A field-scientific approach to Clinico-Informatics

— Towards a methodology for technology transfers —

Yoshiki Kinoshita * **and Toshinori Takai**

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We propose clinico-informatics, as a research field for dealing with risks of information systems based on informatics. In this paper, we consider a model of technology transfer from the authors' experiences, i.e. transferring verification technology to industry in the various fields which involves information system development. A scenario for technology transfer is proposed with the methodology of field-science and we discuss roles of the techniques used in the scenario, for instance, fieldwork, interviews and participant observation.

Keywords : Clinico-informatics, qualitative research, risk, fieldwork, dependability, formal method, model-checking

1 Introduction: clinico-informatics

Anyone involved in informatics would naturally be led to the study to reduce risks related to information processing by applying results of the study in informatics. There are three principal subjects of study to that end:

1. methods to analyze the situation in the field (which corresponds to *diagnosis* in medicine,)
2. methods to improve the situation in the field (which corresponds to *therapy* in medicine) and
3. methods to propagate the technologies.

The methods in 3 are methods to propagate methods, so it is in a sense of a different level to that of 1 and 2. It corresponds to the activities in clinical medicine where the results of research are conveyed to medical practitioners for use in their own therapy, where medical associations and other organizations play important roles. Because of this analogy, we shall call the study, *clinico-informatics*, the study about information processing which aims at these three subjects. We borrow the word "clinico-" or "clinical" from clinical medicine. We emphasize that clinico-informatics does not mean a branch of informatics which is applied in clinical medicine. Rather, by clinico-informatics we mean the study of therapies of information systems which corresponds to clinical medicine which is a study of therapies of human beings.

Therefore, technology transfer is one of the three subjects of clinico-informatics study. While diagnosis and therapy has natural analogues in medical care, the analogy does not extend so naturally to technology transfer. Technology transfer itself is usually not considered as a subject of clinical medicine. It would, however, naturally be a subject of clinico-informatics, as technology transfer is nothing but a flow of information.

During the 16th century or so-called the Age of Exploration, European people were suddenly exposed to those with totally different cultures and such experiences soon spread out all over. Initially, the dominant view was that the differences in culture could be explained simply by means of *advancement*; everything was considered to be in a development process, so either culture was seen to be more advanced or the other was considered to be behind in the development. In the 20th century, however, the study of cultural anthropology and ethnology started, where cultures are studied as evolution in many directions according to regional and historical characteristics; much more delicate argument about *differences* of cultures was made instead of simple arguments based on *advancement* and *development*. It was recognized, as a result, that the difficulty of mutual understanding between people in different cultures lies in different ways of looking at things, rather than the lack of the ability on the side of the "developing culture". We are now facing a similar *cross-cultural exchange* in technology transfer; academia and industry just have different cultures and neither culture is more advanced than the other.

To see how such cross-cultural exchange happens in modern information processing, consider the first two of the three subjects of clinico-informatics we listed: methods of analysis and improvement of information processing systems. In the study of methodology in general, one inevitably analyzes the situation on site and tries to improve the situation. The scientists and engineers must work together there. Since the information technology nowadays provides basic methods in many technologies, however, the variety of fields of the engineers who deal with the information system on site is

Research Center for Verification and Semantics, AIST 5th floor, Mitsui Sumitomo Kaijo Senri Bldg., 1-2-14 Shin-Senri Nishi, Toyonaka 560-0083, Japan (current affiliation: Collaboration Promotion Department AIST Kansai Collaboration Center Collaborative Research Team for Verification, AIST 3-11-46 Nakoji, Amagasaki, Hyogo 661-0974 Japan) * E-mail : yoshiki@m.aist.go.jp

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extremely wide. It varies from electronic and mechanical engineering to chemical process, and more. It is therefore necessary for those who study clinico-informatics to communicate with the engineers of various fields and to exchange information for analyzing and improving the diverse and the complex. Therefore, it is often necessary, as our own experience shows, to start technology transfer by conveying background knowledge such as mathematical logic that is totally foreign to the engineers. We regard it natural to consider such a process as a cross-cultural encounter and exchange.

Thus, we regard the technology transfer process as a kind of cross-cultural exchange. It would then be natural to apply methods in ethnology and scientific technique of other fields to study technology transfer. The techniques to deal with diverse and complex situations include qualitative research, ethnography, and fieldwork or field science. The techniques such as interviewing, participant observation and the KJ method[1][2][3] are used in sociology and nursing as well as ethnology. Incidentally, Kyoto University, from which a respectable tradition of fieldwork has emerged, has recently proposed *field informatics*. They say, however, "Solutions for problems in the field are proposed from the viewpoint of informatics and the various issues that arise in the field[4]," which shows their approach is somewhat different from ours, as we would have said "Solutions for problems *in informatics* (or information processing) are proposed *from the viewpoint of fieldwork*."

The Research Center for Verification and Semantics (CVS), AIST, conducts the study of verification using the Mathematical Methods to check whether a given information system operates as intended. The properties to be verified include: deadlock-freeness (it never stuck), liveness (appropriate service will be eventually provided), termination (execution does not fall into infinite, endless loop), correctness (correct result is calculated), etc. The verification by Mathematical Methods involves the process of representing such properties by means of logical formulae and proving that the implementation of the system meets those properties. If the system has a fault, the proof should not succeed, and in that case a counterexample is often obtained. In some cases the proof is done by a person (Semiformal Methods) and in other cases it is done by a machine (Formal Methods).

CVS has conducted several joint research projects with industry. Those projects are in general called *fieldwork* and include the study in clinico-informatics for the technology called "model checking[5][6]." We start with the *analysis* of the situation by talking with the partner, consider the ways of carrying out the model checking that *improve* the situation most effectively, and then try to *transfer the technology* to the partner. Methods in fieldwork such as participant observation play central roles here. The term *field science* was introduced by Kawakita Jiro[Note 1)] and it includes the *KJ method* (named after Kawakita Jiro). We try to give a systematic account of the technology transfer process of informatics research results, using our experiences of fieldwork as examples and Kawakita's field scientific methods as leading principles.

