Appendix A Declaration of Principles Concerning the Conduct of the Search for Extraterrestrial Intelligence

Preamble

The parties to this declaration are individuals and institutions participating in the scientific Search for Extraterrestrial Intelligence (SETI).

The purpose of this document is to declare our commitment to conduct this search in a scientifically valid and transparent manner and to establish uniform procedures for the announcement of a confirmed SETI detection.

This commitment is made in recognition of the profound scientific, social, ethical, legal, philosophical and other implications of an SETI detection. As this enterprise enjoys wide public interest, but engenders uncertainty about how information collected during the search will be handled, the signatories have voluntarily constructed this declaration. It, together with a current list of signatory parties, will be placed on file with the International Academy of Astronautics (IAA).

Principles

1. *Searching*: SETI experiments will be conducted transparently, and its practitioners will be free to present reports on activities and results in public and professional fora. They will also be responsive to news organizations and other public communications media about their work.
2. *Handling candidate evidence*: In the event of a suspected detection of extraterrestrial intelligence, the discoverer will make all efforts to verify the detection, using the resources available to the discoverer and with the collaboration of other investigators, whether or not signatories to this declaration. Such efforts will include, but not be limited to, observations at more than one facility and/or by more than one organization. There is no obligation to disclose verification efforts while they are underway, and there should be no premature disclosures pending

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verification. Inquiries from the media and news organizations should be responded to promptly and honestly.

Information about candidate signals or other detections should be treated in the same way that any scientist would treat provisional laboratory results. The Rio Scale, or its equivalent, should be used as a guide to the import and significance of candidate discoveries for the benefit of non-specialist audiences.

3. *Confirmed detections*: If the verification process confirms—by the consensus of the other investigators involved and to a degree of certainty judged by the discoverers to be credible—that a signal or other evidence is due to extraterrestrial intelligence, the discoverer shall report this conclusion in a full and complete open manner to the public, the scientific community, and the Secretary General of the United Nations. The confirmation report will include the basic data, the process and results of the verification efforts, any conclusions and interpretations, and any detected information content of the signal itself. A formal report will also be made to the International Astronomical Union (IAU).
4. All data necessary for the confirmation of the detection should be made available to the international scientific community through publications, meetings, conferences, and other appropriate means.
5. The discovery should be monitored. Any data bearing on the evidence of extraterrestrial intelligence should be recorded and stored permanently to the greatest extent feasible and practicable, in a form that will make it available to observers and to the scientific community for further analysis and interpretation.
6. If the evidence of detection is in the form of electromagnetic signals, observers should seek international agreement to protect the appropriate frequencies by exercising the extraordinary procedures established within the World Administrative Radio Council of the International Telecommunication Union.
7. *Post-Detection*: A Post-Detection Task Group under the auspices of the IAA SETI Permanent Study Group has been established to assist in matters that may arise in the event of a confirmed signal, and to support the scientific and public analysis by offering guidance, interpretation, and discussion of the wider implications of the detection.
8. *Response to signals*: In the case of the confirmed detection of a signal, signatories to this declaration will not respond without first seeking guidance and consent of a broadly representative international body, such as the United Nations.

Unanimously adopted by the SETI Permanent Study Group of the International Academy of Astronautics, at its annual meeting in Prague, Czech Republic, on 30 September 2010.

These revised and streamlined protocols are intended to replace the previous document adopted by the International Academy of Astronautics in 1989.

Appendix B Preliminaries

Evolution and Language

Darwinian evolution has led to large variety of living organisms and a multitude of systems for communication between them on Planet Earth. In his book *Darwins Ofullbordade* (Darwin's Unfinished), Bonnier (1997), Stockholm, the well-known broadly oriented Swedish neurophysician and novelist P.C. Jersild writes: "When Darwin claimed in 1859 in his theory of evolution that all now living creatures descend from just a few simple forms of life (that appeared four to three billion years ago), he had only superficial indications for that thesis. It is now known that the variety of species is due to differences in their *genetic maps*. Small differences in genetic codes may mean large differences between species, as between chimpanzees and humans (about 0.5 % difference in genetic code). After the branching resulting in the species that would become chimpanzees and those that developed into *homo sapiens*, it took five million years before the difference reached that value. In this way one can understand that the genetic clock ticks slowly" (translated shortened citation, AO). Interesting aspects of branching have been discussed extensively by Richard Dawkins in several books on palaeontology.

In order to obtain a perspective on the rates of Darwinian progress as it has occurred and is occurring on Earth, governed by the laws of nature, it is useful to compare the genetic clock with some astrophysical time scales. A period of five million years is in astronomical terms rather short: in that interval of time the Sun covers only 2 % of one revolution around the centre of our galaxy. This observation indicates already differences in rates of changes between earthly processes and those in an astronomical context. On Earth, biological (biochemical) processes can produce via genetic evolution complex *organisms* only slowly, in several hundred million years. In astronomy there are many evolutionary processes on time scales ten or more than ten times as large, for example in the formation and development of stars and galaxies. A normal medium-size star such as the Sun gets going as a proto star and evolves in about five billion years to its position in the main sequence of stars it has today. Stars are grouped together in *stellar systems* (galaxies),

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themselves also evolving in time. Stellar systems form *clusters* arranged in a network of filaments in the universe. The universe itself, estimated to be 13.7 billion years old (measured from the primordial explosive event at the beginning of time), has evolved in this period to what we observe today: our own galactic system (the Milky Way) and it neighbours, the local cluster of galaxies and distant galaxies in various states of development, interstellar matter and intergalactic dark matter, and possibly also intergalactic dark energy.

The most important causal differences between evolutionary processes on Earth and those in astronomy are the prevailing circumstances. Life as we know and understand can occur only on the surface of a planet with moderate climate, surface and atmospheric conditions, admitting a rather narrow range of temperatures and a delicate balance of chemical substances—in short a rather restricted biosphere. Once life has established itself on a planet (in a very short time scale from the astronomical point of view), genetic evolution and mutations together with environmental effects evidently can produce complex *species*—and, following Jersild in the book mentioned before, also the social organization of groups within the species. Concurrently, languages and the use of them appeared on the scene. Jersild distinguishes five kinds of language: natural spoken and written language by people, gesture language (body language), the language of mental thought processes (also called *mentalese*) and the language of the genetic code based on the letters G, A, T and C (the building blocks of DNA) extended with rules of expression. Seamlessly one can fit into these kinds the language of music (see Chap. 15 of this book). These languages, and languages in general, are mutually strongly different in character and functionality. In the case of human languages their usage and development necessarily has been (and is) coupled to levels of intelligence and knowledge attained by mankind. As a result of increasing knowledge (in fact in philosophical terms "knowledge of the world") there has been an enormous speed up in the development of societies, their organization and functionality—and in science. Scientific understanding of the world needs linguistic means for expressing insights and knowledge in order to be available to everybody.

Abstracting from these examples we note that for any *lingua* there must be a basic set of some kind of tokens together with rules for the formation of possible expressions (the *syntax* of language)—but also additional rules for the use and goal of these expressions (the *semantics* of language, supplying *interpretation*). Strictly speaking there is a commonly accepted restriction here: a language must admit written representations of expressions—not necessarily in digital form. Sufficiently developed human languages satisfy this requirement, *cf*. Tore Janson's book *Speak: A short history of languages* (Oxford University Press, 2002).

As mentioned, language usage has an objective. Language serves as a means for communication between individuals or parties in societies, it can aid in the task of an individual forming opinions on matters at hand (via *mentalese*), but more generally it is needed for the spreading of knowledge. In genetics the (biochemical) rules of expression are responsible for the shape and functionality of individuals of a species. Language serves also to keep the vulnerability of living organisms under control using information coded in DNA, supplemented with fine-tuned, sophisticated expression rules. Even though humans are usually not fully aware of the way the genetic code with associated processes operates, this particular linguistic background governs the line of life of each individual.

Astrolinguistics Conceptually

The rather broad conceptual framework of language and its usage sketched in the previous section leads to the philosophical question whether in astronomy, i.e. in the cosmos of stars and stellar systems, interstellar matter and voids, dark matter and dark energy, there are phenomena that conceptually seem to be influenced by what can be termed *astrolinguistics*. In view of the prevailing physical circumstances in the cosmos as we understand them, the question might be split into two parts.

First, a point of inquiry could be: can one designate a system of processes in the universe, governed by specific rules, evidently leading to some goal. One case is that of astrophysical processes leading naturally to the formation of stars (even from a more fundamental cosmological point of view) with planets orbiting many of them. As a result of planeto-physical processes in and on these planets together with developments in their seas, atmospheres and geology, life might come into being on some of them. A necessary condition for that to happen is, according to prevailing understanding, that such a planet must orbit its sun in a well-defined habitable zone—not too distant and not too near its sun. The rules governing the processes leading to life are the physical and chemical laws of nature. Biological properties supervene on these laws, *cf.* Chap. 11. Until now only one instance of such a planet is known (the Earth) but there is ample evidence by now to assume that the physical circumstances that led to the case of the Earth are *not* unusual. Note in passing that our universe satisfies the *comprehensibility principle*, stating that of all possible universes, only those in which observations can be made by intelligent beings, are understandable for them. Case proved because we humans are beginning to understand our Universe, the building stones—elementary particles and their interactions—and evolutionary processes. Packets of energy in various forms can be considered to be the basic tokens of a linguistic principle on a cosmic scale. The syntactic rules are those governing interactions between the tokens. In particle physics the comprehensibility principle prevails as well. In physics, astrophysics and cosmology the observational instrumental techniques for investigating the tokens have evolved tremendously since mankind started looking at nature and the skies systematically.

In the second place one might inquire whether linguistics of natural languages on Earth is some sort of derivative of a general cosmic principle, valid for all living intelligent beings in the Universe. It would seem that a straightforward analysis of this matter is out of reach for the moment. One could argue that our languages have been developed and have evolved for our own use, within the limitations of the human brain, not on the basis of a cosmic principle. However, an important feature of natural languages is the fact that they are able to explain their own rules governing "well-formedness" of expressions. Children learn their native language effortlessly, without being consciously aware of grammar and formation rules for expressions.

Early in life, they grasp the semantics of their vocal expressions by trial and error. Later on in life they learn to handle non-trivial complexities of their language explained in that language itself. Human languages are able to interpret (explain) themselves—they admit in fact *self-interpretation*. Is this linguistic feature part of or derived from a general cosmic principle?

Suppose that we earthlings some time from now in the future discover that we are not alone in the universe and that there exists in the galaxy a planet with a society of intelligent beings. If we would receive a message unmistakably emitted by those *aliens*, how are we to interpret the message? If it would contain some means for self-interpretation we might be able to get a relatively quick start in understanding some of the message content. More important, if this feature is provably present in such a communication, a strong ground would have been achieved for the assumption that the concept of self-interpretation is a general cosmic linguistic feature. The feature itself is an essential part of what can be understood to be *astrolinguistics*.

The above discussion leads to an important point: should we on Earth decide to start a project aimed at *Communication with ExtraTerrestrial Intelligence* (CETI) and agree on transmitting a message into the Galaxy, then we should use a *Lingua Cosmica* (abbreviated to LINCOS) based on the simplest possible grammatical structures. At the same time the expressive power of the *lingua* should be sufficiently large to express information we deem useful to transmit. These requirements should be met because our messages must be conceived in such a way that they fulfil two goals: it must be possible for *aliens* to recognize that the message is of a *linguistic* kind and the message is meant to be understandable for them—in fact after the non-trivial task of decoding the stream of digitized information has been completed. In addition extra information should be included in the LINCOS text informing receivers that the system admits self-interpretation (in accordance with the general astro-linguistic principle outlined above). These requirements, however, are part of a more general issue. For CETI we need to identify and exploit the use of an astrolinguistic *common ground*—a conceptual system which all intelligent symbolic species in the Universe can be assumed to share with one another. The search for a common ground as meant here is like the search for the Holy Grail. The existence of it is uncertain and it might even prove to be an ideal never completely reachable. We can, however, strive to get a better understanding of the issues involved—and designing a linguistic system for interstellar communication based on logic (as presented in this book) can contribute in this respect. Should we find the right base for CETI, a kind of looking glass, it would give us a clear view of the road to be taken: like Anceaux's glasses gave a Papuan in New Guinea a clear view of his and our world (see Fig. 1).

