# Sixth Generation Computing: a Conspectus of the Japanese Proposals

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This paper gives a precis of the sixth-generation computing systems research proposal, *Promotion of Research and Development on Electronics and Information Systems That May Complement or Substitute for Human Intelligence*. The proposal was requested by the Japanese Ministry of Science and Technology in January 1983, prepared by the Subcommittee on Artificial Intelligence of The Council for Aerospace, Electronics and Other Advanced Technologies, and submitted in March 1985. It proposes an interdisciplinary research program on the nature of human intelligence involving physiology, psychology, linguistics, logic and computer science.

## 1 Introduction

When the Japanese *Fifth Generation Computing System* (FGCS) development program was announced in 1982 great emphasis was placed on artificial intelligence and the development of advanced human-computer interaction (Moto-oka 1982, Gaines 1984). However, the ICOT research activities have concentrated on machine architectures for knowledge-based systems based on high speed Prolog and relational database machines (Kawanobe 1984) involve no direct research on artificial intelligence or human-computer interaction. The publication in 1985 of the *Sixth Generation Computing System* (SGCS, STA 1985) development proposal shows a serious intention in Japan to go beyond current FGCS activities and tackle the human-related aspects of computing on a broad front.

The term "sixth-generation computing proposal" is the name used in the Japanese press for the report, Promotion of Research and Development on Electronics and Information Systems that may Complement or Substitute for Human Intelligence, from the Subcommittee on Artificial Intelligence of The Council on Aerospace, Electronics and Other Advanced Technologies in Tokyo. The Council was asked by the Ministry of Science and Technology in January 1983 to report on artificial intelligence in these terms. It formed a sub-committee (Table 1) that met 12 times, used the term knowledge science for its subject matter, and reported in March 1985. The English translation comprises some 18,000 words. It is reported that MITI has agreed to fund at least part of the SGCS proposal with $32 million over 10 years commencing mid-1986 as an extension of ICOT's activities (Chapman 1985).

Four objectives are specified for promoting knowledge science: innovations in frontier high technologies; economic and cultural advancements; contributions to the expansion of human potential; and establishing a foundation for creative science. The most interesting feature of the proposed research program is that it moves outside the boundaries of computing technology and is based on inter-disciplinary interaction with physiology, psychology, linguistics and logic. The report analyses the state of the art in these four relevant sciences and proposes the development of eight technologies based on them for application in four major areas; I have summarized this in Fig.1. The application areas do not differ from those of the FGCS program but the path specified to them is far more foundational.