This paper is written as follows. In chapter 2, we explain the technology called model checking, which we transferred to our partners of joint research projects. In chapter 3, we try to give a systematic account of technology transfer using Kawakita's notion of field science and related models for problem-solving. The general scenario of technology transfer in clinico-informatics is presented in chapters 4 and 5; the scenario for technology transfer that we have conducted is described in chapter 4, and the outline of some of the element techniques used for technology transfer is explained in chapter 5. In chapter 6, we present two of the most typical technology transfer projects that we conducted, and try to evaluate the outcome. Finally in chapter 7, the proposed model for the technology transfer process is discussed, as well as issues left for future work.

2 Technology transferred: model checking

This chapter is a short introduction to the model checking[Note 2)] for readers not familiar with informatics. Model checking is the technology which was used in our joint work with industry in verification and diagnosis of the system (fault removal[Note 3)]).

Model checking is one of the technologies in software development methodology called *Formal Methods*. Formal Methods is, in a sense, nothing but a scientific approach to software development, where one describes and proves propositions according to mathematical logic. In application of Formal Methods, one first sets up a *formal language*, in which data and the propositions about them can be written as *terms* and *formulae*. Upon that language, a *formal theory* is built, where *axioms* and *rules of inference* are provided. Then an *interpretation* is given that specifies the mathematical objects and their properties as the *denotations* of terms and formulae of the formal language. The fact that a proposition ψ is true under an interpretation M is written as $M \models \psi$, and we say ψ is true under M. An interpretation under which all axioms of the formal theory are true is called a *model*. When ψ is true under any model, we write $\models \psi$, and we say ψ is *valid*. One is usually interested in the validity of propositions, but in some cases, one is rather interested whether a proposition is true or false only under a given specific model. Checking whether a proposition is true or false under a given model is called *model checking*. Model checking under formal theories of a special kind, i.e., formal theories in *temporal logic*, are target of our interest here. Temporal logic is useful in describing dynamic properties of control programs and nowadays is one of the indispensable methods in program verification. Model checking in formal theories in temporal logic is our principal concern here. A model of a formal theory in temporal logic is usually given in the form of a *transition system*[Note 4].

Software which automatically performs model checking is called a *model checker*. A model checker is given two input data: a model and a property expected to hold for the model. The model checker reponds on whether the former satisfies the latter in the form of YES or NO. When the answer is NO, it normally gives a counterexample, too. In the case that the formal theory is in temporal logic, a model checker usually gives a counterexample in the form of an execution trace (state sequence) of the transition system. Hereafter, we only consider model checkers for formal theories in temporal logic; so the formal theory concerning model checkers is assumed to be in temporal logic.

Faults in an information system may be detected using a model in the following way. First, a user defines a transition system that represents the system. The transition system will work as a model of the formal theory of concern. Now, information systems are in the *real world*, while transition systems are in the *mathematical world*. So, the defined transition system is different from the information system. We say that the transition system is obtained from the information system through (mathematical) *abstraction*. While abstracting the information system, one intends to retain every feature which affects the addressed property. There are, however, no mathematical ways to make sure that every such feature is really retained, since the information system lies outside the mathematical world. The defined transition system may not sufficiently retain the property of the original information system. We shall come back to this problem later. Hereafter in this chapter, we shall exclusively consider the transition system rather than the original information system to be verified, unless otherwise stated.

Now, whether the transition system has the expected property boils down to whether the property is true under the model given as a transition system. So, it can be checked by a model checker. If the model checker answers NO and gives a counterexample, which indicates a candidate of the malfunction of the original information system, then the counterexample, given in terms of execution trace of transition system, is interpreted in terms of the original information system and judgment whether it does give an example of malfunction of the original system is done by the information system designer, not the verification engineer. Even if the model checker says YES (satisfied), however, it does not necessarily mean that there are no faults in the original information system (false positive). This is because it is not clear whether the transition system given as a model adequately represents the original information system.

As shown above, the model checker checks the transition system. To use the model checker to check the original information system, some manipulation is necessary to fill in the gap between the original information system and the transition system. For example, even if the model checker answers NO, one cannot conclude immediately that there is a fault in the system (false negative), and the counterexample should be analyzed. The issue is who does such analysis. Ideally, someone from the development team participates in the analysis in addition to the people doing the verification (fault finding), and the final decision on whether it is a fault or not is done by the development team.

3 Field scientific method of technology transfer

In this chapter, we give a systematic account of technology transfer by applying the W-model for problem solving attributed to Kawakita. The *Full Research* model, which has been discussed since the establishment of AIST, is also applied and is compared with Kawakita's model.

3.1 Kawakita's W-model for problem-solving

Kawakita observed that study in science is classified into three categories: bibliographical science, experimental science, and field science[1]. Study in bibliographical science is conducted on desktop using the *earlier literature* by means of *deduction*. Mathematics is its typical example. Experimental science is an *inductive* study where a reproducible phenomenon is recreated in the laboratory through *experiments* and one investigates whether a hypothesized theory holds with respect to the phenomenon; an example is experimental physics. These two kinds of study are based on some given theory, but field science focuses upon *abduction* where one goes out to the *field* to observe a possibly non-reproducible phenomenon on site in order to set up a theory or a hypothesis. What occurs in civil society immediately after an earthquake is an excellent example of such an observation. The difference between these three kinds of study is purely methodological, and so the field is

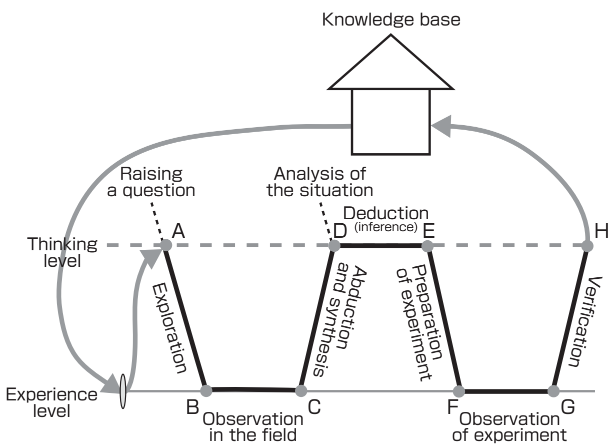

Fig. 1 Kawakita's W-model for problem solving. (taken from [1] and reconstructed)

not necessarily outdoors, but may well be on desktops in your bibliography or, in the case of informatics, in the office of software development. The relationship between these three kinds of study is depicted in the W-model for problem solving shown in Fig. 1[2].