Anceaux's glasses not only symbolize the need of obtaining a clear view of the possibilities of CETI. Likewise they help us to realize the existence of some aspects of the fundamental problems facing the development of a *Lingua Cosmica* for CETI research:

– Enormous cultural and linguistic differences between human societies and those of intelligent beings elsewhere in the universe are to be expected.
– Communication over interstellar distances in real time is impossible as far as we know the laws of nature, excluding tachyonic velocities; therefore the possibilities of "testing" the effectiveness of LINCOS are extremely limited.

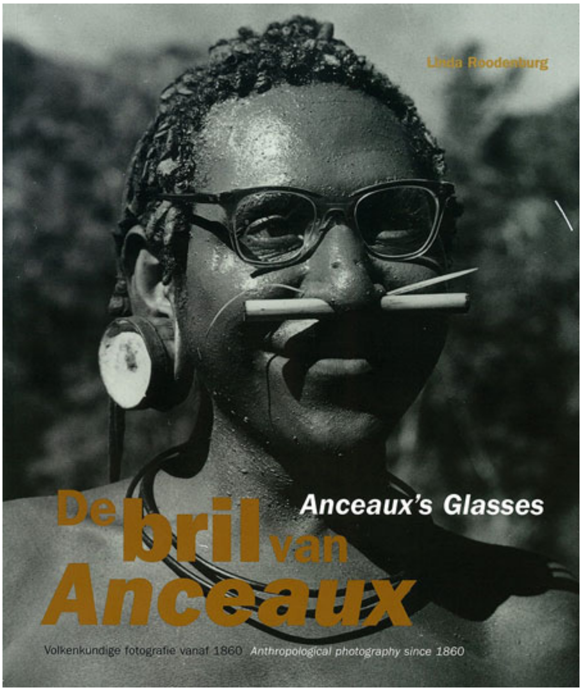

Fig. 1 *Anceaux's glasses*. Reproduced by permission. The National Museum of Anthropology, situated in Leiden, The Netherlands, organized in the year 2002 the exhibition "Anthropological Photography from 1860" and one of the pictures displayed was the one shown in this figure. Linda Roodenburg's text for the exhibition catalogue mentions: "Professor Anceaux, the well-known Dutch linguist and anthropologist from Leiden University took part in 1959 in the last Dutch expedition to New-Guinea. He gave his spectacles to a Papua—the picture shown was taken on that occasion. Anceaux' glasses symbolize the Western view on 'the others' and the Papua wearing the glasses is a symbol for 'the others', those who in this way can look back at us". (Translation by the author of the present book). Dr. Anceaux was a former colleague of the author

– The possibility of effective CETI might lie beyond our horizon at this point of time; after more than 50 years of SETI with the largest radio telescopes of the world, we have not seen any signs of (intelligent) life in the neighbourhood of the Sun and beyond.

Logic as Common Ground

The choice of logic as the base of a *Lingua Cosmica* is motivated by the view that logic can be considered to be a reasonable and useful common ground for interstellar communication between galactic symbolic species. One cannot expect a species without the power of logical reasoning to be able to interpret an interstellar meaningful message. Two questions then present themselves immediately: what kind of logic to choose and in which manner to use it.

The first question is related to the purpose of logic *ipso facto*. The common denominator of all applications is correct reasoning over abstractions of reality, so that argumentation on the basis of tools of logic leads to reliable results. At the same time logic is useful for clarification. For these purposes many kinds or modalities of logic have been developed. The propositional calculus is a basic one. The syntax is simple: assertions are combined into expressions using the "and", "or", "implication" and "negation" connectives. The meaning of the expressions, i.e. the semantics of the calculus, is given by the well-known truth tables. Assertions, however, are restricted to abstractions of individual entities, and in this calculus one cannot express abstractions over a class of objects satisfying some predicate. For achieving that predicate calculus has been developed, using the "all" and "exists" quantifying operators (quantors) in addition to the propositional connectives. It is therefore a stronger logic. Because of these operators the syntax is more extensive. The semantics of this calculus is rather complicated.

In order to appreciate the latter somewhat, suppose all entities in some collection have a property in common expressed by a predicate. Then the assertion that there exists an entity with the mentioned property is not correct unless such an entity existed already or is constructible with instruments of the logic. Observations of this kind have lead to the development of *constructive* logic. Expressions in this modality of logic are provided with types, either by introductory declarations or by simple construction and reduction rules. The existence problem mentioned above is resolved by the declaration of a constant entity of the right type, i.e. that of the collection.

Using ingredients from constructive logic, abstracts of message content are elegantly expressed. The modality chosen admits simple grammatical syntax, sequential notation, decidability of conclusions (since they must be constructible in a finite number of steps) and large expressive power. Interpretation of expressions in this logic by recipients presents a separate problem. There are in fact two (intertwined) issues involved here: the need for a signature identifying the modality and the explanation of the semantics of the system employed. Both of these are non-trivial matters. For solving these questions either self-interpretation can be used or else recourse must be taken to instruments exterior to the logic. In interstellar message composition, the use of natural language for the latter purpose is not applicable. Natural language is capable of self-interpretation, but only understandable for observers who know the language sufficiently well. In our case we describe at a meta level, i.e. outside of the language, the logic contents of a message, written in sentences and collected into larger units. As a side effect, features of the language employed might become understandable, but providing linguistic insights is beyond the goal of the research reported here (Fig. 2).

The image symbolizes some fundamental problems confronting research in the field of Communication with ExtraTerrestrial Intelligence. Of course there will be immense differences (also culturally) in operational linguistics as used between terrestrial human societies and as used between extraterrestrial alien ones—but the

Fig. 2 *Blue Planet Calling*. Reproduced by permission. Created by artist C. Bangs, New York, in 2003, especially for Astrolinguistics

magnitude of them cannot be estimated. Can the somewhat mystical face of the woman, embedded in terms of logic, but also projected on our Blue planet, help in understanding each other? In any case the image will hopefully trigger interest in our messages, whether or not formulated in the new LINCOS.

Research in Astrolinguistics

The previous section illustrates that multidisciplinary research on aspects of life in the Universe, its origin, existence and evolution on Earth and elsewhere, connects in various ways with linguistics in a general sense. Species as they develop and evolve will devise linguistic means for communication. Since communication between intelligent species on spatially separated planets may need to overcome large distances, one is even *a forteriori* concerned with astrolinguistics. Intra planetary communication in *real time* might be feasible but only in the case of multiple planets supporting intelligent life and orbiting around the same star. On planet Earth research *ipso facto* in astrolinguistics has been carried out in several fields:

- Search for ExtraTerrestrial Intelligence (SETI), detection of linguistic information in low-noise electromagnetic radiation from the Universe.
- Fundamental principles of communication between mutually different and totally unknown intelligent species—over interstellar distances.
- Universal semantic machines.

- Coding and decoding algorithms.
- Construction of interstellar messages.
- Creation of a Lingua Cosmica.

Moreover the following topics can be considered to be related to the field of astrolinguistics as well:

- Astropsychology—studies of Darwinistic or other kinds of development of intelligent, symbolic (i.e. linguistic) types of life on planets more or less similar to Earth.
- Astroarcheology—searches for artefacts produced by intelligent life in the galaxy and intentionally or accidentally left behind, "forgotten;" studies of linguistic principles as templates for the development of life elsewhere.

The scientifically challenging topics in the broad field of astrolinguistics are evolving strongly since the first SETI searches and have already led to a number of interesting projects and results. In the SETI Institute in Mountain View, California, there is the productive research group *Interstellar Message Construction* (project leader: Prof. D. Vakoch). The interesting research by Dr. John Elliott in England in the field of semantic machines has produced valuable and useful analyses—while

Fig. 3 *Alexander Ollongren.* Conceptualizing LINCOS. Photographed by Dap Hartman (2000). Reproduced by permission. The author had already seriously started developing the new *Lingua Cosmica* around the time this photograph was taken in Leiden in the Netherlands. The term Astrolinguistics for the surrounding scientific discipline was coined in an article by the author in Wikipedia (2010)

further development is to be expected. The present author's second-generation *Lingua Cosmica* detailed in this book represents a new step in designing linguistic systems for interstellar communication. This project will certainly be followed by further research—some possible lines are suggested in the present book. Astroarcheology and astropaleontology are appearing as completely new disciplines, witnessed for instance by the work of Dr. Kathryn Denning in Canada and the Fermilab Dyson Sphere Searches directed by Dr. Richard Carrigan in the USA. Work in these fields is sure to attract and stimulate new research in the humanities. Finally the important large and broad fields of bioastronomy and astrobiology need to be mentioned. These fruitful areas of research forcefully emerged in the last two decades, have already attracted many researchers from various disciplines, and is fully blossoming right now (Fig. 3).

Appendix C History

I miman fick vi in att det finns liv
på flera hall.
Men var ger miman ej besked om.
Det kommer spår och bilder, landskap och fragment av språk,
som talas någonstans, men var.[0]
Harry Martinson [1], ANIARA [2], En revy om människan i tid och rum [3], 1956
Poem 6, verse 1

Background

The orientation of the present monograph is multidisciplinary. It is concerned with universal aspects of linguistics (here referred to as astrolinguistics), applied logic and especially conceptual non-technical issues in the field of possible message exchange (communication) between intelligent species (or information processing artefacts) in the Galaxy using a *Lingua Cosmica*. The (astro) linguistic system advocated for that purpose is based on formal logic. The modality of the logic used is constructive, supplying the design of the LINCOS for interstellar communication with a solid foundation. As an introduction to the enterprise and problems of designing a *Lingua Cosmica* we supply the following historical remarks.

More than 50 years ago Elsevier North-Holland Publishers in Amsterdam brought out LINCOS, *Design of a Language for Cosmic Intercourse*, Part I [Freudenthal 1960], written by the well-known prominent Dutch mathematician Dr. Hans Freudenthal († 1991) of Utrecht University in The Netherlands. Upon getting acquainted with the book many years ago, the present author, educated as a mathematical astronomer in the Netherlands and Sweden, interested in computer science and logic, was almost immediately fascinated by the conceptual problems in designing a language for communication between mutually alien intelligent species in the universe. The book was the first one (and is the only monograph until now) on this topic. Freudenthal's brilliant design of the *Lingua Cosmica* has concepts from

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mathematics and some logic as well at the core. It was published in Elsevier's series Studies in Logic and the Foundations of Mathematics. From the way it was written it is evident that the renowned mathematician enjoyed this excursion into the area for him unfamiliar. That impression was enhanced during the one and only meeting the present author had with Prof. Freudenthal. It occurred during the Dutch mathematician's congress at the Mathematical Institute of Leiden University in The Netherlands in the late eighties of the last century. Colleagues of the present author, having attended in the 1960s Dr. Freudenthal's public lectures on the unusual subject, have confirmed this impression. The work on LINCOS was, however, incomplete. Part II, planned to be devoted to the description of societal aspects of humanity, was perhaps partly conceived but was never published. It is unclear whether topics in this field have been studied more than only cursorily before, during or after the publishing of Part I.

