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Chinese University Development Project

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Abstract This report is a historical document from 1985, with some footnotes highlighting the change towards the present. From a quite personal perspective, Computer Science education at the university level in the USA and West Germany are compared, endeavoring to take the best of both educational systems to derive recommendations for the emerging development in China.

Key words: Computer Science history; Computer Science education; Bachelor; Master; PhD

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This report[1] comprises some observations regarding the present state of computer science education and research at the Department of Computer Science and Technology at Peking University against the background of personal experience as a student and professor, both in the United States of America (Cornell University and UC Berkeley, a year each) and the Federal Republic of Germany (Universities of Hannover, Erlangen, München and Bremen) and gives some recommendations for possible future development and co-operation.

I am very grateful to the Chinese University Development Project[2] and Peking University for giving me the opportunity to visit for one month, and, in particular, to my hosts Profs. Xu Zhuoqun and Wu Yunzeng for the excellent arrangements and their omnipresent care to make me feel at home.[3] My visit has definitely resulted

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[1]This report is possibly of historical interest; thus, after 30 years, I have now been invited by Lu Ruqian to publish it. Most of my analysis comparing the educational system in the USA and West Germany with a view to the future in China (see section 1) is still valid. I have added some footnotes (and an update of chapter 3) regarding the actual developments since then. My Recommendations to the Department (section 2) document, to some extent, the status in China 30 years ago (hardly any offices, labs, or equipment) against the tremendous development since then. My efforts trying to establish co-operations (cf. section 3) were concentrated in subsequent years on inviting Chinese colleagues to stay in Germany for some time and advising (and financing) Chinese PhD candidates in my group.

[2]The one month visit in September 1984 was funded by the United Nations. Prof. Tang Zhisong and Prof. Lu Ruqian (see section 3) had been the initiators – two long-standing friends since 1978, when they first appeared at a meeting of the *International Federation of Information Processing* (IFIP) Working Group 2.4 on System Implementation Languages.

[3]At the end of the one-month stay on behalf of the *Chinese University Development Project* I was greatly honored by an invitation from the Chinese Government to attend the 35 years celebration of the foundation of the People's Republic of China, with a huge parade and a banquet in the Great Hall of People, opened by the Chairman.

in the strengthening of one of the many ties between Germany and China, at the personal level, establishing continuing contacts and often deep friendships to several colleagues and students at Peking University, the Chinese Academy of Sciences, North China Institute of Computing Technology, and Beijing Institute of Aeronautics.

1 Computer Science Education in the USA, West Germany and China

It is not surprising that Computer Science in China is strongly oriented towards the USA, as is, indeed, the case in Europe. Many colleagues in China have been to the USA, a few to Europe, but virtually none to both for a longer period of time. Consequently, few colleagues are able to compare; "the West" is largely equivalent to the USA (although it includes Europe and even Japan from the Chinese viewpoint). However, it was a surprise for me to learn during my stay in China that there are a lot of similarities between China and Germany from a cultural point of view that also seem to affect education and research, even in such a modern field as Computer Science. Since China will (and has to) eventually go its own way, a closer look at the German and American education system, and their differences, might be in order to derive the best from both.

1.1 Computer Science Education in the USA

Flexibility. The American education system is very egalitarian until the high school diploma (after about 12 years starting from the age of 6); some say too levelling at the expense of a loss in quality. College (about 4 years, leading to the Bachelor's degree) is available to everyone essentially, is very flexible, and allows a wide range of professional qualifications. It combines general academic education with vocational training. A definite advantage of the flexibility in the American system is that a student can gather professional experience before returning to Graduate School, and is by then much more motivated: s/he can better appreciate "why" and "what for" s/he is studying certain subjects. Graduate School combines scientific qualifications for the Master's Degree (1 to 2 years) and work for the PhD (study and research for about 4 years total).

Quality Distinctions. At the level of colleges and, in particular, the graduate schools of universities, there is a great variety in the quality of education; degrees of the recipients are judged relative to the esteem of the awarding institution. This "elite system" of universities (foreigners usually know only the ten or twenty best ones) is partly due to historical reasons, partly to the fact that almost all of the very best are private universities that can attract funds for better equipment etc., even barter for good students.