The technology transfer is a way of problem solving, so we set up our hypothesis that the process of technology transfer can be understood using the Kawakita's W-model for problem solving. With this approach, we try to give a systematic account of technology transfer, occasionally referring to our own experiences.

We apply the Kawakita's W-model for problem-solving to technology transfer as follows. First, under a vague expectation or problem proposal that some technology may be useful somewhere in some society, one visits (make exploration) there and observes the situation (field observation)[Note 5]. As a result of the observation, one determines the way the technology which initially seemed useful can in fact be made useful (abduction). Other technology may turn out to be necessary in this phase (integration). Then one goes back to the laboratory, the overall situation is overviewed (understanding the situation), and it is decided whether the initial plan is to be performed or not. In the former case, the specific procedure of technology transfer is designed in detail (reasoning), and the experiment that allows the procedure to go forward is prepared and performed. The result of experiment is observed, verified and evaluated.

If the technology transfer is conducted without such a systematic view as above, at least three problems arise, according to our experience.

1. If some technology is transferred without sufficient understanding of the overall situation due to insufficient social observation (field observation), we may just hard-sell a technology not suitable in the situation.
2. Technology transfer is a difficult and large scale process that takes at least several months, or even several years in some cases. A comprehensive understanding of the whole technology transfer process would help the stakeholders much because they can then understand where they stand in the whole process. Such an understanding would especially help the involved engineers and scientists, when they face with difficulty in the process. Also, such a picture will make it easier to provide explanations to other stakeholders (especially the project sponsors).
3. Although the concrete technology transfer process itself is unique between a research institute and its industrial partner, there are cases where several similar cases are discussed all together. Such a comprehensive discussion would only be possible under the existence of a general theory of technology transfer.

In particular, the target of technology transfer of concern in this paper is for a methodology of software development in general, not a method or know-how of developing specific software, such as an algorithm or even a parameter of some algorithm. In the former case, systematic training of engineers (knowledge transfer) would be inevitable, while a need for such training is not so obvious in the latter case. It seems that the difficulty arising with knowledge transfer has an aspect of a *complex system* issue, and it is where Kawakita's W-model for problem-solving could come in.

3.2 Full Research and W-model

Type 2 Basic Research[7] was first proposed by Hiroyuki Yoshikawa as a process of conveyance of knowledge (results of study) *from abstract to concrete*. It is a part of the life cycle of research called *Full Research*[8][9], which consists of the three processes: *Type 1 Basic Research*, *Type 2 Basic Research*, and *Product Realization Research*. As both Yoshikawa's *Full Research* and Kawakita's W-model are frameworks of problem solving, the following comparison could be made.

Since Kawakita's model is intended for problem solving in general, it can be applied comprehensively at various levels; Kawakita himself in fact proposed that the W-model process should be repeated six times for large-scale problems. In particular, we can apply Kawakita's model to the overall life cycle of *Full Research*, as well as to the individual processes of *Type 1 Basic Research*, *Type 2 Basic Research*, and *Product Realization Research*.

In both *Full Research* and the Kawakita model, abduction plays an important role, no less than deduction and induction. The Kawakita model has the processes of *experiment* for induction and exploration for abduction; the Yoshikawa model, on the other hand, has a process called *synthesis*, which seems to correspond to a mixture of experiment and exploration in Kawakita's terms.

The levels of thought which are called *concrete* and *abstract* in the Yoshikawa model corresponds to the *experience* and *thinking* level in the Kawakita model. So, the slogan "from abstract to concrete" of *Type 2 Basic Research* corresponds to the transition from the thinking level to the experience level in the Kawakita model. As shown in Fig. 1, there are two types of transitions, exploration and experiment preparation. If we apply the W-model to the whole life cycle of *Full Research*, *Type 2 Basic Research* corresponds to the V-shape on the left half [Note 6] of the W-shape. The other V-shape to the right where reasoning, experiment, and verification are done would be understood as *Type 1 Basic Research*. Our explanation here may sound as though *Type 1 Basic Research* is always done after *Type 2 Basic Research*, but the order is not a major issue here, since the whole research activities are cyclic where the results of the *Type 1*

Basic Research are stored in the *warehouse of knowledge*, according to Kawakita, and are supplied to the *Type 2 Basic Research* process in the following cycle.

There were considerable amount of discussions to clarify what *Full Research* is, but it seems there has not been enough discussion on how *Full Research* is done. On the other hand, the KJ method, which was initially proposed as a method to support abduction, is now extended to the method to support the whole processes in the Kawakita W-model. The reviewer informed us of Reference [10] by Nakashima. Although it is interesting that the importance of abduction is also discussed in [10], we wish to discuss about it from our viewpoint in detail in another, proper context.

3.3 Qualitative research and quantitative research

Qualitative research nowadays is often discussed in contrast to quantitative research. In physics and chemistry, qualitative research tends to be undermined as being less accurate or not very precise. This is wrong. There *is* accurate and precise qualitative research and it often even provides foundations of quantitative research. The validation of selection of parameters used in a quantitative research, for instance, is inherently qualitative, so all arguments which follow the selection of parameters are based on qualitative research.

Incidentally, real numbers are often used to represent quantity, but there are other mathematical objects which could be used here. There are many cases where the quantitative argument can be carried out by means of only the ordering (comparisons) and limits (maximum and minimum). In such cases, the argument can be given by only using the structure of *partially ordered sets*, *lattices or complete lattices*, but not by using the whole structure of real numbers.