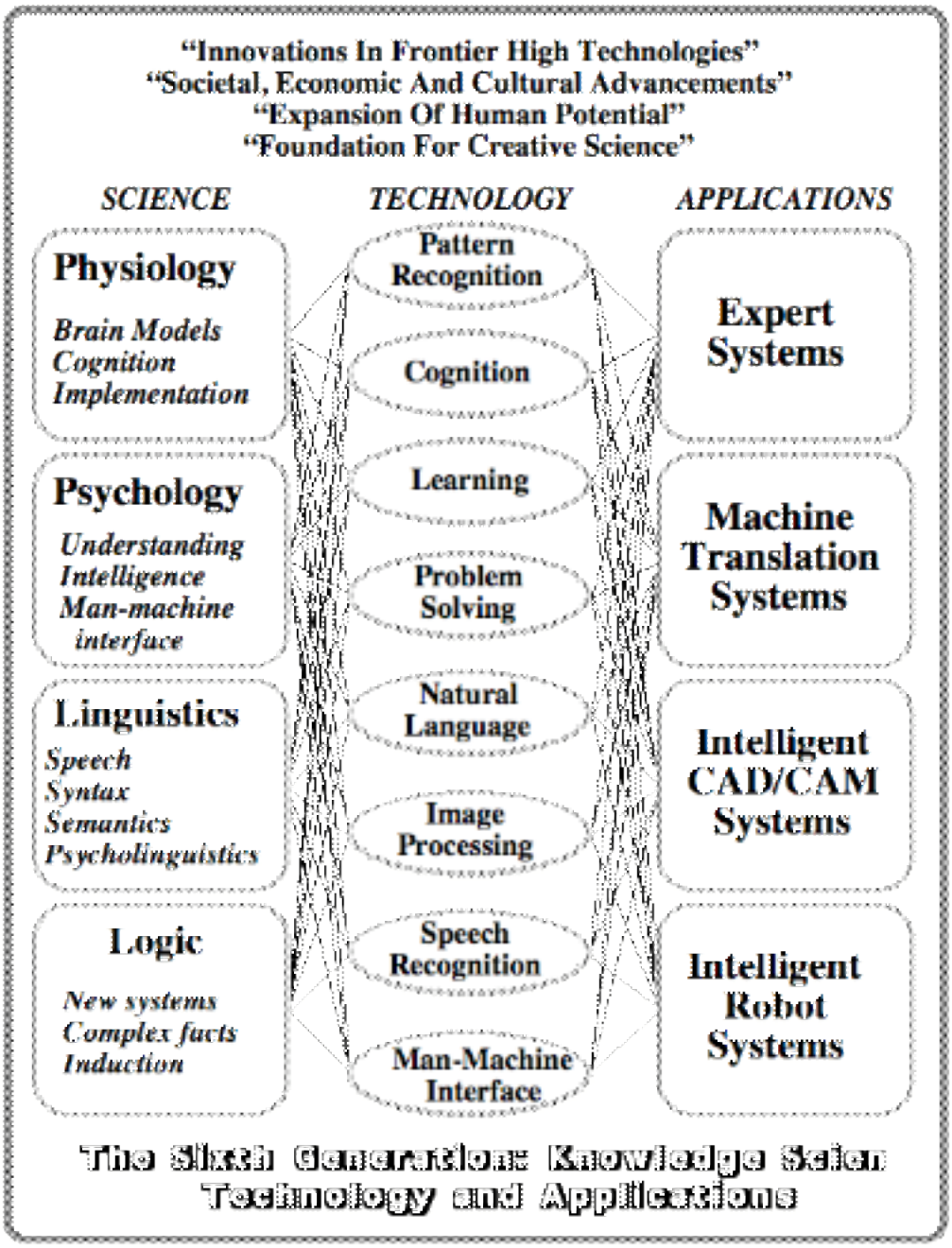


**Figure 1 Japanese "sixth generation" program**

This path through brain and human sciences to future generation computing was previewed in an interview with Fuchi, the Director of ICOT, when in reply to the question:

> *"Are you saying that the design of the fifth-generation may be modeled by learning more about the human thinking process?"*

he answered:

> *"Yes, we should have more research on human thinking processes, but we already have some basic structures. For more than 2000 years man has tried to find the basic*

*operation of thinking and has established logic. The result is not necessarily sufficent; it's just the one that mankind found. At present we have only one solution - a system like predicate calculus. It is rather similar to the way man thinks. But we need more research. What, really, is going on in our brain? It's a rather difficult problem." (Fuchi, Sato & Miller 1984)*

What is going on in our brain is certainly a difficult problem but the development of advanced computing systems demands that we resolve it. The SGCS proposal sets out to do this and makes no detours to avoid using words such as "intuition, analogy and creativity" in its description of human reasoning capabilities.

It was not easy for those in the computing industry to accept the concept in the FGCS proposal that artificial intelligence research was sufficiently advanced to be the basis for a next generation of computing systems. It will be even more difficult to assimilate the concept in the SGCS proposal that physiology, psychology, linguistics and logic are the proper scientific foundations for these systems. Few industrial research groups or university computing science departments have personnel qualified in these disciplines. However, the arguments for interdisciplinary collaboration in developing SGCS are developed convincingly, and at length in the Japanese report. The report is long and repetitive because each section stands alone with little cross-referencing. At least two translations are available and this paper has used these to provide a conspectus covering the key issues briefly but comprehensively. I have not modified the structure or headings of the original but have summarized the text, attempting to be highly concise but not to deviate from the sense of the original. Hence I have added no comments or references of my own to this version—it is intended to offer to a wider audience an accurate, condensed account of the Japanese SGCS proposal.