Competition and Individualism. The result is an elite, and heavy competition, both on the faculty and the student side. The advantages are obvious: a highly stimulating and intellectually challenging atmosphere, concentration of physical and intellectual resources. However, there are also disadvantages. Grading in American educational institutions is almost always relative and (not necessarily) absolute: a

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The official visit was followed by a personal two-week trip to Shanghai, Xi'an and Hangzhou (with the unique chance to get to know a China that hardly exists nowadays), made possible only by the kind participation of a PhD student from Peking University as guide and interpreter.

student's success is rated in relation to the average of the class, on a standard more or less normal distribution curve. This intentionally creates heavy competition. It also has, from my point of view, the unfortunate side-effect of creating the single-minded over-individualistic student, who has no interest in helping a fellow student to study or prepare for an exam, since that fellow's increased success would be detrimental to her/his own, since it would affect the average of the class. This analysis may seem a bit far-fetched, but there can be no doubt that the emphasis in the American education is on individual competition rather than co-operative success.

At the faculty level, the individualistic attitude seems to be the more prevalent the better the university is. There is often an appalling lack of concern for, let alone interest in, co-operation with fellow faculty members. I think it is no accident that (as far as I know) there are extremely few joint research projects between several universities or joint research proposals from one institution involving more than two proposers. In this respect, the success of the concentration of high quality has its limits in the individualistic ambitions and, sometimes, even jealous isolation. It is no wonder that foreign visitors are often disappointed at the lack of attention that is (can be?) given to them at top universities.

Publish or Perish. Again, one reason for the individualistic approach might be another side-effect of institutionalized competition: the need to demonstrate research success on a short term basis. About every two years, the scientific quality of each faculty member is rated by the other faculty members; this rating officially concerns promotion, but may actually mean "demotion" and less income if no salary increase is awarded, taking monetary inflation and rising living costs into account. This process obviously does not contribute to co-operation or collegiality (in Germany one would find it extremely awkward to rate a close colleague). Perhaps more importantly, since (superficially) the most tangible proof of research success is the number of publications, the resultant "publish or perish" mentality leads to competitive short-term research on a quantitative basis and may, in effect, inhibit higher quality longer term research that needs a certain freedom from short term concerns. I have heard several colleagues that emigrated to the USA bitterly complain about this situation.

Mobility. The elite system encourages mobility. It is not unusual that (especially younger) faculty members move from one university to another every two years. Such moves, while again being detrimental to longer-term co-operation, are obviously in the "upwards" direction only. This has the very unfortunate effect of a constant "brain drain" on the less known universities. Consequently, a medium university in the USA is likely to have mediocre teaching and research quality by most if not all faculty members, and not just on average over all its faculty, and it is very difficult to attract good people. This is analogously true for the student population, at least at the graduate level.

Pragmatism and Sophistication. The short-term goal ("get things done quickly") and pragmatic attitude ("make things easy") is perhaps an indication of a general American mentality and the outcome of a cultural background that lacks sophistication. I boldly conjecture that it leaves its mark on research content (and not only the way in which research is done). There is excellent theoretical research in the USA, and undoubtedly great success in HW and SW development. But there is a gap between theoretical and practical Computer Science, both in education and practice. Engineers and researchers do not usually base their inventions on a solid theoretical basis or guide their developments by a concern for elegance.

It is no accident that the ideas of "structured programming" only became popular in the USA in the early seventies although Algol 60 had been around for more than ten years in Europe; most of the important developments in programming languages or methodologies have come primarily from Europe: e.g. Algol 60/68, SIMULA, Ada, applicative and logic programming languages (except LISP); VDL, Hoare's logic, mathematical/denotational and algebraic semantics; structured programming, VDM, transformational program development.