Nevertheless, qualitative research can be conducted without losing preciseness, and are actually used widely in ethnology, sociology, and nursing. Common to these fields are the facts that they deal with phenomena which are related to human beings, that the subjectivity is involved in the subject of study[Note 7], that they deal with phenomena which are not reproducible or hard to reproduce, and that the subject of study is complex. Parameters used to examine complex subject of study, in general, should be chosen with care. The validity and adequacy of the selection must be thoroughly and carefully studied, but such is only done by qualitative research, as we explain above. Qualitative research is important here and we need a methodology for it. The KJ method[1][2][3] by Kawakita and the grounded theory approach by Glaser and Strauss[11] are examples of such methodologies.

It would be appropriate, in the study of technology transfer from the viewpoint of clinico-informatics, to take the qualitative research approach to grasp the right direction of the research. The reason is that technical transfer involves human beings and, like other such humanistic subjects, it concerns with wide and complex variety of phenomena. The decision of whether a specific enterprise employs the new technology is entirely subjective, like all other decisions. Moreover, technology transfer in an individual enterprise is a non-reproducible process.

So, qualitative research plays a large role in the study of clinico-informatics, at least in its earlier phases. There can, however, be much use of quantitative research in the study of clinico-informatics. The authors are not totally negative about quantitative research, but qualitative research must come before it. It is only necessary to give serious thought about the selection of quantities to be investigated before starting quantitative approach, and such thought would unavoidably lead to qualitative research.

4 A scenario of technology transfer

We present, in this chapter, a typical scenario for the technology transfer process abstracted from our fieldwork experience in transferring the model checking technology.

1. [Interview] At first, the research team *interviews* its industrial partner in order to collect detailed explanations of the situation.
2. [Trial experiment] The *participant observation* process is repeated through the trial experiment where the model checking (technology to be transferred) is applied to development projects conducted by the industrial partner. This is done jointly by the research team and its industrial partner.
3. [From *engawa* (entrance) to *oku-zashiki* (backyard)] The trial experiment is started targeting system development with smaller risks of failure; this we call the *entrance* stage. As the trials are repeated several times, the target developments are chosen from those with larger risks of failure, and we call this process being introduced *backyard*. An example of development with little risk is a prototype which was once developed some years ago; the experiment can be done using left records of the prototype project. Development of test products has more risk, and that of commercial products for sale would have the largest risk for industrial partners.
4. [Training of engineers] The trial experiment is initially conducted solely by the research team, but in due course it should be taken over by the industrial partner, because that is the goal of technology transfer. In order to enable it, training for the use of technology is given to the industrial partner. The objective is to impose technological discipline on engineers so that they can carry out the trial experiments on their own.
5. [Objective achieved] The objective of technology transfer (such as manual writing and state-of-the-art engineer training) is achieved.

While we set up the above scenario, we followed several rationales based on our experiences in our fieldwork conducted through joint research with industry. Some of the rationales are listed here.

a) Some of the industrial partners asked the research team to develop an automatic checker that checks the correctness of software in response to a press of a button. The research team did not, however, agree to do it. There are at least two reasons:

(I) It is known in mathematical logic that there is no such general procedure that automatically proves whether an arbitrary given program satisfies an arbitrary given specification (undecidability of Church's first-order predicate logic).

(II) Even though the model checker itself is an automatic checker, the whole verification process using it is an interactive process because the property to be checked is usually found by try and error. On some occasions the property must be changed because there was a misunderstanding or impreciseness in setting it up; on other occasions, too much resource, memory or CPU time, is required by the verification software that the property must be divided into smaller ones or some other action is necessary. Such iteration seems to be inherently interactive and non-automatic, so, the research team was rather negative against the effort to increase the degree of automation.

It seems our industrial partner wished (I) because they considered the technology transfer for detecting faults by model checking as merely a flow of information. However, it involved a more complex phenomenon than a mere flow of information, as described in b) in the actual technology transfer process.

b) The verification technique, including model checking that we used as the subject of technology transfer, is a part of design technique. Design is a dynamic process rather than a static knowledge. The written texts and lectures on technical information does not convey by themselves the whole skill needed. It was necessary to convey the way how one uses the knowledge in a face-to-face manner. Here we see a kind of cross-cultural encounter; the culture of engineering or industry and the culture of academia. Incidentally, this is the reason why the technology transfer must be done as a *joint* work with a research team and an industrial partner, rather than as a contract and merely delegating the whole work to either side.

To exemplify how the basic knowledge differs from one field to another, take the basics of mathematical logic, which is necessary to describe the logical formula to be checked in verification. Such subject is not taught at all in high schools and in most university courses, as opposed to basics of linear algebra and analysis. Even most university courses in computer science in Japan do not teach it. So there is a rather large gap between the engineer's background and what is required for a person who uses model checking in verification in industry. According to our experience, it normally takes a few months or even a year to fill this gap, i.e., to teach the necessary basic facts about mathematical logic to the engineers who need to acquire model checking technique.

c) Another reason for us to employ fieldwork for technology transfer is that we have to show to the management of our industrial partner how effective the technology of concern is in the context of actual work done at their own site.

For our industrial partner to fully deploy the technology, it is necessary for them to evaluate the technology with their own eyes in their own context. But it takes time for the situation to come to that stage, as we wrote in 3 in the scenario, and the scientist in charge can often be frustrated, which of course would result in no good results. With the slogan of "moving from entrance to backyard" in mind, the scientist in the research team should try to observe where in the stage of technology transfer he/she stands, and that helps him/her keep himself/herself away from any frustration.

d) Each fieldwork project started training or education of engineers individually, but it did not take long for us to realize the need of a systematic way of training. We needed an education specifically meant for engineers at work. Therefore, we developed an independent training course of model checking for engineers and have provided it to the project participants[12]. The course has been designed so that the engineers are thoroughly drilled on the basics of mathematical logic, and that the facts independent of each particular tools are emphasized and clearly distinguished from tool-dependent knowledge.

e) The goal of model checking technology transfer is diverse. How our industrial partner wishes to incorporate the technology of model checking into their own development process differs much according to their culture and strategy. Some industrial partners tried to eliminate dependency on experts as much as possible by means of providing manuals. Other industrial partners tried, on the contrary, to depend on experts as much as possible, so we first trained a small number of engineers, and then those engineers trained other engineers after going back to industry.