An interesting, comprehensive and in-depth review of Freudenthal's book written by Bruno Bassi was to be found a few years ago in Wikipedia. The paper is entitled *Were it perfect, Would it Work Better? Survey of a Language for Cosmic Intercourse* [5]. As that article presents unusual and illuminating perspectives not only on the book itself but also on philosophical aspects of Freudenthal's undertaking, some relevant quotations are incorporated into the present historical resumé. The author is thankful for the permission received from Dr. Bassi for quoting him extensively here. In the opening paragraph of the review Bassi stresses the point that there is:

> … a sort of paradox that is implicit in the whole enterprise, an oscillation between a formalist and a communicative trend that makes Lincos a hybrid experiment from the point of view of the design of a perfect language.

Bassi also remarks:

> … Lincos is a very peculiar educational (gedanken-) experiment. Usually, linguistic education takes place through the use of a language already known to the learner (as in case of learning by adults) and/or in real-world contexts in which people smile, frown, gesticulate, point at objects, and in which the learner can observe other speakers' behaviour and get feedback from them (as happens to children and anthropologists). On the contrary, in the ET case we can rely neither on a known language nor on an extra-linguistic context. All we can do is to speak pure Lincos. The language is to be taught through the language itself, used one-way in an absolutely pure fashion.

There are some further important points in Bassi's article, quoted here:

> …'Decoding Lincos would be an easy job' (Freudenthal 1974:1828). Provided that the ETs who are receiving it fulfill certain requirements. A basic requirement concerns their technology: they must be able to receive radio signals and to measure their duration and frequency. In order to understand Lincos texts they should be humanlike with regards to mental states and communicative experiences. In particular, if they are to understand the initial part of the program, they should have intuitive arithmetical conceptions somehow similar to ours. This may seem a strong assumption. However, given that we have to start off with some universally understood topic, the choice of natural numbers arithmetic seems to be, after all, quite a reasonable one. Then, our ETs must of course have some sort of language of their own. It may be completely different from our languages, but its handling of context, of presupposition and of implication should be essentially the same as what we are accustomed to. … Anyway, it is *not* requested that ETs already know all the things we are telling

them about. A lot of mathematics as well as 'behavioral rules' are learnable through Lincos itself once an agreement about the fundamentals has been reached.

… Dr. Freudenthal explicitly introduces his language as a step towards the design of a '*characteristica universalis*'. Due to the progress achieved in this century by formal logic, we should be much closer to such a result than Leibniz, for instance, was. The only trouble is the difficulty of choosing a starting point. We need to start with a "concrete, sharply defined and narrow problem" (p. 12). The problem of communicating with ETs should serve as such a starting point.

… A man decides to build a perfect language. The philosophical tradition in which he places himself is one that pursued formalization, both as a requirement to be fulfilled by the artificial languages it produced and as a deep principle to be posited underneath the surface structure of natural languages. He claims that the formal instruments at his disposal are adequate to the task. Then, in the actual design of the language, he applies his formal devices only to a few specific syntactic features, and for the rest he relies on the structure of natural languages. People usually build perfect languages in order to override traditional 'unsatisfactory' features of natural languages, such as the fact that they are subject to non-sense, ambiguity, lexical and grammatical irregularity, context-dependency. Yet, many of these features are still somehow present in Lincos. Why did Dr. Freudenthal, who has not at all a naive approach to this sort of issues, let things go this way?.

… The idea of applying achievements from symbolic logic to the design of a complete language is deeply linked to a strong criticism towards the dominant twentieth century trend of considering formal languages as a subject matter in themselves and of using them almost exclusively for inquiries about the foundations of mathematics. 'In spite of Peano's original idea, logistical language has never been used as a means of communication … The bounds with reality were cut. It was held that language should be treated and handled as if its expressions were meaningless. Thanks to a reinterpretation, 'meaning' became an intrinsic linguistic relation, not an extrinsic one that could link language to reality' (p. 12).

… In order to rescue the original intent of formal languages, Lincos is bound to be a language whose purpose is to work as a medium of *communication* between people, rather than serve as a formal instrument for computing. It should allow anything to be said, non-sense included. In Lincos, 'we cannot decide in a mechanical way or on purely syntactic grounds whether certain expressions are meaningful or not. But this is no disadvantage. Lincos has been designed for the purpose of being used by people who know what they say, and who endeavour to utter meaningful speech' (p. 71).

… As a consequence, Lincos as a language is intentionally far from being fully formalized, and it has to be that way in order to work as a communication tool. It looks as though the two issues of communication and formalization radically tend to exclude each other. What Lincos seems to tell us is that formalization in the structure of a language can hardly generate straightforward understanding.

… Our Dr. Freudenthal saw very well this point. 'there are different levels of formalization and … in every single case you have to adopt the one that is most adaptable to the particular communication problem; if there is no communication problem, if nothing has to be communicated in the language, you can choose full formalization' (Freudenthal 1974:1039).

… But then, how can the solution of a specific communication problem ever bring us closer to the universal resolution of them all? Even in case the Lincos language should effectively work with ETs, how could it be considered as a step towards the design of a *characteristica universalis*? Maybe Dr. Freudenthal felt that his project needed some philosophical justification. But why bother Leibniz?.

… Lincos is there. In spite of its somewhat ephimeral 'cosmic intercourse' purpose it remains a fascinating linguistic and educational construction, deserving existence as another Toy of Man's Designing.

Freudenthal, Hans 1960 *Lincos–Design of a Language for Cosmic Intercourse*, Amsterdam, North Holland 1974 "Cosmic Language", in T. A. Sebeok (ed), *Current Trends in Linguirstics*, vol 12, The Hague: Mouton, pp. 1019-1042

SETI

The publication of Freudenthal's book, now only available antiquarian, coincides with the beginning of an epoch: the start of international projects in the Search for ExtraTerrestrial Intelligence (SETI). Rather remarkable is that Martinson's book ANIARA was published a few years earlier. That visionary, interesting book preludes in the form of poetry on the immense difficulties that can be expected in the field. In the more than 50 years elapsed since then several aspects around SETI have been cleared up [Ronald D. Ekers et al 2002]. Modern astrophysical research has revealed that it is not to be expected that *real-time* interstellar communication will be possible. There exist indeed numerous solar type stars of about the same age as the Sun in the habitable zone of our Galaxy, many planets orbiting stars have been found but so far none of them are earth-like (astronomers expect to find this type of planets in the near future). Exiting discoveries are to be expected as soon as the observational techniques will permit analyses of planetary atmospheres. However, there is the fact that our nearest neighbours (whether or not harbouring intelligent species) are on the average at a distance of scores of light years away. Laws of physics forbid the transmission of information with tachyonic velocities (exceeding the velocity of light). So no highly developed technological society can expect to "get in touch" directly with another one in the Galaxy. Nevertheless such societies (and ours too) can be assumed to be not only interested in transmitting information about themselves to whoever is "listening", but are in fact even putting some effort in doing so. One reason might be because they could be inquisitive (in the sense of striving to acquire knowledge—as our species is by nature) and wish to know about "the others". For both the purposes of transmission and reception of messages, a rather sophisticated linguistic system for interstellar communication is needed. In the author's view Freudenthal's design, brilliant as it is, is outdated now. The design of a new system should satisfy at least some basic properties:

– Linear notation and simple syntax.
– Clarity of expression (self-interpretation of messages).
– Rich contents of messages, redundancy.
– Possibility of structuring and sizing messages.

In addition the system should be able to describe not only static relations but also dynamic processes. This extremely important capability is discussed in some detail in the present book, in fact in the separate PART V—devoted to the representation of various kinds of processes in the proposed new LINCOS. In addition this part presents an opening to the matter of representing and using aspects of (computer) information processing programs in the system.

It is not unreasonable to assume that an intelligent species receiving an interstellar message unmistakably bearing a linguistic signature will put automatic information processing machines at work to do the decoding and some of the interpretation. We would do the same thing! Therefore messages should be large-sized and contain a large amount of redundancy.

Multi-Level Approach

The writer of the present new book, belonging to a generation younger than Prof. Freudenthal's, has since the late fifties been exposed intensively to basic concepts in computer science: low-level assembly programming systems, procedural (ALGOL-like) and functional (LISP-like) and logic programming languages, besides formal languages and automata—and the mathematical/logical *lambda* calculus. All of our computer programs in low-level languages *had* to be written in the early days of computer science in linear notation, preferably in prefix form, i.e. the Polish version. Years later, those experiences supplied the author with the idea that Freudenthal's abundant use of super- and subscripts and the numerous *ad hoc* agreements (resulting in a rather unwieldy notation), might be simplified with some effort by using ingredients from "modern" theories on computer programing. At the same time it was realized that the overall purpose of Freudenthal's work might be achieved in a better way if one *abstained* from using just a single level in interstellar message construction—that of the *Lingua Cosmica* itself.

Thus an idea was born: messages meant for interstellar communication with extra-terrestrial intelligent societies should be essentially *multi-level*, they should consist in part of a (large) text in some natural language supplemented with annotations in a formal system at another level. In that case the other level has the role of a *meta* level in which descriptions about the contents of the basic level are available. The basic level can but need not necessarily contain only text. Pictures supplemented with text but also music could be placed there. Using *formal logic* at the core of a *Lingua Cosmica* enables one to describe not only the logic contents of texts in such messages but also the definitional framework (comparable with an environment created by the vehicle of declarations in computer programming). Seen from this starting point the proposal in this treatise is in fact a linguistic *system* to be used for interstellar communication.

In the wake of this view Freudenthal's idea of using mathematical notions as a central core in the language was abandoned. Instead it was realized that sophisticated *type* declarations and *type* notions from proposition and predicate logic should be given central positions. Logic reasoning about textual contents can be (and are in the present setting) shifted to the mentioned *meta* level. If mathematical reasoning of some sort is needed to explain properties, that can be done in yet another level.

When the author got well acquainted with the French Coq [Gérard Huet et al 1999] implementation of the calculus of constructions with induction (CCI) based on the typed lambda calculus, it was realized that the basics of that proof system provide a suitable vehicle needed for the design of a new linguistic system for interstellar communication. The specific formal logic on which the new system is based, has by its nature rich declarative and expressive powers. It seemed not to be a good idea to translate Freudenthal's expressions into terms in constructive logic. A better idea was to use CCI and the underlying type theory in a totally different way and circumvent at the same time some of the problems present in the first *Lingua Cosmica*. One of these is that that *lingua* is very suitable for expressing mathematical relations, but much less useful for describing structural aspects of human societies. As mentioned before, Freudenthal's unpublished Part II was meant to deal with aspects as these. In the late 1980's, Prof. Freudenthal, during the mentioned conversation with the present author, gave the impression of having lost interest in the project.

A predominant requirement for the present author's undertaking was, right from the beginning, that a message meant for an extra-terrestrial civilization should in some way carry information for the interpretation of the formal language employed—or methods for achieving this goal. So aspects of auto-interpretation have been incorporated and worked out in the system. The new *Lingua Cosmica*, also referred to as LINCOS, developed and described in the present monograph rests on concepts of CCI formulated in terms of type theory. Moreover it uses linear notation. Several computer implementations of this particular logic are available. Some of these have been used for verifications of lemmas in this book. Therefore occurring facts (i.e. lemmas in the form of term expressions in LINCOS) in the book are guaranteed to be correct—a remarkable, important aspect. The elimination machinery employed is rather different from that in the Coq system. The notation, largely based on the conventions of type theory, has been adapted in order to improve readability. The set of primitives is kept very small. As a result of this the dynamics of verifications become transparent. The requirement of obtaining an "easy to handle" (linear) notation is met as well. All of these aspects are explained in detail in the book.