## Acknowledgements

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## Appendix

Precis of *"Promotion of Research and Development on Electronics and Information Systems That May Complement or Substitute for Human Intelligence"*

*1 Basic Considerations in the Promotion of Knowledge Science*

1 Outline of Knowledge Science

*(1) Background*

Humans have invented devices to enhance their capabilities, at first mechanical aids to physical ability, and now computational aids to intelligence. However, conventional computers may become inadequate as social and economic structures change, and as non-specialists become major users. For an information society computers must be developed with intelligent abilities: intuitive recognition of situations; inductive inference; knowledge acquisition; learning; and improved human-computer interfaces.

*(2) The evolution and present state of artificial intelligence*

(i) Evolution

Artificial intelligence research developed in the USA from 1950s to 1980.

(ii) Present state

Fifth Generation Computer System development commenced in Japan in 1982 and has stimulated projects worldwide.

(iii) Expectations toward new development

To develop integrated artificial intelligence systems with human capabilities it is necessary to: clarify the brain's thought processes; construct a basic model for the technical development of intelligent functions; and establish theories of the model. This involves physiology, psychology and linguistics. Implementation can take advantage of major hardware advances in very large-scale integration.

*(3) What is knowledge science?*

Knowledge Science is *"science and technology for clarifying advanced intelligent functions of human beings, that is recognition, learning, inference, and so on, while developing these functions technically for the construction of various systems."* Knowledge science will revolutionize many science and technology fields and contribute to progressive global change.

2 Objectives for Promoting Knowledge Science

*(1) Innovations in frontier high technologies*

Information technology has contributed to advanced technologies such as aerospace and medicine, and Knowledge science will be the nucleus of innovation in information technology.

*(2) Contribution to societal, economic and cultural advancements*

(i) Contribution to societal development

Versatile mass media, machine translation and expert systems will improve lifestyles, international relations, health/educational services, and aid handicapped.

(ii) Contribution to economic development

Robots and CAD/CAM will upgrade productivity and quality, and knowledge science developments will create new industries.

(iii) Contribution to cultural development

Intelligent systems will contribute to culture, lifestyle and the arts.

*(3) Contribution to the expansion of human potential*

Knowledge of human intelligence in knowledge science will enable human capabilities to be enhanced.

*(4) Establishing a foundation for creative sciences*

Japan is finding it difficult to import technologies and needs to do original research in knowledge science to be seen as a contributor.

3 Basic Considerations in Promoting Knowledge Science

*(1) Promotion of integrated research and development*

To develop artificial intelligence technology studies in human cognition and computer science must be integrated through basic research on knowledge science drawing on psychology, physiology, logic, and linguistics. Applications studies should also be carried out to stimulate basic research and development.

(i) Basic research

To clarify human intelligence models of information processing in the brain should be developed, simulated and analysed mathematically.

(ii) Research and development of basic technologies

Systems will require these intelligent functions: pattern recognition; learning; deductive, analogical and inductive inference; problem-solving; and language processing. Image and speech understanding, and human-computer interface technologies, are also required.

(iii) Research and development of application/utilization technologies

The most important applications are to expert systems, intelligent CAD/CAM, machine translation and intelligent robots.

*(2) Promotion of interdisciplinary research and development*

Networks and researcher mobility should be set up to promote interdisciplinary research.

*(3) Promotion of long-term research and development*

A long-term strategy should be established to increase the number of researchers in knowledge science.

*(4) Promotion of research and development with concern for societal needs*

Knowledge science may affect society more than any other technology and its social impact should be studied and monitored.

*(5) Problems in promotion*

Society will come to depend on intelligent systems and they must be reliable and transparent, i.e. able to explain their procedures.

*2 Present State and Future Development of Science and Technology Related to Computer Science*

1 Present State and Future Development in Basic Sciences

*(1) Research and development of knowledge science based on physiology*

(i) Present state

a) The brain consists of independent functional regions.

b) Information processing in each region is hierarchical.

c) Regions exchange information to perform functions as part of a complex system.

(ii) Problems in research and development to be solved in the future

A brain model must be constructed which approximates human cognitive processes.

*(2) Research and development of knowledge science based on psychology*

(i) Present state

Cognitive psychology has developed models of human behavior, perception and learning, linked these with brain physiology and simulated them.

(ii) Problems in research and development to be solved in the future

1) Clarification of the nature of understanding

People integrate knowledge to understand objects or ideas, recall typical examples from experience, and generate analogies by modifying them and by deductive inference. The means by which people prevent malfunctioning, lighten mental strain, use creative cognition, and use language must be understood.