Finally, we discuss which step of our scenario corresponds to which process of Kawakita's W-model for problem-solving. 1) The *interview* corresponds to the *exploration* on the leftmost edge of the W-shape where the flow goes from the thinking level to experience level. It is a step for gathering information to analyze the situation. 2) *Trial experiments* correspond to *field observation* and, in some cases also to *experimental observation*. The *model experiment* and *restoration experiment* that will be mentioned later also correspond to field observation, and the *blind experiment* and *man-hour measurement by engineers* to experimental observation in the laboratory. 3) What we call "*from entrance to backyard*" is nothing but the cycle of the entire W-shaped process; a perfect model solving process in the KJ method is a six time iteration of the W-shaped process. 4) *Training of engineers* corresponds to the path from the "warehouse of knowledge" to the starting point of the problem solving cycle in the left top of the W-shape. The knowledge is given to the engineer, and the next cycle of the W-shaped process is started. 5) The final step corresponds to "*abduction and integration*". For example, after the procedure is written as a manual, the adequacy of the manual is checked by experiment.

5 Element techniques for technology transfer

In this chapter, we discuss several element techniques for technology transfer that may be used in the scenario described in the previous chapter.

5.1 Fieldwork of technology transfer

Technology transfer may be conducted by a research team in the form of fieldwork. As mentioned earlier, fieldwork in clinico-informatics is not methodologically organized compared to fieldwork in the fields of ethnology and sociology; there are many to be learned from these fields of study, especially methods for information gathering or exploration. At any rate, we conducted our fieldwork with the following slogans.

a) Proceed according to the values in the field

The fieldwork of technology transfer should be conducted according to the values in the field rather than that in academia. To solve the problem in the field takes priority over writing a research paper on each element techniques[Note 8)].

So, the specific technique to be transferred should not be selected for the sake of applying a particular research result of a research team. This does not necessarily mean, however, that the research team must swallow every bit of what people in the field say; on the contrary, the research team may occasionally have to be opposed to the opinion of the people in the field, provided they think in terms of the values in the field, not in academia. In spite of initial possible disagreement, however, it is important for both to come to an agreement to proceed further.

For example, there was the aforementioned case where the industrial partner insisted in development of a fully automatic tool, but the research team did not regard it as a good solution. It should be emphasized that the research team in this case totally took the standpoint of the values in the field. In another example[13], the industrial partner requested the problem to be solved in the implementation process. It is, however, usually considered more effective to apply Mathematical Methods to processes in logically upper levels such as the requirement analysis process and the design process in software development. Accepting the industrial partner's requirement, the research team in this case made several trial experiments, through which they even developed some element techniques. As a result, they confirmed that the model checking technology was also effective in the implementation procedure. This is a case where the request from the field was incorporated successfully.

b) Principle of 4:6

Scientists involved in the research team of fieldwork are expected not only to be competent in scientific research, but also to be able to think and work in context of the field—in our case, industry. From the viewpoint of administration of research, it is important to organize a system where scientists involved are well motivated in fieldwork; in other words, there should be some academic element in their work. Also, we expect some bidirectional and mutual reaction between thought in an industrial context and that in an academic context. The slogan we made up to proceed in this direction is the principle of 4:6, which means researchers involved in fieldwork should use 40 % of their effort for fieldwork and 60 % for traditional academic work, that is, work in bibliographical science and experimental science. The idea is that traditional scientific work not only motivates scientists but also enables the use of methods and knowledge of the frontier of basic science in the fieldwork. In that way, a new direction of academic research may well be created, reflecting the issues in the field. It is often essential to evaluate the results of the fieldwork from the viewpoint of academia, but in such a case, knowledge and ability of the involved scientist in basic science is important[Note 9)].

Here is a case study in verification of software in industry[14]. The target was the design of web user interface, and there were two specifications: one for the screen transition as seen from the user, and the other was a flowchart that described the control flow of the program. The request from our industrial partner was to check for the *consistency* between the two specifications. The research team attempted to clarify the word "consistency" used in the field, and it was found that the word in their context meant a certain *simulation relation*, which nowadays is one of the basic notions in programming semantics. Fortunately, the research team was able to introduce an essential and effective model of the system by use of the notion of simulation relation in this case. This is an example that the knowledge in basic science worked well enabling such an effective model to be obtained because the research team had known the notion of simulation relation well before this industrial collaboration.

The processes of our technology transfer fieldwork were conducted almost precisely according to the description in chapter 4. The element techniques used in this procedure are explained below. Section 5.2 is an explanation of the interview technology used in the first step. Section 5.3 discusses the participant observation used widely in fieldwork. Finally in section 5.4, the model experiment, predevelopment experiment, post-development experiment, restoration experiment, and blind experiment used in trial experiments are described.

5.2 Interview

At the start of fieldwork in technology transfer, the research team must learn the domain knowledge of the field. In most cases, some written material about the domain knowledge is available, and the research team can ask questions, to which the industrial partner answers. We call this step the *interview*. Since the knowledge and the background or culture of the research team and the industrial partner differ, one must choose the vocabulary carefully during the interview. Yet the communication between the research team and the industrial partner often is so hard at first that it looks almost impossible. This is why we say technology transfer is a cross-cultural exchange. The techniques of interview overlap in a large part with *requirement analysis* in system and software engineering.

Interview is done during the whole process of fieldwork, not just at the start. So, the project should be scheduled taking the time for interview into account. Another thing to consider is that the interviewee is not necessarily cooperative to the interview, especially when he/she is not a member of the project, as the interview must occasionally be done with a person who is not a project member. Special preparation for interviews should be considered for such cases.

5.3 Participant observation

Participant observation is one of the standard techniques in qualitative research. The observer becomes a part of what is observed, therefore the act of observation itself may effect the result of observation. It is widely used in ethnology and sociology.

Processes of information system design and development are typical examples of non-reproducible processes. If the methodology of experimental science is applied simple-mindedly, one would immediately face with difficulties caused by the non-reproducibility, as well as the influence of the observer on the object.