The study of interstellar communication requires *ipso facto* an interdisciplinary approach. It is concerned with cosmology, astrophysics, -chemistry, -biology, but also with information processing, linguistics and coding theory besides concepts in mathematics and logic. So the underlying central themes of the book are in fact situated in the broad context of astrolinguistics. Within that context the new *lingua* is used for describing in a concise and interpretable manner a selection of physical reality as we humans experience it. For that purpose abstractions of reality, and more in particular logic static relations occurring in reality, are modelled. They are represented mostly as strictly logical forms. It appears, however, that modelling of more involved dynamic relations needs extra means of reasoning—as in cases treated in Part V. That can be done by arbitration utilizing a separate level.

An Example

Some of the easier to understand ideas behind the proposed LINCOS are illustrated below by a simple example (see for details Chap. 7). We use for that in the present notes one of the easier well-known syllogisms of the Greek philosopher Aristoteles (384–322 BC). The important concept of Aristotelian syllogisms has survived more than 2,000 years of development in logic and has been enormously influential. At one level (say the basic level) one might use the following example of an Aristotelian basic syllogism:

all Humans are Mortal and *all* Greeks are Human
so *all* Greeks are Mortal.

This kind of expression, called *Barbara* by mediaeval scholars because of the three occurring symbols *all* (logic quantifiers), is evidently representative of a whole class of logic expressions.

In Aristotelian logic there are four mutually distinct basic classes of expressions (*cf*. Chap. 7). A suitable *environment* is needed in order to describe in LINCOS at another level (the *meta* level, but it is in a way also a *deep* level) the logic contents of the particular expression shown above. It consists of a universe of discourse D, and moreover humans, mortality and Greeks introduced as *types* using LINCOS notation:

CONSTANT D : Set. (universe of discourse)
CONSTANTS Human, Mortal, Greek : D → Prop.
(maps representing subjects and predicates)

These are declarative items, specifying the environment needed.

Set is a predefined type and D of type Set is introduced.
Prop is also a predefined type, distinct from Set.

If *a* and *b* are abstract representations of logic propositions (assertions) then
a, *b* : Prop, i.e. they have type Prop. The type of Human is D → Prop, i.e. a (mathematical one to one) mapping or function. Note that Human, Mortal and Greek have the same type. So if *x* has type D, then the functional application of Human to *x*, written (Human *x*) has type Prop but also (Mortal *x*) and (Greek *x*) have the same type Prop.

The syllogism itself is written in the spirit of Aristotelian logic as a lemma, stating the non-elementary type of Barbara

FACT Barbara :
(ALL *x* : D)
((Human *x*) → (Mortal *x*)) ∧ ((Greek *x*) → (Human *x*)) →
(Greek *x*) → (Mortal *x*).

Here → denotes logic implication and ∧ is used for logic conjunction. Above fact is easily understood by humans (and perhaps ETI)—it hardly needs verification. But in order to explain it in a logical sense it needs a proof. The present book explains in general how facts are verified in a formal sense *within the system itself*. In above case Barbara can be shown to be equal (in Leibniz's sense) to a constructed lambda form (see Chap. 7).

Suppose that in one of our messages for interstellar communication the Aristotelian syllogism as shown (*e.g.* in the form of a text file) is embedded. In it are then above declarations and the fact Barbara of the non-trivial type shown—perhaps augmented with a proof (verification) of the fact. A recipient of this message wishing to decode and understand the contents of this fragment faces several non-trivial problems. In order to simplify the issue we suppose that it is recognized that one of the natural languages spoken on Earth (unknown to the receiver) is used at one level, and that the logic structure of the sentence is explained at another level with the help of terms in a logic system. The recipient knowing (propositional and predicate) logic, upon analysing the incoming signals (text), recognizes that a constructive form is used, and will discover soon the meaning of ALL (universal quantification), and the connectives → (implication) and ∧ (conjunction). He/she/it might immediately add to these ∨ (disjunction) and ~ (negation), as well as Ex (existence), absent in this example. Furthermore the items Human, Mortal and Greek appear in the text as well as in the deep structure (and in the proof of the fact). All of this is helpful for the decoding and interpretation problem.

However, we may well assume that small-size messages will be unintelligible for recipients or their information processing artefacts (i.e. ETI), despite much effort from their side. In order to effectively provide help for the interpretation problem, messages should therefore contain much or very much redundancy. Thus, as a part of a more extensive message in LINCOS, one could include and formulate at least several examples of all four basic Aristotelian syllogisms. They need not necessarily be in the form available in Chap. 7 of this book, because those are meant to be informative for human readers. In the present monograph the author has developed the necessary formalizations in terms of the linguistic system proposed. Thus each of the four basic syllogisms is formulated as a fact, verifiable within the framework of the language itself. This (general) powerful aspect of the system may prove to be one of the important keys for decoding purposes.

There are other instruments as well for explaining in our messages the structure and conceptual set-up of the LINCOS system. These are assumed to be feasible and effective because the design of the system is based on extremely simple grammatical rules. One could *e.g.* use music at the basic or even third level with annotations to the score in the LINCOS language, see Chap. 15. Also useful for this purpose is pictorial information (possibly at again another level) as for instance available on the famous anodized gold plaques on board the Pioneer 10 (launched in 1972) and Pioneer 11 (launched in 1973) unmanned space crafts. The contents of pictures can (partially) be described in LINCOS, see also Chap. 14. Using multiple levels coded information of these kinds could be included (simultaneously) as well.

Note: some material in the present book is based on the author's contributions to the international congresses of the International Astronautical Academy from 1998 onwards. The author has retained the copyrights.

References, translations

[0]
In miman it is found that there is life
in several places.
But where the computer does not reveal.
Traces and pictures arrive, landscapes and fragments of language,
spoken somewhere, but where. (transl. by the author)

[1] Harry Martinson (Sweden) 1904–1978, received the Nobel Prize for literature in 1974

[2] Aniara, a space ship, has left planet Earth for a voyage into unknown space. Martinson described (in 1956) in 103 poems the fate of the people aboard, the crew and *miman*, the advanced intel-

ligent computer. From the introduction: Aniara is concerned about everything we personally do not master, but which is part of our lives and belongs to us. (transl. by the author)

[3] A story about man in time and space. (transl. by the author)

[4] H. Freudenthal 1960 *LINCOS, design of a Language for Cosmic Intercourse*, Part I, North-Holland Publishing Company

[5] The article appeared in the volume "Le lingue perfette", edited by Roberto Pellerey, Versus—Quaderni di Studi Semiotici 61/63, 1992, and is available at http://www.brunobassi.it/scritti/lincos.html

[6] SETI 2020 *A Roadmap for the Search for Extraterrestrial Intelligence*, Editors: Ronald D. Ekers. D. Kent Cullers, John Billingham, Louis K. Scheffer, SETI Press, MountainView, Calif. 2002

[7] Gérard Huet et al. 1999 *The Coq Proof Assistant*, early version, INRIA, France

Appendix D A Gentle Introduction to Lambda and Types

Intention

Two of the lesser known theories in mathematics and logic are the λ *Calculus* and *type theory*. In the astrolinguistic setting of this treatise, more in particular for the design of a system for interstellar message construction discussed, both of these are of prime importance. The new Lingua Cosmica described in this book, aimed at interstellar communication, is in fact a *linguistic system*, and these two theories supply the mathematical foundation of the proposed lingua. Therefore it is appropriate that necessary background information on the use of the lambda- and type concepts is supplied. That is the purpose of the present chapter. It is set apart as an appendix because the theories associated with these concepts are rather unusual even though they are in essence quite easily understood. Because of the central position they occupy in the present work, they are discussed here (albeit in a gentle way) in some detail. Readers not supposed to possess any prerequisite knowledge in the relevant fields, are enabled in this manner to get easily acquainted with the main aspects of the theories.

Pillars

The *Lingua Cosmica* (LINCOS) and its use in astrolinguistics as described in the present treatise rest on two main pillars: the *Lambda* (or λ) *Calculus* and a *Calculus of Constructions* including inductive definitions (and therefore sometimes referred to as CCI). In this treatise the Calculus of Constructions used is often referred to simply as CC, even though the germane concept of induction is for some applications (*e.g.* recursion) extremely important. These calculi (see also details described in PART I) with roots in intuitionist logic in turn utilize a number of aspects of the (typed) λ Calculus, unfortunately not well-known outside of mathematics, logic and theoretical computer science. In the formalism of the λ Calculus, functions and functional applications are represented in an unusual way. In the typed version of the λ Calculus

A. Ollongren, *Astrolinguistics*, DOI 10.1007/978-1-4614-5468-7,

each entity is supplied with an abstract *type*. Types, typing and type checking occupy central positions in CC as well. Therefore it is appropriate to discuss in the present appendix some of the concepts and notations figuring in the λ Calculus. There is no need to give a comprehensive discussion of that particular calculus in this book because only a restricted set of expressions is actually used in LINCOS. Concepts, on the other hand, are discussed in the following sections in somewhat more detail. The standard volumes on the Lambda Calculus and its various ramifications are the important books by Prof. H. Barendregt [Barendregt 1984, 1992].

Lambda

The λ Calculus was originally developed by Alonzo Church around 1940 as a logico-mathematical system for formalizing fundamental aspects of mathematics. A remarkable follow-up around 1960 was the definition by John McCarthy of the *List Programming Language* based on this calculus. LISP became eventually the prototype of functional computer programming languages. In contrast to the ALGOL-like (or procedure oriented) languages, these languages are based on the notion of functions (or maps). That idea was inherited from the original λ Calculus without types. McCarthy's LISP functional programming system, which became famous, is also untyped. The author's experience in LISP programming has influenced the development of LINCOS as described in this book, but only indirectly because the Calculus of Constructions uses *typed* λ Calculus, see also PART I of the present treatise. In the present chapter we review both the untyped and typed calculi, albeit briefly, because they provide together a ground and solid pillars for CC and therefore a fortiori for our LINCOS.

We must remark here that the notation employed in CC and LINCOS resembles strongly the notation used in the present chapter, but it is not exactly the same. However, notation in LINCOS is kept as close as possible to the one used in the following sections. Another aspect is that newer computer implementations of the Calculus of Constructions tend to drift away from the conventions of the λ Calculus in view of demands emanating from the area of applications. In our design we have refrained from that tendency since we need a general purpose approach, and also because of requirements brought up by one of our important design objectives: the possibility of self-interpretation of LINCOS. Still deviation from the notation of this section could not be avoided, because of the requirement that LINCOS terms must be expressed in a linear notation. See also the remarks in the POSTSCRIPTUM of this book.

Untyped λ Calculus

In the present section we use arithmetical operators and integer constants, even though they do not figure prominently in LINCOS. This choice is motivated by the fact that concepts in this calculus are easily explained in that way. At the same time we emphasize that this does not mean that arithmetic's ad fortiori should be embedded in messages for Extra Terrestrial Intelligence (ETI).