2) Modeling of intelligent functions

Models must be constructed of visual perception, linguistic meaning, long-term memory, learning and cognitive development.

3) Investigation of the human-computer interface in terms of cognitive science

A cognitive science approach must be taken to the study of the human-computer interface.

4) Integration of psychological and physiological research

Psychological and physiological research must be integrated.

*(3) Research and development of knowledge science based on linguistics*

*(3-1) Research and development of speech*

(i) Present state

Speech production, phonological structure and phonetics have been investigated.

(ii) Problems in research and development to be solved in the future

Interaction between adjacent phonemes must be understood.

*(3-2) Research and development of syntax*

(i) Present state

Research has been done on transformational grammars, generative semantics, the characterization of natural languages, and computational linguistics.

(ii) Problems in research and development to be solved in the future

Systematic lexicons of concepts and their relations, computational dictionaries, grammars including semantics and context, and rules of syntax, semantics and phonology, must be developed.

*(3-3) Research and development of semantics*

(i) Present state

The lexicon and the semantics of clauses, sentences, and their contexts have been studied but little is known of the semantic relationships of words in juxtaposition.

(ii) Problems in research and development to be solved in the future

The relationships of syntax and semantics, the role of the scene, the relation between listener and speaker, the knowledge and psychology on which an utterance is based, must be clarified to provide a model of discourse.

*(3-4) Research and development of psycholinguistics*

(i) Present state

Some features of language processing in the brain are known. There has been extensive research on the acquisition of language. Studies of long-term memory have been linked with case grammars and semantic networks.

(ii) Problems in research and development to be solved in the future

A model must be developed of natural language understanding, from the single sentence to the full complexity of discourse.

*(4) Research and development of knowledge science based on logic*

(i) Present state

Logic is the foundation of knowledge science and research must extend it from pure formal logic to a general system applicable to artificial intelligence.

(ii) Problems in research and development to be solved in the future

1) Establishment of a new logical system

A logic must be developed describing complex facts, processing prepositions and predicates, and suitable for learning and inductive inference.

2) Relationship between research in logic and in other fields

Logic, linguistics and cognitive psychology must be integrated.

2 Research and development on the basic technologies

*(1) Technologies related to pattern recognition*

(i) Present state

Simple character and speech recognition systems have been developed.

(ii) Problems in research and development to be solved in the future

1) Abstraction and discrimination of features

Improved feature abstraction and pattern-matching discrimination processes must be developed for effective recognition.

2) Generation and verification of pattern hypotheses

Efficient inductive information processing must be developed for templet and hypothesis formation with ambiguous data.

3) Relationships with other kinds of basic research

Human perception must be studied psychologically and physiologically to clarify recognition processes: feature extraction; role of knowledge; situational influence; inference of whole from parts; and decomposition of input.

*(2) Technologies related to cognition*

(i) Present state

Expert systems have encoded specific knowledge but not general knowledge.

(ii) Problems in research and development to be solved in the future

1) Technologies for knowledge representation

a) Highly descriptive methods for knowledge representation

A highly descriptive, structured knowledge representation must be developed.

b) Formalization and systematization of common sense

Common sense as widely applicable knowledge must be formalized.

2) Technologies for utilizing knowledge

Efficient search and inference processes must be developed incorporating: meta-rules; common sense; induction; and analogy.

*(3) Technologies related to learning*

(i) Present state

Pattern and parameter learning has been developed and attempts have been made to encompass language, analogy and induction, but research is still at an early stage.

(ii) Problems in research and development to be solved in the future

Functions for inferring similarities and differences and for acquiring cognitive abilities stage by stage must be developed.

*(4) Technologies related to problem-solving*

(i) Present state

General problem solvers generating intermediate goals have been developed.

(ii) Problems in research and development to be solved in the future

1) Problem solving

Systems must be developed to apply available knowledge to problem-solving.

2) Intelligent programming technologies

Systems must developed for automatically generating problem-solving procedures.

3) Computer languages

Languages going beyond Lisp and Prolog, based on a new logic system, must be developed.

4) Application to the development of human intelligent abilities

Programming may provide a model of learning and be applied to education.