5.4 Trial experiment

There are several objectives in trial experiments.

1) To give examples of application of the technology of concern in the context of the industrial partner, in order to make it easier for them to evaluate the value of the technology.
2) To exemplify applications of the technology of concern.
3) To ease the learning of the technology by the industrial partner, by means of tutoring by the research team.

Of these, 1) and 3) are for the interest of the industrial partner, while 2) is for that of the research team. No special method is necessary for 2) and 3), but we make a list of some specific methods for 1) (Fig. 2).

a) [Model experiment] Trial experiment for past prototypes and past development cases
The risk is small since there is no damage even if the technology application fails.

b) [Reconstruction experiment] Take an old system development, for a part of which the recorded document is missing. Reconstruction experiment is conducted by tracing exactly the old development according to the recorded document wherever it is available and making up the undocumented part by doing new development. For example, the specification is rebuilt in consultation with the preserved source code if the specification document is missing, and model checking is done according to the newly built specification document and the source code.

c) [Pre-development experiment] Trial experiment for a commercial product under development or for its development process

d) [Post-development experiment] Trial experiment for a commercial of products already available in the market
This includes conducting analysis of failures reported

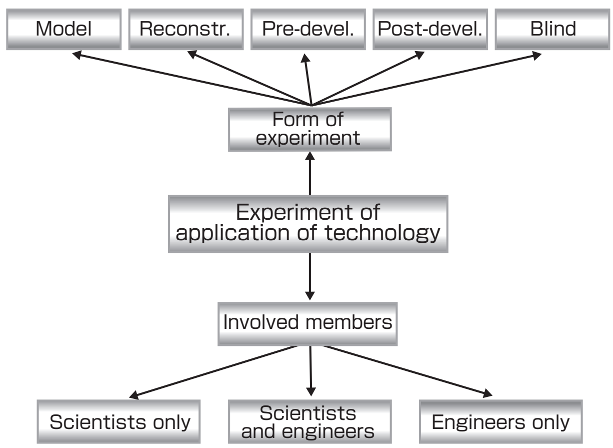

Fig. 2 Classification of experiments of application of technology.

from, for instance, the market.

e) [Blind test] Take an old development with some properties (nice or bad—it can be a fault). It is assumed that the technology of concern can ease the findings of those properties. The properties are hidden from the research team who tries to clarify them using the technology of concern and evaluating the results of the process. For instance, take an old development with some known, recorded faults. These faults are hidden from the research team who tries to find them using model checking. This can be a good way to evaluate the value of model checking.

Who exercises the technology of concern? There are at least three possibilities.

i) By a team composed only of members of the research team
ii) By a team composed of a mixture of members of the researchers and those of the engineers
iii) By a team composed only of engineers of the industrial partner

In early stages, one tends to follow i) to display the effect of the technology of concern; then the technology is gradually transferred to the industrial partner by means of ii), and finally, the trial experiment is conducted by iii) to evaluate the cost.

6 Two case studies

Amongst many fieldworks of ours, there were two cases that were continued for more than three years which were concerned, as a result, not only with a short term goal but also with a middle term one. In this chapter, these two works are presented and we try to evaluate their outcome.

6.1 Industrial partner P

The fieldwork done jointly with our industrial partner P started in response to a demand by P for introducing model checking into their development process. P reached model checking after their search for a method of developing reliable software with high quality.

1. A "Model experiment" was conducted for a small piece of software of P. Model checking was conducted for about one month, and an engineer on the side of P learned the process of verification using model checking, while the research team learned how to read the specifications written in P and the basic domain knowledge. This was repeated several times.

2. A "Blind test" was conducted after repetition of 1. All the faults that should be discovered were found by applying model checking. A good set of examples showing the effectiveness of model checking was obtained through this Blind test.

3. Up to this point, the work of model checking itself was done by the research team. At this point, the project decided to write a manual which enables engineers of P to conduct model checking without assistance of experts. To that end, model checking is now done jointly by the research team and engineers of P and this joint team repeated "pre-development experiments" and "post-development experiments," several times to write down a guideline for a verification process using model checking, and a manual to verify a module in nine days. The guideline was written jointly but the manual was completed solely by the engineer team.

Unfortunately, we have not received any report from P about how model checking was introduced into their own development process after this fieldwork was completed. We assume it has not been deployed in a large scale, to our disappointment. Note that, however, P is a world wide enterprise having more than a hundred thousand employees, so for them to deploy a new technology would itself be a huge project.

For a technology transfer project to succeed, there are various points that must be considered, other than technical problems that would be solved by trial experiment as discussed above. We realized through this fieldwork that the research team must set up a view about intellectual properties; that is, it must have a fixed strategy concerning which results would contribute to intellectual properties and which results would contribute to academic publications, and such strategy should be set up at an early stage of the whole project. Take, for example, the writing of a manual as described in 3 above. The manual was written only by the engineers of P and no one from the research team participated in the writing. This, however, prevented information sharing between the engineers and researchers. In retrospect, the researchers should have supported the manual writing much more because some information which must be written down in a manual is not so important as an intellectual property or as a result of academic research but, at the end of the project, we tended to regard every information written in the manual as valuable either as an intellectual property or an academic result.

6.2 Industrial partner Q

A fieldwork for technology transfer jointly with our industrial partner Q started when engineers of Q became interested in model checking, and the top management of Q dispatched one engineer to AIST for two years.

While the fieldwork with P was done with the intention to write a manual to propagate model checking to exclude the dependency on experts, in the case of Q, technology transfer took place in an extremely expert-oriented style where the technology was thoroughly taught to one engineer. This engineer participated in several research projects at CVS and went back to Q, after two years, with ample experience in conducting "restoration experiments" and "pre-development experiments."

As a result, the trained engineer has been active and has established a study group of model checking after the completion of the fieldwork project. The group extended even to other companies and he created his own model checking training course for engineers, which is readily used in Q.