Beginning with the calculus without types: let *f, g, …, x, y, …* be *variables* and let there be a collection of *constants*, *e.g.* the integers, the Booleans or something else, with denotations written in some notational system. Standard *operators* of arity 1 or more (1 or more arguments required), such as the arithmetical √ ("square root", arity 1), + ("addition", arity 2), – ("subtraction", arity 2), × ("multiplication", arity 2) and / ("division", arity 2), or logical ∧ ("conjunction", arity 2), ∨ ("disjunction", arity 2), → ("implication", arity 2) and ~ ("negation", arity 1) can be considered to be constant (or fixed) *functions*. A variable can also be considered to be a function, but then of arity 0. The context in which a variable appears shows which set of constants is the relevant one. The essence of the untyped calculus is that the relevant sets are not made explicit. *Expressions* in the calculus are built using variables, constants and functions, formally

$$\text{expr} ::= \text{constant} \,|\, \text{variable} \,|\, \text{function}$$

$$\text{function} ::= \text{expr}\,\text{expr} \;|\lambda\, \text{var}^{+}.\text{expr}$$

This is a context-free generative grammar (in the Chomskyan sense) describing the linguistic deep structure of the λ Calculus. Note the extreme simplicity of the grammatical rules. The notation used here is derived from the report defining the syntax of the Algorithmic Language ALGOL-60, by the computer scientists J.W. Backus et al., and P. Naur (Editor) in 1960. The token | denotes a choice, expr expr denotes functional *application*, and λ var^{+}. expr is a so-called *lambda-abstraction*. var^{+} indicates a sequence of one or more than one variable.

The (extremely simple, but complete) grammar given above is abstract (in a linguistic sense), showing form structure only. In order to obtain surface structures the constants, variables and functions must be represented by *denotations* in some way. It is seen that a function is either an application of one expression to another or a lambda-abstraction. As above grammar supplies syntactic form only, comprehensive semantics are needed to give *meaning* as well to expressions and functions. Doing this comprehensively for the λ Calculus is a formidable task and lies far beyond the scope of the present treatise. Instead we shall discuss the necessary fundamental semantic concepts figuring in the calculus using illustrations. First expressions, abstraction and binding rules are explained.

Expressions representing mapping from a domain to a codomain are written in prefix notation. The simplest λ-abstraction has the following form

$$\lambda\, x.\, \text{expr}.$$

In this case only one variable (*x*) occurs in the λ-abstraction and the domain of the mapping is the domain of the variable. In the λ-form shown, the dot is followed by expr, called the *body* of the abstraction; it is an expression for a map from the domain of *x* to the codomain. So expr will in general be dependent on the variable *x*, *bound* by the λ and with as the *scope* of it the body of the abstraction. Note that *x* can but need not occur in the body—this is evidently an aspect of prime importance.

The body can contain further λ-abstractions with local variables. If such variables are introduced in the body, the usual *scope rules* in the theory of high-level programming languages apply—we will not go into this in any detail. The λ-abstraction above is a way of defining a mapping without giving it a name—this is also important. The map itself is written by convention in the operator prefix notation, i.e. operators are written first followed by its arguments. So we might have

$$\lambda\ x.\left(+x\ 31\right)$$

representing the concept "adding thirty one". The variable x ranges over some domain, admitting an interpretation of the + operator.

Next *conversion rules* are explained. Above example is not the only representation of the concept is concept "adding thirty one". Consider for instance

$$\lambda\ y.\left(+y\ 31\right)$$

representing the same operation. So we have

$$\lambda\ x.\left(+x\ 31\right)=\lambda y.\left(+y\ 31\right)$$

the equality sign expressing that the two expressions are the same, not literally but representing the same mapping. The one and only difference in their appearances is that the variable x has been renamed to y (or the other way around). This process of renaming is called *α-conversion*. An example of a simple expression with two bound variables, showing another α-conversion is

$$\lambda\ x,y.\left(+x\ y\right)=\lambda y,x.\left(+y\,x\right).$$

A λ-expression representing a function can be *applied* to an argument to yield a result. Consider the following example of the concept of functional application

$$\left(\lambda\ x.\left(+x\ 31\right)\right)21=+21\ 31$$
$$\left(\lambda x,y.\left(+x\,y\right)\right)21=\lambda\ y.\left(+21\ y\right)$$

Note the replacement rule used here: 21 must be substituted for x (the first formal argument) not for the second, y. The case of two applications is illustrated by

$$\left(\lambda\ x,y.\left(+\,x\,y\right)\right)21\ 31=\left(\lambda\ y.\left(+21\ y\right)\right)31=+21\ 31$$

It is seen that the underlying association (in fact functional composition) is from left to right. Further one can say that applying a λ-expression to arguments entails a form of evaluation. The mechanism illustrated by these examples is called *β-conversion*. Note that β-conversion is not able to change λ $x,y.(+\ x\ y)$ into λ $x.(+\ x$ 31). The following example uses only β-conversion

$$\left(\lambda x,y,z.\left(+x\,y\right)\right)21\ 31=\lambda y,z.\left(+21\ y\right)31=\lambda z.\left(+21\ 31\right)=+21\ 31$$

The last step is justified because z does not occur in the expression (+ 21 31).

One additional conversion rule, the so-called η-*conversion* needs also to be mentioned.

Let f be a function of arity at least 1, independent of a given variable x. Let $(f\ x)$ be the application of f to x. Write $f\ x$ for this case, a simple one as far as brackets are concerned. Consider the equality $(\lambda\ x.\ f\ x)\ y = f\ y$ due to β-conversion (and because f does not contain x). This means that the equality $\lambda\ x.\ f\ x = f$ is justified. This remarkable result is called the η-conversion rule. Note the equality $(\lambda\ x.\ f\ x)\ x = f\ x$.

Here are some examples showing useful conventions.

Because brackets in function application associate to the left (one can say that they *cluster* on the left-hand side), they need not always be written:

$$+21\ 31 = ((+21)\ 31)$$
$$+(+21\ 31)\ 41 = (+((+21)\ 31)\ 41)$$
$$((f\ g)x) = (f\ g)x = f\ \ g\ \ x, \text{functional composition,}$$
$$\text{first } f \text{ is applied to } g \text{ then the result to } x$$
$$f(g\ x), \text{first } g \text{ is applied to } x \text{ then } f \text{ to the result.}$$

Sometimes it is necessary to give a name to a λ-expression representing a function (especially in view of applications in LINCOS). So for the first of above examples we might write

$$\text{DEFINE f} := \lambda\ x.(+x\ 31).$$

This feature is mandatory in the case of functions defined in terms of themselves: i.e. when we need recursive (or inductive) definitions. The standard example of this is the definition of the product $n! = 1\times 2\times 3\times \ldots.\ \times n$ for any natural number $n \geq 0$, using another declarator

$$\text{INDUCTIVE fac} := \lambda\ n.(=n\ 0) \rightarrow (\text{fac}\ 0) | \sim (=n\ 0) \rightarrow (\times\ n(\text{fac}(-n\ 1))).$$

The above is a recursive (or inductive) formalization of (fac n) in terms of (fac 0) and (×n (fac (− n 1))), where (fac 0) = 1 can be added as an “afterthought”. The body of the λ-form contains two clauses. The expressions (=n 0) and ~(=n 0) have the role of induction hypotheses. The vertical stroke |, a *separator*, is used to keep the hypothesis apart from one another. Under a recursive evaluation of fac with some natural number as argument, both hypotheses are evaluated successively. These aspects return in the discussions on CC.

Note: the tokens DEFINE and INDUCTIVE are examples of the so-called *declarators*.

Consider now the following alternative definitions, the first inductive, the second not.

$$\text{INDUCTIVE Fac} := \lambda\,\text{fac}', n.(= n\ 0) \rightarrow (\text{fac}'\ 0) | \sim (= n\ 0) \rightarrow (\times n (\text{fac}'\ (-n\ 1)))\ \text{Fac}.$$

$$\text{DEFINE H} := \lambda\,\text{f}, n.(= n\ 0) \rightarrow (\text{f}\ 0) | \sim (= n\ 0) \rightarrow (\times n (\text{f}\ (-n\ 1))).$$

This implies the equality fac = H fac. In other words the map H applied to fac yields fac. This means that fac is a *fixpoint* of the map. One expects that the fixpoint can be computed, for instance that 3! can be evaluated to (×6 (fac 0)). That is done as follows using β-conversion several times, not on Fac but on fac.

$$(\text{fac}\ 3) = (\times 3 (\text{fac}\ 2)) = (\times 3 (\times 2 (\text{fac}\ 1))) = (\times 3 (\times 2 (\times 1 (\text{fac}\ 0)))) = (\times 6 (\text{fac}\ 0)).$$

The last step requires evaluation of the multiplication operator over the natural numbers. The computational facility using β-conversion shown here is in principle available in LINCOS as well. Its usefulness is in general, however, limited. An exception is the case of representing processes (Chap. 17). Alternatively we might extend LINCOS with concepts of symbolic computation (computer algebra), see PART VI.

Typed λ Calculus

We proceed now with a discussion of the *typed* λ Calculus. We mentioned in the previous paragraph that an expression as λ *x*(+*x* 31), considered to be a function, can be given an argument in the range of the variable, some number but certainly not a Boolean. If the range of *x* is the set of natural numbers, the requirement can be expressed by adding the *type* of *x* in the expression, by changing it into

$$[\lambda x : \text{nat}].(+x\ 31).$$

In this way *x* is supplied with the type nat, the type of natural numbers (distinct from the set of natural numbers). The semicolon is used to formalize the relationship "has type" or "is of type" (see also Chap. 1). Types generally are abstract and can be structured. The constituents of above expression should then also have types. To begin with, take an important step by stating the type of addition

$$+ : \text{nat} \rightarrow \text{nat} \rightarrow \text{nat}.$$

This is because the map designated by + is a binary operator expecting two arguments of type nat and delivering a result of type nat. This means for example

$$(+21) : \text{nat} \rightarrow \text{nat}$$
$$(+21\ 31) : \text{nat}.$$

Since it has been explained that the λ expression can be applied to an argument of type nat to yield a result of type nat, it should be no surprise that the type of the complete expression is

$$[\lambda\ x : \text{nat}].(+x\ 31) : \text{nat} \rightarrow \text{nat}.$$

In the typed λ Calculus everything should be typed. Consider for example the definition

$$\text{DEFINE f} := [\lambda\ x : \text{nat}].(+x\ 31).$$

The type of f is evidently also nat → nat. As a result (f 21) : nat, and using β-conversion it is seen (f 21) = (+ 21 31). In agreement with this, note that + : nat → nat → nat, so (+ 21 31) : nat. In view of later requirements in the Calculus of Constructions, consider another example, but now using the quantifier ALL. Let g be declared by

$$\text{HYPOTHESIS}\, g : (\text{ALL}\, y : \text{nat})(+y\ 31).$$

The token HYPOTHESIS is also a declarator. The type of g designated in this way is different from the type of f. In addition we have the normal form (ALL y:nat) (+y 31) : nat, with arity 0 for g. See H. Barendregt [Barendregt 1984] for a comprehensive discussion on normal forms. Substituting 21 for y we find (g 21):(+ 21 31), where (+ 21 31):nat. As (+21 31)=(f 21), we find rather remarkably, (g 21):(f 21).