*(5) Technologies related to natural language processing*

(i) Present state

Research and development has been mainly: translation; question-answering; and kana-kanji conversion.

(ii) Problems in research and development to be solved in the future

1) Syntactic analysis

Syntactic analysis is technically complete but natural language is grammatically imperfect and metaphoric, and account must be taken of the influence of semantics and content.

2) Semantic analysis

There are problems in knowledge representation, numbers, negation, temporality and anaphora.

3) Generation of sentences

Sentences have been generated by filling slots but more general methods must be developed.

4) Understanding paragraphs

The relation between language processing and the total contextual scene must be analysed.

*(6) Technologies related to graphic image processing*

(i) Present state

Research has been done on: feature abstraction; input/output of two-dimensional images; description and generation of three-dimensional scenes; moving images; and graphic data bases. Simple vision systems have been developed for integrated circuit bonding and mask inspection.

(ii) Problems in research and development to be solved in the future

In future graphic technologies must be integrated, improved, and speeds increased.

1) Research and development of technologies related to graphic image processing

a) Technologies for abstracting features

Point, line, domain, color and shade feature extraction programs have been developed and techniques must be developed for their effective application.

b) Technologies for describing and constructing three-dimensional landscapes

The human capabilities to construct mental images and use knowledge must be understood.

c) Technologies for processing moving images

Technologies must be established to analyse three-dimensional movement from images.

d) Technologies for high-speed graphic image processing

Parallel, hierarchical processing systems must be developed for speed.

e) Technologies for generating images

Three-dimensional images should be generable from real objects and rough specifications.

2) Relationship with other base technologies

a) Technologies related to pattern recognition

Technologies must be developed to: use and express knowledge about objects; separate objects; derive models from features; incorporate geometry; and express graphic knowledge in natural language.

b) Technologies related to learning

Learning must be used to verify generated graphic models and derive inference methods.

*(7) Technologies related to speech recognition*

(i) Present state

Restricted speaker/vocabulary recognizers have been developed for limited applications.

(ii) Problems in research and development to be solved in the future

1) Research and development of technologies related to speech processing

a) Method for discriminating between existence & nonexistence of speech at the acoustic level

It is important to establish measures for the presence of speech.

b) Processing of articulating combination at phoneme level

Interaction between adjacent phonemes makes phoneme-cluster processing necessary.

c) Processing of speech by non-specific speakers

A breakthrough is necessary in the recognition of differences between voices.

d) Construction of a speech data base

A data base of speech is essential to the development of recognizers.

2) Relationship with other base technologies

a) Technologies related to natural language interface

Inference based on linguistic knowledge will aid recognition.

b) Technologies related to learning

Learning will play an important role in the development of recognizers.

*(8) Technologies related to the human-computer interface*

(i) Present state

There is too little research on the requirements that: casual users experience no problems; a knowledge base, inference and problem-solving should be available; ambiguous and incomplete information should be understood and supplemented.

(ii) Problems in research and development to be solved in the future

1) Human-computer interface for general users

The system should communicate in natural language and images, recognize speech and images, need little maintenance, attract human interest, be easy to master and adapt to users.

2) Assignment of intelligent functions

A knowledge base, inference, problem-solving, ambiguity-tolerance, user-adaptation, understanding intentions, and question-answering, should be available.

3) Understanding human factors

Ergonomics, human factors and cognitive science studies should be used to develop flexible, adaptive human-computer interfaces.

3 Present state and future development of application systems

*(1) Expert systems*

(i) Present state

Expert systems in medicine, chemistry and design, in the USA and Japan, show that knowledge science can be used to develop effective decision aids.

(ii) Problems in research and development to be solved in the future

1) Relationships with base technologies

a) Technologies related to knowledge

Technologies must be developed for: large knowledge bases; knowledge representation incorporating time, causes and models; and inference based on ambiguous knowledge.

b) Technologies related to learning

Systems must be developed to modify their own knowledge bases.

c) Improvement in the performance of the human-computer interface

Speech and image communications with expert systems must be developed.