The two cases of fieldwork above differ in their strategy for propagation of the technology inside the industrial partners, even though both were trials to apply the same technology. The reason seems to lie in the diversity of software development. The field to which the information technology is applied tends to be diverse and that implies that qualitative research is effective here.

7 Discussion and conclusion

7.1 Issues

We are still in the process of collecting experiences in the fieldwork for technology transfer. Therefore, the scenario presented in this paper should be regarded as tentative. There are, however, at least two issues for the future.

a) There is room for further systematic study on observations obtained through our fieldwork. It seems qualitative approaches, such as the KJ method, are effective for such a study.
b) While there are active discussions on measurements and quantity for the software development processes[15][16], in clinico-informatics, how to use such measurements in concrete technology transfer[Note 10)] still remains as an issue to be discussed.

Just as there are issues of finding the cause of a disease and clarifying the mechanism of a disease in clinical medicine, there are issues of finding the cause of risks and clarifying the mechanism of faults in clinico-informatics, and these issues must be solved by collaborating with the basic research of informatics. The risks (or dependability, if one looks at the other side of the same phenomenon) of information systems are widely studied nowadays, and an approach that takes into account the diversity and complexity of information processing, as presented in this paper, seems to be worth emphasizing more.

7.2 Conclusion

In this paper, we attempted the systematization of clinico-informatics based on the field scientific methodology by Kawakita. The KJ method seems particularly effective as a method of information gathering in the requirement analysis, as it is one of a few methodologies about abduction. To apply the KJ method to the actuality of clinico-informatics is our future theme.

Acknowledgements

This study was done using the experiences of the technology transfer activities conducted by a succession of research groups: Collaborative Research Team of Informatics, Laboratory for Verification and Semantics and Research Centre for Verification and Semantics, which continues since the establishment of AIST. We are grateful to all enterprises involved, the engineers thereof, and the researchers of AIST who participated and contributed to these technology transfer activities. Professor Hideyuki Nakashima and Professor Naoto Kobayashi kindly reviewed the paper, and provided several essential, *synthesiological* comments. In many cases in the review process, the authors' understanding was improved in an essential way. We are deeply grateful to be given this opportunity of writing this paper and of discussion.

Note

Note 1) We write Kawakita's family name before his given name, as is usual in Japanese. We guess he had a definite opinion on how his name should be put, from the fact that the KJ method was named as it is after his own name.

Note 2) Model checking is a technique (or technology) in system and software engineering. It is an application of mathematical logic to software engineering, which is generally called Formal Methods. For an overview to Formal Methods, refer to Reference [17].

Note 3) Reference [18] is a proposal for the terminology of the dependability and risk of information systems such as fault, error and failure. We try following them. The notion of *fault removal* is explicitly defined in [18], and it includes *verification* (finding the fault).

Note 4) A transition system is a mathematical structure given by a pair (S, R) of a set S, whose member is called state, and a binary relation R, which is called the transition relation, on S. If $s\ R\ t$ holds between states s and t, we say there is a transition from s to t. Automaton is obtained by adding some additional data such as input and output symbols and relations around them to a transition system. A state transition diagram often used by programmers may be seen to denote a transition system. In that sense, transition systems are widely used in practice as a mathematical model of information system.

Note 5) In some cases, all stakeholders come to an agreement on what the problem in the field is. It may also be a case, however, where stakeholders do not come to such an agreement because some stakeholders do not have a clear understanding of the essence of the problem the field faces. Even in such a case, the research team involved may be able to capture, because of their academic background, the essential problem there; that many other issues would automatically be solved if that problem is solved. The role of a research team here would be to detect such an essential problem, explain it to the stakeholders and propose a solution to it. *Exploration* of the situation and observation with open eyes with as little bias as possible would make it possible for the research team to play such a role.

Note 6) This is a point indicated by the main reviewer. The authors initially objected to the comment, but after thinking through, we changed our position and came to this conclusion.

Note 7) This does not necessarily mean that we are stating that these disciplines engage in subjective discussions.

Note 8) As a result, some of the authors' colleagues suffered from lack of volume in their publication lists. We emphasize that there are people even in academia who understand the importance and difficulty of fieldwork and that being seriously involved in fieldwork inevitably implies a small number of academic publications. Having said this, we must observe that there are still many who do not recognize this causality and tend to accuse scientists in fieldwork of lack of academic publications.

Note 9) Consider a researcher in clinical medicine who is not trained in basic science such as molecular biology and he/she tries to connect a result of a clinical study to basic science. It is widely known that he/she may go round and round for years over the same topic because he/she does not have the overall view of the whole picture, and it is often attributed to lack of his/her ability in basic science. Such a phenomenon is called PAIDS (paralyzed academic investigator's disease)[19].

Note 10) It seems the KJ method could be used effectively as a method for system analysis (requirement analysis, safety analysis, etc.). Conceptual tools such as Goal Structuring Notation (GSN) and Claim, Argument and Evidence (CAE), based on the operation of relating different objects by arrows, are recently used widely for safety cases, but the KJ method, based on the operation of putting things together by circles, seems to work from different perspectives. This is, however, an open issue to be investigated.

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Declaration

This paper was written based on the two authors' discussions and collaboration. Therefore, there is no "principal author" in this paper, but the two authors made equal amount of contribution.

Authors

Yoshiki Kinoshita

1981 B.Sc. in Information Science from the University of Tokyo. 1981-1983 Texas Instruments Asia Limited. 1989 D.Sc. in Information Science from the University of Tokyo. 1989-2001 Electrotechnical Laboratory. 2001- AIST. 2004-2010 Director of Research Center for Verification and Semantics, AIST. Currently, Chief Senior Scientist in Collaborative Facilities for Verification, AIST.

Toshinori Takai

1996 B.Sc.Graduated from the Department of Artificial Intelligence, School of Computer Science and Systems Engineering, Kyushu Institute of Technology. 2002 D.Eng. from Nara Advanced Institute of Science and Technology. 2001- AIST. Research Scientist in Collaborative Facilities for Verification, AIST.

