhuman entities. It is an empirical fact that all coordination and organisation within and between cells, tissues, organs and organisms needs signs, i.e. molecules that serve as signals or symbols in messages, or serve as vital indicators of environmental conditions. Because no natural code can encode itself, in the way that no natural language can speak itself, these signs must be sensed and interpreted in the correct way by biological agents, i.e. there must be subjects of sign production and sign interpretation. The consequence of this is that sensing, as well as interpretation, may fail. This can result in inappropriate behaviour, or even be of fatal consequence, for cells, tissues, organs, and organisms.

The method of analysing any part of a machine in detail to get a picture of the whole functional blueprint, which can then be used to reproduce or manipulate it, or to produce an even more perfect example, taking artificial genetic engineering as an example, is still useful if we are dealing with machines. In contrast communication between cells, cellular components, tissues, organs and organisms is far from being a procedure that can be reduced to mechanistic input/output or cause/reaction descriptions. It is evident that communication processes between living organisms include a variety of non-mechanistic circumstances and competences that must be fulfilled in parallel if communicative acts are to have successful consequences, for example, to innovate common coordination to adapt to new environmental conditions. Machines cannot create new programs out of a functional blueprint, which is in contrast to the abilities of living organisms that are able to communicate between each other.

Firstly, no single organism is able to communicate as an emerging property; it must be part of a community, society or swarm of organisms that share an identity and have a competence to sense whether others are part of this identity or not (self/non-self differentiation competence), even if this competence is solely shared genetically. In contrast to former opinions, it is now evident that communication is not primarily the exchange of information between a sender and a receiver, but it is actually a variety of social interactions. To communicate it is necessary that organisms have assets that serve as signs, signals or symbols, such as chemical molecules, either produced directly by the organism, or as secondary metabolites, or even molecules in the surroundings, but which can be manipulated according to the organisms needs.

Secondly, organisms must also share a competence to use these signs in a coherent manner, which means using these signs in a strict temporal and spatial context. In most cases it is not just one signalling molecule, but several, that are combined in a specific manner to transport messages or information. This represents a common feature of sign use in communication processes, and is termed the correct combination or syntax.

Thirdly, organisms are part of the natural habitat in which they live, together with similar organisms of the same or related species, but usually also with an abundance of unrelated organisms. This historically developed context exactly represents the natural history of the swarms or communities in the way that they have evolved certain abilities and are able to mount appropriate response behaviours to enable their survival. These competencies, which include sensing, monitoring, learning and memory, are preconditions for faster adaptation.

Finally, the signalling molecules, which serve as signs, transport messages with meanings (semantics). The informational (semantic) content which is transported, triggers certain response behaviours in the same, related, or even unrelated, organisms. Interestingly, the signal sequence or content does not necessarily depict a strict meaning, i.e. a function, but can vary according to different situational contexts. This means that identical signs can transport a variety of different messages according to different contextual needs. This is important in very dense ecological habitats, for example in mycelial differentiation, or root ecospheres. The different uses of identical signs, or sequences, enable the generation of dialects within the same species that can transport messages which are micro-ecosphere specific. This includes a very sensitive self/non-self recognition between slightly differently adapted populations of the same species in the same ecological habitat.

Although sign-mediated interactions (i.e. communication processes) are very reliable in most cases, they do not function mechanistically in a strict sense. Syntax (combination), pragmatics (context) and semantics (content), must function in parallel to ensure and optimize coordination, and thus survival of group members.

These three levels of semiotic rules (syntax, pragmatics and semantics), do not function mechanistically but can be varied, deleted, or, in certain circumstances, and in contrast to the capabilities of machines, generated *de novo*. Additionally, semiotic rules do not function by themselves but need semiotic subjects, i.e. living organisms that utilise such rules. If no living organism is present, semiotic rules, signs and communication are absent. Although highly conserved semiotic rules are modifiable, environmental circumstances, such as stress, can trigger adaptive responses. In such cases, signals may transport new messages which previously did not exist, broadening the communicative competences of organisms, i.e. broadening their evolutionary capabilities.

To answer the preface question, we can see that biocommunication in fungi integrates the biology of fungi with their communicative competencies, and gives a more coherent explanation and description of the full range of fungi capabilities than would be possible by mechanistic or even reductionist approaches. Natural communication assembles the full range of signal mediated interactions that are necessary in order to organise all evolutionary, and developmental coordination within, and between, cells, tissues, organs and organisms.

Contributions to the Biocommunication of Fungi

After the introduction in which a general overview on the key levels of communication of fungi is given in the first section on intraorganismic biocommunication of fungi, Jaqueline Servin, Asharie Campbell and Katherine Borkovich begin with the G protein signaling components in filamentous fungal genomes. Maria Bertolini, Fernanda Freitas, Renato de Paula, Fernanda Cupertina and Rodrigo Goncalves describe metabolic regulation processes in *Neurospora crassa*. Robert Cichewicz reports in the important role of epigenetic regulation processes. Jeremy Bruen investigates the role of double stranded RNA Viruses in nuclear genomes of fungi. David Soll reports on signal transduction pathways used by *Candida albicans* and related species. Tatiana Potapova investigates cell- cell communication in the tip growth of mycelial fungi. Elizabeth Hutchison and Louise Glass report on programmed cell death and heterokaryon incompatibility in filamentous fungi.

In the second section on interorganismic biocommunication of fungi Zdena Palková and Libuse Váchová investigate communication and differentiation in the development of yeast colonies. Philippe Silare focus on self versus non-self fungal recognition. Silvia Polaino and Alexander Idnurm describe the important role of pheromone signalling. Kenneth Nickerson, Audrey Atkin, Jessica Hargarten, Ruvini Pathirana and Sahar Hasim.

The third section in transorganismic biocommunication of fungi starts with Danielle Troppens and John Morrissey report on metabolite-mediated interactions between bacteria and fungi. Rusty Rodriguez and Marilyn Roossinck describe cross-kingdom communication and mutualism between viruses, fungi and plants. Aurélie Deveau, Jonathan Plett, Valérie Legué, Pascale Frey-Klett and Francis

Martin describe communication processes between plant, fungi and bacteria whereas Eli Borrego and Michael Kolomiets focus on signalling processes between fungi and plants. Andrey Averyanov, Tatiana Belozerskaya and Natalia Gessler focus on phytopathological aspects of the reactive oxygen species in fungal development. Massimo Reverberi, Anna Fabbri and Corrado Fanelli report on the role of oxidative stress and oxylipins in interactions between plants and fungi. Katharyn Affeldt and Nancy Keller investigate the role of oxylipins in fungal-mammalian interactions. Drion Boucias, Verena Lietze and Peter Teal investigate chemical signals that mediate insect-fungal interactions.