In spite of the present domination of the USA in the HW/SW market this means that countries outside the USA can still have considerable success in the future production of portable, adaptable and reliable SW products that are produced in a systematic way. In Europe there are presently great hopes in the standardization of one programming language (Ada) and its support environment to increase portability and to create an industry and exchange of SW components. If the application of Formal Methods to program development will have any effect on Software Engineering by producing correct programs, then it is likely to come from Europe.

I see a unique chance for China as well to draw on a sophisticated culture with a tradition of thousands of years. Ingenuity and skilled craftsmanship with a concern for detail, combined with creativity, a "western" mathematical background, and training for abstraction should be very successful. It is my belief that a comprehensive practical Computer Science education can only meet the challenges of the Software Engineering crisis in the future, if it is combined with a solid theoretical background; the Chinese mentality that seems to combine pragmatism and sophistication should be an excellent basis for a successful education in this sense.

1.2 Computer Science Education in West Germany

"College" at the Secondary School Level. In West Germany, school education splits after the first 4 years in Primary School (starting at age 6) into a continuation of Primary School for a total of 9 years, or Secondary School ("Oberschule, Gymnasium") for a total of 13 years, the last 2 at a so-called "College Level". Not everybody goes to Secondary School (like virtually everyone to High School in the USA), but since the percentage is quite high (above 30%), one cannot call this an elite either; there are no major quality distinctions or "elite" secondary schools in West Germany.

As a result, the general advanced education has high quality. It provides a comprehensive basic pre-academic education, leading to the "Abitur" diploma that qualifies, in principle, for any university study. Since it does not attempt a combination with vocational training, it is not a job qualification in itself. One advantage of the comprehensiveness in a total of 13 years is that the general education is now done with, and university education can concentrate on a particular field of study.

(As an aside: one form of vocational training in Germany is the 3-year apprenticeship with a qualified "Journeyman" degree after 9 years of Primary School. It is combined with a one-day-a-week school for theoretical background. I believe that the highly qualified craftsmanship resulting from the apprentice/ journeyman/master education for many hundred years forms the backbone of Germany's technological and commercial success.)

Integrated M.S. Program. Everyone who applies for a university education has decided for a particular field of study (as, for example, Mathematics or Computer Science, i.e. "Informatik") and will study for about 4.5 or 5 years towards the Master's Degree ("Diplom", or equivalent). There is no intermediate Bachelor's Degree, although some educational institutions other than universities[4] award similar degrees as final qualifications; the university education provides an integrated M.S. program. A typical university study is usually structured into 4 semesters of fundamental education in the field (for example, among other things, Mathematics for Computer Science students) leading to a qualifying (but not final) degree called "Vordiplom", then 4 semesters of advanced education with the possibility for specialization of emphasis (for example in SW, HW or applications), and a half year for a thesis.

As a consequence, the curriculum can be planned and structured over a period of 4 years (plus thesis), with a comprehensive background, and no time is "lost" in non Computer Science subjects (although I deplore the deletion of the optional "Studium Generale" in the first year). The percentage of highly qualified University Diploma / M.S. graduates, as opposed to the less qualified B.S. graduates, is relatively high: about 70 Computer Science M.S. graduates per million inhabitants per year.[5]

No Elite Universities. There are no private universities in Germany (with 3 negligible exceptions). In principle, admission is open to everybody who has passed the final Secondary School examination ("Abitur"). However, in some subjects such as Medicine (possibly also Computer Science in the near future) restrictions have been imposed because of the limited number of available places ("Numerus Clausus"). Students are then admitted based on the quality of the "Abitur" and, occasionally, other factors of suitability depending on the field of study. They are distributed among available places according to preference, by a central institution. There is virtually no quality distinction between universities that would guide the choice of a student; s/he may be attracted by a particular city, short distance to home, or other such factors.

As a result, the quality of students and faculty is quite evenly distributed. Of course, some universities are larger than others, but generally there is a mixture of good and mediocre people everywhere. Particular faculty may be attracted to a particular university in a particular field, but such a situation is usually guided by a

[4] "Hochschule", now called "University of Applied Science".

[5] For several years now, the Bachelor plus Master system has been established all over Europe; the Master's degree has replaced the Diploma in Germany.