Discussions with Reviewers

1 "Clinico-informatics"

Question (Hideyuki Nakashima, Future University Hakodate; Naoto Kobayashi, Center for Research Strategy, Waseda University)

Although the meaning of "clinico-informatics" is clearly explained in the text, I am afraid that a careless reader may easily misunderstand the word to mean "informatics for clinical treatment." What do you think of using the term *rinjo johogaku* or "on-site informatics"?

Answer (Yoshiki Kinoshita, Toshinori Takai)

Even outside of medical domain, the term *clinical psychology*, for instance, has been widely accepted. We agree, however, there is a possible misunderstanding which you pointed out, so we rewrote the text to avoid it. It could also be said that clinico-informatics is a study of therapy for systems, or *systemtherapy*.

2 Technology transfer

Question (Naoto Kobayashi)

You write that 1) analyzing the situation (diagnosis), 2) improving (therapy), and 3) deciding and executing the improvement policy (technology transfer) are the three principal subjects of study in clinico-informatics, making analogy with clinical medicine. I am anxious to clarify the chronological order of these activities; in particular which of 2) improvement and 3) technology transfer comes first in chronological order? It seems that 2) usually comes after 3). Is it the case that 2) is first done by the research team and then 3) the technology is transferred to industry step by step, or that 2) improvement and 3) technology transfer are done in parallel? Could you clarify the chronological order of 2) and 3)?

Is there no transfer of technology (of medical treatment) from medical doctors to clients (of course there is none because of the law), while there may be advice about treatment and prevention? If you include nursing, however, technology transfer does occur from medical doctors to nurses.

Answer (Yoshiki Kinoshita, Toshinori Takai)

2) comes after 1), but 3) is to shape the technology of 1) and 2) into a form that can be used (deciding the improvement policy) by general engineers (general physicians), and to communicate (execute). 1) and 2) are activities at a level different to that of 3), so there is no specific chronological order between 2) and 3).

The technology transfer we are considering as an example corresponds to a flow of knowledge from research institutes to the medical doctors, not from medical doctors to clients. Since it is done between medical doctors with proper licenses, (i.e., from those working in research institutes to those working in clinics,) the limitation by law does not matter here.

Question (Naoto Kobayashi)

I understand your notion of technology transfer and the analogy to what happens in clinical medicine, but I still do not understand that "3 to propagate the technologies" comes after "2 to improve the situation in the field" It would be strange if a medical doctor cares for the patient before deciding the therapeutic policy, wouldn't it? Could you explain more about what you mean by "to propagate the technologies"?

Answer (Yoshiki Kinoshita, Toshinori Takai)

After giving another thought, we concluded that analysis of the situation, improvement, and propagation of the technology transfer are *subjects* of study in clinico-informatics, and the propagation itself is not part of the study of clinico-informatics; clinico-informatics studies *methods* for propagation. We rewrote the text to emphasize this distinction. We appreciate your point.

3 W-model for problem solving

Question (Hideyuki Nakashima)

You compare the W-shaped and V-shaped processes in chapter 3. Is not a W-shaped process a repetition of two V-shaped processes? (Refer to: H. Nakashima: Discipline of constructive research fields – Toward formalization of *Synthesiology*, *Synthesiology*, 1 (4)) Moreover, I do not think Yoshikawa's model is wrong; I would rather think processes of his model is repeated in reality.

Answer (Yoshiki Kinoshita, Toshinori Takai)

The V-shaped part on the left of the W-shaped process is a stage of abduction where the theory emerges, while deduction and induction are performed based on the theory emerged there. Therefore, we think the W-shape is not a repetition of the V-shape. We added some explanation about this point to the text.

By the way, we do not at all say that the Yoshikawa model is wrong. Our point is that the methodology for abduction has not been discussed at all or the discussions have been far from sufficient, if any.

Question (Naoto Kobayashi)

You wrote that the V-shaped part on the left side of the W-shaped process was missing in the Yoshikawa's framework of *Full Research*. If so, the process for the left V-shaped part is predetermined in the framework of *Full Research*. However, such a situation is rarely found in reality, but there usually must be a process of the research team going out to society or industry to observe the situation. The difference of *Full Research* and your fieldwork may be as follows. In the case of fieldwork, the two V-shaped parts in the W-shaped process are always linked serially and the W-shaped process is repeated again and again several times. On the other hand, the left hand side V-shaped part is assumed not to be repeated usually in the case of *Full Research*.

Therefore, it seems to me that the whole W-shaped process also exists in *Full Research* but it is not symmetric, and the study in most cases is performed by repeating the right hand side V-shaped process.

Answer (Yoshiki Kinoshita, Toshinori Takai)

We did not intend to say, "The research theme is predetermined," but we do intend to say, "Discussion on the process for determining the research theme has been missing." Therefore, I absolutely agree with you in that "such a situation is rarely found in reality, but there usually must be a process of the research team going out to society or industry to observe the situation."

By the way, the difference between *Full Research* and the W-model is the emphasis of the presence of the left hand side V-shaped part and the presence of a methodology for conducting it. The difference is not the number of times the left V is repeated. Whether it be *Full Research* or anything else, the left hand side V-part, i.e., abduction stage, is there, and what matters is whether one is conscious of that part and look at it with emphasis or not.

Question (Naoto Kobayashi)

In Kawakita's W-model for problem solving, I think the left hand side V-shaped part ("exploration," "field observation," and "abduction and synthesis") is important. In the process of the application of model checking, you wrote "under a vague expectation or problem proposal that some technology may be useful somewhere in some society, one visits (make exploration) there and observes the situation (field observation)." In practice, however, don't you conduct technology transfer to respond to some clear issue that your industrial partner has? Or, do you mean that the problem of your industrial partner is clear, but how to solve it is vague? Could you clarify the word "vagueness" in your statement here?

Answer (Yoshiki Kinoshita, Toshinori Takai)

The industrial partner involved does not necessarily have the full understanding of the essence of the problem. Therefore, there may be a more pressing issue touching to the essence. That issue must be solved first; the other issues are often automatically solved as soon as such an essential problem is solved. It is the responsibility of the research team, which is equipped with more of scientific knowledge and experience, to explore and observe the field with open eyes with as little bias as possible.