These examples show that a map can be defined as a λ term, but also as a type, written as a hypothesis using the universal quantifier. We have here a *principle of choice*. If a definition is chosen, β-conversion can be used for evaluation purposes, if a hypothesis defining a type is declared, evaluation is evidently not possible. The principle characterizes the difference between the introduction of an entity being by specifying its type and by defining it to be equal to another entity. If two entities have the same type, they are said to *type check*, but they need not be equal. In the next examples the declarator VARIABLE is used.

$$\begin{aligned}
&\text{VARIABLE a} : \text{Prop}.\\
&\text{DEFINITION I} : \text{Prop} \rightarrow \text{Prop} := [\text{x} : \text{Prop}].\text{x}.\\
&\text{Note}(\text{I a}) : \text{Prop and}\,(\text{I a}) = \text{a}.
\end{aligned}$$

Sometimes we use the declarator DEFINITION instead of DEFINE.

$$\begin{aligned}
&\text{VARIABLE a} : \text{Prop}.\\
&\text{HYPOTHESIS}\, g : (\text{ALL y} : \text{Prop})\text{y} \rightarrow \text{y}.\\
&\text{Note}(\text{ALL y} : \text{Prop})\text{y} \rightarrow \text{y} : \text{Prop and}\,(g\,\text{a}) : \text{a} \rightarrow \text{a}.
\end{aligned}$$

Next consider the case of recursively (inductively) defined types (functions). As an example consider the recursive map fac discussed above. In introducing types in the inductive definition we must see to it that fac is assigned the type nat → nat, of arity 1, and in addition we arrange that the inductive clauses are typed. Let the latter be given names h1 and h2. The definition of fac written as a parametrized function becomes then

$$\text{INDUCTIVE fac}\left[\lambda n:\text{nat}\right]:\text{nat} :=$$
$$\text{h1}:\left(= n\ 0\right)\rightarrow\left(\text{fac}\ 0\right) \mid \text{h2}:\sim\left(= n\ 0\right)\rightarrow\left(\times n\left(\text{fac}\left(-n\ 1\right)\right)\right).$$

The form [λ*n*:nat] is moved to the left in order to introduce the *selectors* h1 and h2. Note that the defined fac requires an argument of type nat and delivers a value of type nat, so the requirement fac:nat → nat is fulfilled. The constants h1 and h2 should *not* be assigned types globally, i.e. outside the definition of fac. Here are the types, using *n*, inherited from the definition of fac

$$\text{h1}:\left(\text{ALL}\ n:\text{nat}\right)\left(\left(= n\ 0\right)\rightarrow\left(\text{fac}\ 0\right)\right).$$
$$\text{where}\left(\text{ALL}\ n:\text{nat}\right)\left(\left(= n\ 0\right)\rightarrow\left(\text{fac}\ 0\right)\right):\text{nat, the normal form.}$$
$$\text{h2}:\left(\text{ALL}\ n:\text{nat}\right)\left(\sim\left(= n\ 0\right)\rightarrow\left(\times n\left(\text{fac}\left(-n\ 1\right)\right)\right)\right).$$
$$\text{where}\left(\text{ALL}\ n:\text{nat}\right)\left(\sim\left(= n\ 0\right)\rightarrow\left(\times n\left(\text{fac}\left(-n\ 1\right)\right)\right)\right):\text{nat, the normal form.}$$

In passing we note that

$$\left[\lambda n:\text{nat}\right]\left(\left(= n\ 0\right)\rightarrow\left(\text{fac}\ 0\right)\right):\text{nat}\rightarrow\text{nat}$$
$$\left[\lambda n:\text{nat}\right]\left(\sim\left(= n\ 0\right)\rightarrow\left(\times n\left(\text{fac}\left(-n\ 1\right)\right)\right)\right):\text{nat}\rightarrow\text{nat.}$$

The possibility of referring to induction hypotheses outside definitions is useful and will be exploited in applications of LINCOS. So, as expected the inductive clauses are correctly typed.

Combinators

We leave the set of natural numbers aside in this section and suppose instead that we have available a basic collection of entities called Set. The collection is not interpreted in the set theoretical sense and no special set theoretical operators such as membership, intersection or union over the collection are assumed. However, abstract mappings over Set and conglomerates will be used, but not interpreted (i.e. we do not associate mathematical objects with those). The combinators to be introduced here are useful for definitions of functions in terms of basic ones. But in this section we define them in order to illustrate with examples the phenomenon of *type checking*, of prime importance in applications of LINCOS. Note that a function of arity $n \geq 1$ applied to one argument yields a new function of arity $n \geq 0$ and of another type.

Consider the following definitions:

$$\text{DEFINE I} := \left[\lambda\ x:\text{Set}\right].x$$
$$\text{DEFINE K} := \left[\lambda\ c,x:\text{Set}\right].c$$
$$\text{DEFINE S} := \left[\lambda\ f:\text{Set}\rightarrow\text{Set}\rightarrow\text{Set};\ g:\text{Set}\rightarrow\text{Set};x:\text{Set}\right].\left(f\ x\left(g\ x\right)\right)$$

So that

$$\mathrm{I} : \mathrm{Set} \to \mathrm{Set} \;\; \mathrm{K} : \mathrm{Set} \to \mathrm{Set} \to \mathrm{Set}$$
$$\mathrm{S} : (\mathrm{Set} \to \mathrm{Set} \to \mathrm{Set}) \to (\mathrm{Set} \to \mathrm{Set}) \to \mathrm{Set} \to \mathrm{Set}.$$

In the following examples of type checking we make use of the rule that brackets in function application associate to the *left* so that they are not written.

I is called the *identity function* because

for any x:Set, I x:Set and I$x = x$, using β conversion.

For any c, d:Set, application of the defined K function yields this

K c d:Set and K c d = c, using β conversion.

I c and K c d *type check* and they are also *equal*. This is might be called the *chameleon effect*, as it is much like the ability of the reptiles referred to of changing their colour while retaining their identity.

Another kind of examples is obtained by applying S to K, justified because the first argument of S must be of type Set → Set → Set. Before application S has arity 3, so

$$\mathrm{S\,K} : (\mathrm{Set} \to \mathrm{Set}) \to \mathrm{Set} \to \mathrm{Set} \text{ of arity } 2.$$

Since I:Set→ Set, SK can be applied to I, so with β conversion

$$\mathrm{S\,K\,I} : \mathrm{Set} \to \mathrm{Set}.$$

Next, using the definition of S, consider equalities

$$\mathrm{S\,K} = [\lambda\ g : \mathrm{Set} \to \mathrm{Set}; x : \mathrm{Set}].(\mathrm{K}\ x(g\,x))$$
$$\mathrm{S\,K\,I} = [\lambda\ x : \mathrm{Set}].(\mathrm{K}\ x(\mathrm{I}\ x)) = [\lambda\ x : \mathrm{Set}].(\mathrm{K}\ xx) = [\lambda\ x : \mathrm{Set}].\ x = \mathrm{I}.$$

So S K I *type checks* with I and at the same time S K I = I. It is seen that SKI and I also are subject to the chameleon effect.

For any maps f : Set → Set → Set, g : Set → Set and for x : Set we have

S f g x : Set, and on the other hand
g x : Set.
f x : Set → Set.

f x(g x) : Set, so (S f g x) and f x(g x) are of the same type (they *type check*) whereas equality is not concluded.

Various chapters in the main body of the present book supply an impression of the prominent role of type checking in the design of LINCOS.

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Appendix E Postscriptum

Views in Retrospect

Intention

In these "afterthoughts", written after completing the main parts of the manuscript, we endeavour to embed the undertaking which resulted in the present treaty, in a wider context. In addition some thoughts are formulated on applications of the linguistic system not discussed hitherto. Also briefly considered are possible ways and means for further development of LINCOS, as well as the validation issue. Finally the significance of developing a *Lingua Cosmica* is analyzed.

Universals in Language

Chomsky's paradigm on properties of natural languages, for a long time leading in general linguistics, includes the (strong) assumption that there exist universals in languages. They would be abstractions of structural properties common to all languages used on planet Earth. This idea would make sense under the supposition that humans are born with the ability in the developing brain to recognize universals of this kind and make use of them in learning how to handle languages operationally.

It seems clear indeed that children already at very young age are able to recognize auditive and visual *patterns* supplied by the environment they live in. How patterns such as these are processed and reprocessed (because there is a dynamic aspect as well) is a subject for research—but that some kind of abstract representation of environmental information is stored in the (developing) brain seems an unavoidable conclusion. As a consequence of this humans might be supposed to have the capability of recognizing linguistic patterns in kinds and diversity in natural language, and storing representations of them in their brains. Such patterns could be specific for a given language, not necessarily subjected to a Chomskyan generative

A. Ollongren, *Astrolinguistics*, DOI 10.1007/978-1-4614-5468-7,

grammar, and need not be truly universal. They can, however, be considered to be intimately connected to, in fact represent the *signature* of a given language. In that case the concept of signatures of languages together with the human capability of recognizing them as such would be the cornerstones of language processing by humans, be it in an auditive sense or in reading textual representations.

This, however, need not necessarily be the only way in which (linguistic) information processing could be carried out by extraterrestrial intelligent beings or their information processing artefacts (supposing that they exist). Apart from that aspect, any linguistic system for interstellar communication should possess a specific signature over possible expressions, not only for the purpose of distinguishing them from random noise, but especially because in that way an aid for the interpretation of language content is supplied. We have seen in Chap. 16 that the LINCOS system as presented in this book possesses specific signatures.

Universal Structures

Are there universal structural properties of some kind in systems for information exchange used (spoken and/or written) by intelligent beings and societies elsewhere in the Universe, within or between them? The existence of some kind of means (languages or otherwise) for information exchange between intelligent beings need not be questioned. If elsewhere in the Universe languages are involved, we do not know whether they are more or less structurally similar to—or perhaps entirely different from natural languages used by humans on planet Earth. It seems to be impossible to falsify the existential question as far as languages are concerned—simply because the universe is too large for an exhaustive search. In addition there seems to be no evident useful inductive principle available in order to arrive from evidence in a restricted part of the universe to a valid conclusion in the large. But also verification will be hard to obtain, without quite a bit of luck!

In the chapter PRELIMINARIES we mentioned the important role a *common ground* can be expected to play in possible CETI. In this book we are using logic for that purpose. Let it be mentioned here that we do *not* assume that the complete set of tools at the base of LINCOS should be recognized or understood more or less immediately by receiving ETI. From messages containing an (possibly large) amount of redundancy, one can imagine that receivers could eventually reconstruct (or even guess) the basic ingredients. A process such as this might be somewhat similar to the way humans reconstruct memories. Neuro-medical studies seem to indicate that reconstruction is based on the processing of many large or even small fractions of impressions of happenings stored in the brain. The processing time scale involved in the case of ETI attempting to decode our messages might be considerable from the human point of view.

In view of the foregoing, in the discipline of astrolinguistics one is not explicitly interested in the development and use of a *lingua universalis* for interstellar communication. One pursues a much more modest goal: research on the capabilities and possibilities of a rather restricted linguistic system for (effective) information exchange, a *lingua cosmica*—in our case one with the possibility of validation (as explained in Chap. 10). A legitimate scientific question is then: what characteristics should such a system have, what kind of signature should it possess, what universal structures are presupposed? It seems clear from the discussions in the PRELIMINARIES what it preferably should *not* possess: a linguistic signature similar to those we know and study in natural languages on Earth. Because of this, the term *lingua* (*cosmica*) might be considered to be in some way a bit of a misnomer. Yet, we feel that it is justified to use this term in view of common usage of expressions such as “the language of mathematics”, “the language of logic”, but also “formal languages and automata”, and “programming and algorithmic languages”.

Since all expressions in any astrolinguistic communication system must necessarily be digitized and represented by linear strings of symbols organized in streams, the question of characterization can be reformulated: what digitized patterns are or should be distinctive in a *lingua cosmica*?

Partially an answer of a rather general nature has been given already for the particular communication system LINCOS explained in the present treatise. The signatures of the system, as discussed in Chap. 16, result from the basics of the system, the formation rules for terms, the use of a context-free abstract grammar inclusive recursion for the deep structure, and deeply rooted expressions. Important formation rules are those governing the creation of accessible environments by means of declarations. Then there are the rules governing the appearance of terms and restricting possible expressions. Examples are: the functionality of delimiters, restrictions on declarations (usually deterministic, except in PART VI of this book), the occurrence of free and (λ-)bound variables, scope rules, a strict agreement on the use of pre-, post- or infix notation—preferably not intermixed, and the use of inductive structures.

