# Conclusion

Contextual recognition and action, both external and internal, are essential for a functional model of natural language. For their realization, the fields of robotics and database semantics will need to work together much more closely than is currently the case.

Thereby the benefit provided by robotics to database semantics – permitting verification in terms of ever more powerful SLIM machines – is equal to the benefit provided by database semantics to robotics: the storage of propositional content in a word bank in combination with inferences can provide the long overdue reduction in search space required by artificial vision and speech recognition.

For the construction of a SLIM machine, the following criteria have evolved:

DESIDERATA OF COMPUTATIONAL LINGUISTICS RESEARCH

1. *No simulating simulation*
   The construction must be based on a robot which functions in the real world. This is in contrast to modeling both the cognitive agent and its environment on the computer screen, or defining both language and the 'world' in a logical model.
2. *Separating the levels of language and context*
   The internal structure of the robot must distinguish between the level of context and the level of language. The context is a database comprising the automatic representation of the external environment, memories of earlier states and actions, plans and desires, as well as information transmitted by means of language.
3. *Requirement of procedural realization*
   The construction of the robot must be based on a declarative description shown to be suitable for a procedural realization. This is in contrast to, for example, a metalanguage definition of infinite sets of possible worlds.
4. *Real time requirement*
   The components of syntax, semantics, etc. used in the construction must have an algebraic definition on the basis of which they are shown to be of sufficiently low mathematical complexity. This is in contrast to generative grammars with exponential, undecidable, or unknown complexity.
5. *Input-output equivalence requirement*
   A realistic model of natural language communication requires that the robot be

input-output equivalent with the natural speaker-hearer. It follows that the robot's algorithms for analysis and interpretation must be time-linear.

6. *Sign-theoretic realization of reference*
   The construction of the robot requires a theory of signs for explaining how the different sign types of natural language relate to the context of interpretation. Thereby, the different mechanisms of reference must be reconstructed in a functional manner suitable for the computer.
7. *Separating motor algorithms and propositional content*
   Reading language- and context-based recognition into, and action out of, the robot's internal database requires a distinction between the motor algorithms powering the operations and the propositional content transmitted by them.
8. *Complete treatment of basic cognitive states*
   The construction of the robot must model the relation between language-based and context-based recognition and action. This requires that the information received in the hearer mode can be verbalized in the speaker mode or realized as non-verbal action. Furthermore, the system must be able to describe non-verbal recognition in language, as well as memories, sensations, plans, etc.

With these criteria in mind, the different – and often implicit – assumptions, goals, and methods of a multitude of previous approaches were classified and their suitability for modeling the mechanism of natural language communication was evaluated.

For a transparent presentation with a historical perspective, our description has concentrated on the motivation and basic assumptions of the original approaches rather than belated attempts to repair their inherent defects. This broadly-based investigation concluded that a solid solution, i.e., a coherent functional theory of natural language communication, has so far been lacking. As a consequence, more and more researchers have concentrated their efforts on smart solutions (cf. Section 2.3) such as finite state technology and statistics, which try to get by without a theory of how natural language communication actually works.

The insufficiencies of today's natural language technologies in speech recognition, indexing and retrieval, content analysis, machine translation, dialog systems, etc., are notorious, however. To overcome their frustrating limitations, the modeling of natural language communication must be approached directly.

The SLIM theory of language presents a systematic solution which required several innovations. Some adapt insights from the past. One example is the time-linear structure of language interpretation, conceptualization, and production – in accordance with de Saussure's second law. Another example is the theory of signs – strangely absent in nativist linguistics, model-theoretic semantics, and speech-act theory.

Other necessary innovations were developed from scratch. Examples are the methodological principle of surface compositionality, the functional principle of internal matching, and the definition of LA-grammar as an efficient time-linear algorithm – providing the first, and so far the only, alternative to the Chomsky hierarchy.