2) Technologies related to the construction of systems

a) Security of the reliability of systems

For reliability systems must: clearly explain their inferences; check input; request confirmation; evaluate reliability of inference based on ambiguous data; and justify inference through past cases and background information.

b) Research and development on tools

Tools must be developed for: automatic transfer of expert knowledge; acceptance of knowledge in natural language; comparison of new knowledge with that stored; and general-purpose inferencing.

*(2) Intelligent CAD/CAM systems*

(i) Present state

CAD/CAM systems construct models, evaluate performance and process design data.

(ii) Problems in research and development to be solved in the future

Technologies must be developed for: constructing three-dimensional models; using knowledge from engineering data bases; integrating CAD/CAM systems; improving the human-computer interface.

1) Relationship with base technologies

a) Technologies related to pattern recognition

Three-dimensional models incorporating structure, shape and characteristics must be constructed.

b) Technologies related to knowledge science

Multiple data bases must be integrated using engineering knowledge.

c) Technologies related to problem solving

Procedures must be automatically generated and assigned.

d) Technologies related to graphic processing

Graphic interfaces must be developed for rapid manipulation of three-dimensional images.

2) Research and development on technologies related to the construction of systems

a) Automation of design processes

Technologies must be developed for: offering partial solutions; combining and modifying past solutions; analysing solutions against requirements.

b) Understanding of needs

CAD/CAM systems should be targeted on specific industrial needs.

*(3) Machine translation systems*

(i) Present state

Some experimental systems have been developed and experience accumulated.

(ii) Problems in research and development to be solved in the future

Processing of natural language for meaning and content must be developed together with a large lexicon and interactive modification.

1) Relationship with base technologies

a) Technologies related to natural language processing

Knowledge-based syntactic rules, sentence production and learning must be developed.

2) Research and development of technologies related to the construction of systems

a) Research and development of intermediate language systems

The possibility of a general intermediate language should be investigated.

b) Clarification and modeling of human translation functions

The cognitive processes of human translators should be studied.

c) Improvement of the quality of translation

Systems should be developed for supporting human translators with pre- and post-processing, advanced editing functions, and a large lexical dictionary.

*(4) Intelligent robot systems*

(i) Present state

Current robots are playback systems for repetitive tasks with some touch sensing and primitive vision but no capability for understanding, learning and inference.

(ii) Problems in research and development to be solved in the future

1) Relationship with base technologies

a) Technologies related to natural language processing

Knowledge bases must be developed about tasks, objects and environments.

b) Technologies related to problem solving

Automatic plan generation must be developed.

c) Technologies related to learning

Technologies for adapting to similar tasks and using past experience must be developed.

d) Technologies related to pattern recognition

Pattern recognition for spatial and temporal sensory information must be developed.

e) Others

Programming languages must be developed which validate input, movement description, parallel movement control, use environmental models, graphic and speech understanding, and effective human-computer interfaces.

2) Research and development on technologies related to the construction of systems

High performance sensors must be developed and integrated with the knowledge base.

*3 Methodology for Promoting Knowledge Science*

1 Basic considerations

Knowledge science research and development problems range from the basic to the applied and need to be pursued by a cooperative program based on national policy. Not all aspects of human intellect may be modelable and a hierachy of research goals should be established for government support of basic research. The spin-off in improving human welfare should not be forgotten. Knowledge science research is being pursued world-wide and Japan should ensure sufficient government support and capital investment.

2 Research and development systems

Knowledge science is highly significant but its research and development life cycle is very long and an infrastructure must be developed through: training; expanding existing, and building new, research institutes; bringing together researchers; and organizing long-term research and development with industry-university-government cooperation. A network with shared databases should be established encouraging researchers in different disciplines to communicate and collaborate.

3 Developing and retaining the necessary manpower

There are not enough knowledge science researchers and training/retraining should be undertaken. Interdisciplinary symposia should be held.

4 International cooperation

The shortage of knowledge science researchers should be alleviated by international cooperation.

5 Multi-approach integrated promotion of the project

Knowledge science research and development should be promoted both in basic science and in applications.

*(1) Research on the clarification of human intelligence*

Human intelligence should be studied through physiology, psychology, linguistics and logic.

*(2) Research on systems for the acquisition, utilization and control of knowledge*

The acquisition and life cycle of knowledge should be studied.

*(3) Research on intelligent human-computer communication systems*

The more advanced the system the easier should be human-computer interaction.