The importance of patterns in LINCOS is evident throughout the book, but is especially clear in the formulation of Aristotelian expressions already mentioned in the history part and fully worked out in Chap. 7. We have examined and explained in detail there the basic pattern called a *predication*, often used in language. Elementary examples of these (containing a singular) are:

– Socrates is a Greek, all Greeks are human, so Socrates is human.
– Socrates is a Greek, no Greek is an animal, so Socrates is not an animal.

Provided many examples of these kinds are contained in messages, including a fair amount of redundancy, predications as such should be recognizable for ETI as special *forms*. The various kinds of predications in the form of Aristotelian syllogisms are reviewed in a short section towards the end of this chapter.

Future Studies

The aspect of validation, mentioned in Chap. 10, deserves further discussion. One form of validation is already present in the Lingua Cosmica developed in the present treatise, because, as we have explained, a form of self-interpretation is built in: lemmas, theorems (called facts) are verifiable within LINCOS itself. A presupposition is that for a given application the operational environment (a stage) is sound. In order to guarantee that, or at least to assure that the terms in a given environment are non-contradictive, the first thing to do is to consult Wittgenstein's Theatre. But that is conceivably impractical in most cases because of the sizes, i.e. the number of terms the relevant objects generally consist of.

What perhaps could be done as well is replacing the environment by an equivalent stage formulated in an existing computer implementation of constructive type logic. Here a problem might be the designing of an equivalent stage, given one in LINCOS, see [Ollongren 2012]. The equivalence should also be verified, how? Matters such as these can hopefully be cleared up by future studies. Assuming Freudenthal's LINCOS to be the first generation and ours the second, future studies certainly might lead to a third, new-generation *Lingua Cosmica*, one in which open questions such as these are tackled.

On the Interpretation Problem

LINCOS as a linguistic system rests on several pillars. One of them is the multilevel character of the system. The level carrying actual expressions in the formalism proposed is mostly used to annotate information contained in other levels where other formalisms and expressive systems are used (expressions in natural language, possibly pictorial information, music). So LINCOS terms are interpretations of other information—but the other way around can also be claimed: information in another level can be useful for clarification of LINCOS. This view brings up the question whether LINCOS texts *an sich* could be supplied with interpretations. Could interpretation be carried out by automata? LINCOS terms describe logical relations—not in the first place operations and actions as for instance computer programs do. Therefore one is *not* in the first place interested in an operational semantics using *e.g.* interpreting automata (see [Ollongren 1974]). Suppose that ETI's artefacts are to do the interpretation of LINCOS texts. They would have to do a kind of relational analysis in order to arrive at an interpretation. Hopefully the abstract signature of LINCOS expressions (or collections of expressions) will prove to be helpful in indicating that concepts from the lambda-calculus and constructive logic are involved. For the purpose of attaining more or less complete interpretations, generally knowledge of the state of affairs ("knowledge of the world") is needed. This is one of the serious difficulties the designers of messages from Earth for ETI are faced with: which knowledge of the world and how much of it should be transmitted?

Self-Interpretation, -Knowledge and -Reflection

Apart from the more general matter of interpretation and in a way more basic is the matter of auto-interpretation. Natural languages are able to explain their grammatical structures, expressions and rules forming them, by themselves—i.e. a natural language can explain itself—fortunately for our youngsters learning their first and perhaps at the same time another language. One of the cornerstones of Chomskyan theory is the use of recursion in describing the grammatical structure of a natural language. The important feature of self-explanation should preferably be present in any cosmic language as well. The vehicle for achieving this in the case of LINCOS described in the present treatise is the proof machinery for facts—sometimes using the concept of logical induction, see Chap. 2, but always without recourse to external means, see Chap. 13. The basic principle is that facts are verifiable within the system itself. In essence this is due to the general fact that expressions in the system are so to say explained by their types, more in particular: are shown to satisfy correctness criteria, in terms of the system primitives themselves.

Next there is another matter: the question whether LINCOS possesses a form of self-consciousness. In terms of design criteria of the system we can split the question in two parts. To begin with the system evidently "knows" all information stored in the environment extended with proven facts and dynamically extensible. "Knowing" means here that the system has this information accessible and can use it. What the system does with available information depends on tasks given to it. A simple task could be: "Prove Fact F", where the type of F is in the environment, but the proof not (yet). Once the system constructs a proof, its knowledge base is enlarged with that proof and the system is able to refer to it (self-consciousness). Note that LINCOS is not designed to create tasks on its own—in this respect there is no self-consciousness.

However, in a different respect there is a form of self reflection. This results from the fact that the system is designed as a multilevel system. At some level it may contain a text, and at a (in a way deeper) level the text is interpreted (often by way of the construction of proofs, verifications of statements). But we can of course imagine the use a level containing *programs*, themselves consisting of tasks, such as simple ones as in the example above. Tasks can also be of a self-reflecting type, for example "reconsider" a sequence of steps. In this way the system would be able to "know" or "consult" the information embedded in programs, and descriptions of "what to do", as well. In the wake of this the system could be able to learn from experience, i.e. using knowledge acquired in decision making. This might be achieved by means of communication between levels. In the present treatise, aspects as these have not been worked out in detail—that could be a task for a new-generation LINCOS in the future.

Another aspect is the question whether LINCOS is able to communicate with a program not only in the sense of extracting information *from* it but by a facility for adding information *to* it in such a way that the program is modified. By verifying (proving) a theorem the environment is enriched—and we can enquire whether a program could be enriched by verified facts. Intimately connected to this question is what interpretation should be given to programs in the LINCOS environment [Ollongren 1974]. A new generation of LINCOS in the future might address these matters.

Finally the question may be asked: why not use one of the computer implementations of formal proof systems—instead of developing LINCOS ab initio?

Doing that would mean loss of transparency. One would then be concerned with three layers. One containing information in some language more or less formalized. Another containing a “translation” to clauses in the proof system and then a third layer with the verifications in yet another formalism. In LINCOS the last two aspects are integrated in one transparent system: a linguistic system based on logic (and only logic).

Supervenience Revisited

We have seen that the purpose of the LINCOS system is to describe aspects of reality in a broad sense. So a LINCOS text is a kind of coded imprint of something in reality—one could also consider LINCOS descriptions to be projections of reality. The philosophical question discussed in this section is whether LINCOS descriptions supervene reality (or reality subvenes LINCOS). The roots of the concept of supervenience lie in philosophical body–mind discussions—material and immaterial aspects of life. Supervenience is discussed *e.g.* in D.J. Chalmers [Chalmers 1996], *The Conscious Mind*. A citation from that book:

> The notion of supervenience formalizes the intuitive idea that one set of facts can fully determine another set of facts. The physical facts about the world seem to determine the biological facts, for instance, in that once all the physical facts about the world are fixed there is no room for the biological facts to vary. (Fixing all the physical facts will simultaneously fix which objects are alive). This provides a rough characterization of the sense in which biological properties supervene on physical properties.

One could argue—if some *situation* in reality is fixed as a set of facts and fully described in LINCOS, then there is no room for an alternative description, it is determined by the real facts of the situation. So LINCOS would supervene on reality—provided that complete descriptions can be attained. Practice shows that descriptions are usually incomplete—only parts of a situation are covered. If those are the main parts of a situation in some sense, the point of view that reality subvenes on LINCOS is reasonable.

In order to get a grip on the matter of supervenience from a logical point of view and formalize the concept one can consider an alternative and discuss a *system of situations*. In that case the following often quoted rather curious definition of supervenience can be used:

– If the properties of a system (of situations, each characterized by a set of facts) can be subdivided in two classes: B-properties (*high level*, *e.g.* biological properties) and A-properties (*low level*, *e.g.* physical properties), then B-properties supervene on A-properties if no two possible situations are identical with respect to their A-properties while differing in their B-properties.

Rather remarkable here is that the vagueness in this description can be removed by formulating an equivalent definition in terms of LINCOS—avoiding double negation. For that purpose we prefer to use the simplified form:

– B-properties supervene on A-properties if for any two possible situations identical with respect to their A-properties, this implies that they are identical too with respect to their B-properties.

Let S: Set represent a system of situations and let A:S → Prop and B:S → Prop represent the A-properties and the B-properties of the system. Further let s1, s2 : S be two distinct situations. (A s1) : Prop is then the A-property of situation s1, (B s1) : Prop is the B-property of s1. In the definition above the notion of properties being identical occurs. So we need a definition of equality suitable for the case under consideration. It is inspired by the equality function inductively defined in Chap. 2, i.e.

```
INDUCTIVE Eq [X : Prop; x : X] : X → Prop := Eq-intro
: (Eq X x x).
Eq-intro : (X:Prop; x : X) (Eq X x x).
```

In view of this we introduce the equality function we need for the systems mentioned above, such as this

```
INDUCTIVE Eqs [X : Prop; Y : Prop; x : X; y : Y] : X → Y
→ Prop :=
Eqs-intro : (Eqs X Y x y).
Eqs-intro : (X : Prop; Y : Prop; x : X; y : Y) (Eqs X Y x y).
```

Suppose that for situations s1 and s2, we have for the A-properties a1 : (A s1), a2 : (A s2) and b1 : (B s1), b2 : (B s2) for the B-properties. In that case

```
(Eqs (A s1) (A s2) a1 a2 ) : Prop
```

expresses that the A-properties of s1 and s2 are the same, and

```
(Eqs (B s1) (B s2) b1 b2 ) : Prop
```

expresses that the B-properties of s1 and s2 are the same. We have now arrived at the stage where supervenience, and as a bonus subvenience can be introduced as hypotheses.

```
HYPOTHESIS supervenience : (Eqs (A s1) (A s2) a1 a2 ) → (Eqs
(B s1) (B s2) b1 b2).
HYPOTHESIS subvenience : (Eqs (B s1) (B s2) b1 b2 ) → (Eqs
(A s1) (A s2) a1 a2).
```

Discussion

Returning Chalmers' book we quote some relevant passages below.

> It should be stressed that the logical supervenience is not defined in terms of deducibility in any system of formal logic. Rather, logical supervenience is defined in terms of logically possible *worlds* (and individuals), where the notion of a logically possible world is independent of these formal considerations. This sort of possibility is often called 'broadly logical' possibility in the philosophical literature, as opposed to 'strictly' logical possibility that depends on formal systems.
>
> At the global level, biological properties supervene logically on physical properties. Even God could not have created a world that was physically identical to ours but biologically distinct. There is simply no logical space for the biological facts to independently vary. When we fix all the physical facts about the world—including the facts about the distribution of every last particle across space and time—we will in effect also fix the macroscopic shape of all the objects in the world, the way they move and function, the way they physically interact. If there is a living kangaroo in this world, the *any* world that is physically identical to this world will contain a physically identical kangaroo, and that kangaroo will automatically be alive.

In the present chapter we have shown that supervenience can be defined in terms of constructability in a system of formal logic, using LINCOS as a carrier. This aspect is a sideline in discussions on truth in LINCOS, see Chap. 11. More important is the observation that the LINCOS system supervenes logically on reality.

Aristotelian Syllogisms Reviewed

Examples of *predications* are (to be a) Greek, (to be) human, (to be) animal. Subjects can act as predications. A single subject (*e.g.* Socrates) is a singular.

Let D be the universe of discourse and let at least one object be of type D, d : D, i.e. D is the case. Let an individual be represented here by the constant d. We can use d to represent for instance Socrates. In that case Socrates exists—or historically existed! Let S and P be subjects and predicates (in the form of predications) both over D, represented by maps is-S and is-P from D to Prop. In LINCOS we have

```
CONSTANT D :Set.
CONSTANT d : D.
CONSTANTS is-S, is-P : D → Prop.
```

A short review follows of the cases **Aps**, **Asp**, **Eps**, **Esp**, **Ips**, **Isp**, **Ops** and **Osp** as discussed in extenso in Chap. 7. This review is meant to display Aristotelian syllogisms from an alternative point of view.

```
"All S are P", i.e. S is included in P
HYPOTHESIS Aps : (x:D)(is-S x) → (is-P x).
```

Note: if HYPOTHESIS **Asp** : (x:D)(is-P x) → (is-S x). is assumed, then S and P are equal.

"No S is P", and "no P is S", i.e. S and P are disjoint

```
HYPOTHESIS Eps : (x:D)(is-S x) → ~(is-P x).
HYPOTHESIS Esp : (x:D)(is-P x) → ~(is-S x).
```

"Some S is P", "some P is S", i.e. non-empty intersection of S and P.

Let y : D be such that (is-S y) is the case and let z : D be such that (is-P z) is the case.

```
HYPOTHESIS Ips : (is-S y) → (is-P y).
HYPOTHESIS Isp : (is-P z) → (is-S z).
```

"Not all S are P, i.e. some S is not P"

```
HYPOTHESIS Ops : (is-S y) → ~(is-P y).
HYPOTHESIS Osp : (is-P z) → ~(is-S z).
```

The predications P and S can be replaced by concrete examples, such as A (for animal),

F (for females), G (for Greeks), H (for humans), S (for singers).

```
CONSTANTS is-A, is-F, is-G, is-H : D → Prop.
```

Some examples of *correct* conclusions.

```
(Ahg d) : (is-G d) → (is-H d) and Ihg : (is-G d) →
(is-H d).
(Ahg d) and Ihg have the same type.
```

Conclusion:

– "Socrates (d) is a Greek, all Greeks are human, so Socrates is human".

```
(Eag d) : (is-G d) → ~(is-A d) and Oag : (is-G d) →
~(is-A d).
(Eag d) and Oag have the same type.
```

Conclusion:

– "Socrates (d) is a Greek, all Greeks are not animal, so Socrates is not animal".

```
Ifs : (is-S z) → (is-F z). some z is F
```

– “Some singers are female”

Conclusion:

– “Some females are singers”, because z is a female and a singer.

```
Isf : (is-Fy) → (is-S y). some y is S
```

– “Some females are singers”.

Conclusion:

– “Some singers are females”, because y is a singer and a female.

```
Ofs : (is-S z) → ~(is-F z). some z is not F
```

– “Some singers are not female”, “Not all singers are female”.

```
Osf : (is-F y) → ~(is-S y). some y is not S
```

– “Some females are not singers”, “Not all females are singers”.
Conclusion:

– Some singers (S) are not female (F), so some females (F) are not singers (S).
Correct, choosing d : D for y and z, because d represents:
either a singer who is not a female, or a female who is not a singer!

Concluding Remarks

In the present treatise we have explained in somewhat detail the structure of LINCOS and ways of using the system. Evidently LINCOS is useful in describing logic structures in the world as experienced by humans, *e.g.* causal relations in a wide sense, as in the examples listed in the last section. Remarkable in this respect is the simplicity of the system: there are only four basic logic operators (⋀, ⋁, ~ and →), there is linear notation, there is the aspect of verifiability within the system—to name some highlights. In addition there is the possibility of exploiting self-explication. We have not actually constructed a message for ETI in this book, partly because that enterprise lies outside the purposes of the book, partly because we feel that this responsible job would best be in the hands of the “Logician in Charge” (see also the DECLARATION OF PRINCIPLES, added to this book).

It has often been remarked that projects concerned with the development of systems such as LINCOS aimed at interstellar communication are of doubtful significance. One reason would be that communication in real time seems to be out of the question—in view of the limitation of the speed of transfer of information, the upper bound being the velocity of light. Another reason is that serious SETI projects have been carried out for more than 50 years now and no evidence of the existence of ETI has been uncovered. Of course the search has been restricted to only a small (let us say flattened spherical) galactic volume of space around the Sun. By now hundreds of planets have been discovered orbiting their suns in that part of space, but none of them appear to be Earth-like. These arguments point to the conclusion that our intelligent neighbours, if they exist, are not round the corner. In addition these arguments, in view of known stellar densities in the galactic spiral arm we find ourselves situated, lead to an estimate of a lower bound for the average distance between planet-bound intelligent civilizations, of at least 50 light years. If we send a message into space we cannot expect a reply within about 100 years—unless we find a target at relatively short distance.

In our view the significance of projects of the mentioned kind is derived from an entirely different point of view—that can be introduced following an argument put forward by radio astronomer Ray Morris from Australia at the International Astronautical Congress in Melbourne in 1998 (as far as the author is aware, the paper has not been published). Morris' research revealed that the Sun is a relatively young star from the point of view of star formation in the Galaxy. In the galactic space around the Sun there must be many stars thousands or ten-thousands of years older than the Sun, barely or not visible for us.

Supposing that there are planets orbiting suns of this type at distances of say 100–1,000 light years away from us, supporting intelligent life, we might assume that these aliens are, compared to our species

- technologically far more advanced
- seeking knowledge in the same way as we do,
- have developed a Lingua Cosmica system of their own,
- and came to the conclusion that the system should to be able to explain itself.

If aliens such as these have decided to send messages out in the Galaxy, in the best case directed towards us, informing about their situation, it would be extremely important for us to decode them. This is because we might gain in this way a glimpse of our own possible future, perhaps of a bright kind, perhaps not. In any case, knowledge of this kind would mean a powerful incentive for us to take well care of our planet!

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[3] D.J. Chalmers *The Conscious Mind. In Search of a Fundamental Theory*, Oxford University Press (1996)

Appendix F Summary in Russian

Астролингвистика

Как наука астролингвистика занимается развитием и применением космических языков для межзвездной радиокоммуникации между внеземными разумными существами в Галатике или во Вселенной включая выбор научной дисциплины как “общую основу”, например физику, химию, математику или логику. Во всяком случае этот предмет должен иметь универсальнй характер. Кроме того, в астролингвистике нужно выбирать пригодные представления формальных выражений.

Первым поколением этих языков был **Линкос,** *Design of a Language for Cosmic Intercourse, Part I*, [Элзевийр 1960] который детально описал со всеми подробностями профессор Др. Ганс Фройденталь († 1991 г.), из Утрехтского университета в Голландии. См. статью Фройденталя *Линкос—междупланетный язык* в сборнике *Населённый Космос* [Фройденталь 1972]. Там автор написал, цитат стр. 310: “Но что же мы будем передавать? С чего начнем? С математики, конечно....”. План этой книги тоже был представлен в итересной статье Бруно Басси: *Were It Perfect, Would It Work Better? Survey of a Language for Cosmic Intercourse* [Stampa (http://brunobassi.it/scritti/lincos.html)].

Значительно позже, в Лейденском университете, тоже в Голландии, голландско-шведский астроном и математик профессор Др. Александр Оллонгрен, в настоящей книге вновь предложил второе поколение космических языков. Новый **Линкос**, или *Lingua Cosmica*, это *система* радиокоммуникации, и основывается на двух принципах. Во первых сообщение для внеземных, разумных существ, должно быть многоуровневым. Короткое сообщение состаяло бы из части большого текста натурального языка и пополнено аннотациями на другом уровне.

Второй принцип заключается в том что аннотации (или объяснения) должны содержать два важных общих исходных пунктов: дедукцию и индукцию, которые формулируются в *логике*. Т.е. мы будем передавать логические выражения вместо математических. Таким образом логическое

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содержание сообщения для межзвездной радиокоммуникации, помещается в абстрактный описательный кадр. Этот кадр, логический *database*, содержит константы и переменные величины, определения, предположения, гипотезы и заключения. Как “общая основа” выбирается формальная математическая логика.

Таким образом намеренное составление языка для межзвездной радиокоммуникации между внеземымми разумными существами, получает новую перспективу. Новая ориентация для *Lingua Cosmica*, определена в настоящей книге, посвященной памяти доктора Фройденталя. Эта книга многодисциплинарная, так как она включает прикладную логику, и универсальные аспекты лингвистики (самая суть астролингвистики).К проекту также относятся вопросы о возможности сообщения между внеземными, разумными существами или артифактами в Галатике.

Новый **Линкос** употребляет конструктивную логику с индукцией—специальная модальность математической логики. Таким образом система *Lingua Cosmica* получил солидный фундамент. У **Линкос** есть сигнатура различная от натуральных языков. Выражающая сила **Линкос** большая, но логические выражения часто очень длинние. Для дополнительных сведений, см. *Astrolinguistics, a Guide for Calling E T* [http://www.alexanderollongren.nl].

[1] Элзевийр (Elsevier) (1960), Амстердам

[2] Г. Фройденталь (H. Freudenthal), в сборнике *Населённый Космос*, Исдательство <<Наука>> (1972), Москва

[3] Stampa, http://brunobassi.it/scritti/lincos.html.

[4] http://www.alexanderollongren.nl

The author expresses thankfulness to Alexander Zaitsev and André Deutz for valuable suggestions resulting in a considerably improved version of the first draft of the above summary.

Appendix G Curriculum Vitae of Alexander Ollongren (* 1928, Sumatra)

– University education in mathematics, Hamiltonian mechanics, physics and astronomy, Leiden University in the Netherlands
– PhD in dynamical astronomy, Astronomical Department, Leiden University (1962)
– Post-doc Research Member in celestial mechanics and Lecturer mathematics at Research Center of Celestial Mechanics, Yale University (1965–1967), USA.

Associate director of the computer centre Leiden University (1967–1969) and Lecturer numerical mathematics and computer science at the Department of Applied Mathematics.

Associate professor of theoretical computer science at the Department of Applied Mathematics, Leiden University (1969–1980).

Full professor theoretical computer science at the Leiden Institute of Advanced Computer Science (1980–1993).

– Visiting research member at the IBM Laboratory in Vienna, Austria (1971).
– Sabbatical Leave: Visiting professor at the Department of Computer Science and Artificial Intelligence, Linköping University, Sweden (1980).

Emeritus professor Leiden University, December (1993), public lecture *Vix Famulis Audenda Parat*.
Member of and Professor at the Leiden University Council "University Level Courses for Eldery Citizens" (1995–2005).
Member of the International Astronomical Union (1962–)
Member of IAU Commission 7, Celestial Mechanics (1967–)
Member of IAU Commission 33, Galactic Dynamics (1962–)
Member of IAU Commission 51, Bioastronomy (1998–)
Member of the European Astronomical Society (1980–)
Member of the Dutch Astronomical Society (1955–)
Member of the SETI Permanent Committee of the International Astronautical Academy (2000–)
Nomination as corresponding member of the International Astronautical Academy (2008)

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Signatory of "Invitation to ETI, a communication addressed to any Extra-Terrestrial Intelligence having the capability to read it", (2002–)

Published research papers in:

- dynamical astronomy and celestial mechanics
- theoretical computer science
- formal languages and automata
- formal linguistics in philosophy
- *Lingua Cosmica*

Actor in the documentary film "Calling E T" by Prosper de Roos, Amsterdam, 2008.

Curriculum Vitae of C Bangs

C Bangs art investigates frontier science combined with symbolist figuration from an ecological feminist point of view. Her work is included in public and private collections as well as in books and journals. Public Collections include the Library of Congress, NASA's Marshall Spaceflight Center, New York City College of Technology, Pratt Institute, Cornell University, and Pace University. Her art has been included in seven books and two peer-reviewed journal articles, several magazine articles and art catalogues. Merging art and science, she worked as a NASA Faculty Fellow; under a NASA grant she investigated holographic interstellar probe message plaques.

www.cbangs.com

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