I became quite convinced of the Bachelor plus Master system, and indeed a fervent promoter, after a few years of actual teaching experience in Germany. The major reasons are: German and international European compatibility with standardized ECTS grade points allowing free transfer between universities during the course of studies; the fact that students get their first (Bachelor's) degree rather quickly after 3 years, and many decide to quit and go into industry at that time – some, who are not suited for further study, as it turns out, finish with a degree and are not studying "forever" only to fail; the flexibility to get work experience with a Bachelor's degree and come back for a Master's degree later; the flexibility to add a Master's degree in a different, related subject, say System's Engineering or Economics.

particular constellation of personalities in a specialized subject and not the university or department as a whole.[6]

Towards Dr. Degree and Habilitation. A typical academic career in Germany in Computer Science starts after obtaining the M.S. degree ("Diplom"). A student, who has shown excellent work in her/his studies and, in particular, her/his M.S. thesis, might be offered a position as an assistant by the professor s/he has worked with so far. Such positions are widely advertised, but the choice is most frequently done locally. Any person with an M.S. qualification (or equivalent) can work on a PhD ("Dr. rer. nat." or "Dr. Ing."), even as a remote candidate in industry, provided that s/he has a professor, who accepts her/him as advisor. Any university "professor" (see below) is entitled to advise PhD students; the degree itself is later administered by a committee, in which the advisor acts as the first ~~review~~ of the thesis.

Positions as assistants to a particular professor are available from the university as combined teaching/research assistants (usually 1 to 3 per professor), or are financed by research funds from outside. Such positions last 3 to 5 years (hopefully sufficient to obtain a PhD) and comprise a full salary that is comparable to a beginner's salary with an M.S. qualification elsewhere. Thus, compared to the USA (or the UK, for example), PhD candidates in Computer Science are more "employees" than "students" having a salary sufficient to support a family, but also a full-time job in (supportive) teaching of labs etc. and assigned research. Usually, the "assigned" research is connected with the "private" research for a PhD. However a PhD takes sometimes longer in Germany than in the USA because of the duties involved in an assistant position. This is different for the few, who have a PhD fellowship; but such fellowships only cover minimum living expenses.

After 3 to 5 years s/he has obtained the PhD and leaves the university to go into industry, or applies for a position as senior assistant (up to 6 years) to work, with very similar duties as before, for another degree that is called "Habilitation" and qualifies for university teaching.

Tenured Professors. This is a major contrast to the USA system: post-doctorals in this position (roughly corresponding to Assistant Professors) do not have the right to teach; they may be allowed to teach special courses on their own on an individual basis, but as an exception. It is somewhat of a contradiction in terms that somebody, who is supposed to qualify for a teaching position, is not allowed to teach with full responsibility to gain sufficient experience.

Also, until "Habilitation", post doctorals are likely to stay at the university where they started their basic education, and then apply for a professorship elsewhere. In the USA, the same person might have applied for Graduate School elsewhere, and would have moved as Assistant Professor to yet another (or several) universities. When s/he finally gets tenure and is promoted to become Associate Professor, s/he usually stays; in Germany this corresponds to "Habilitation" and necessitates a change to apply for a professorship elsewhere[7]. My personal experience is that at least one change during

[6] The institutional desire for excellence has spread in Germany: Universität Bremen is presently one of 11 universities sponsored by the *Excellence Initiative* of the Federal Government to promote top-level research and to improve the quality of German universities and research institutions. In the (Times Higher Education) *THE ranking "100 Under 50"* of young universities it has rank 26 world-wide, and is among the first 3 in Germany.

[7] "Habilitation" has now largely been replaced by "equivalent qualifications", but still exists.

the course of study for the M.S., and immediately thereafter, is advisable (and has a long academic tradition in Germany). A post-doctoral fellowship is also a very good opportunity to broaden one's views. At this stage, however, it is perhaps better not to move around too much, but to come back to a particular place to "grow some roots", interact with a research group and have feedback to the home institution.

There are 3 kinds of professors: Junior (C2; very few) and Senior (C3) Associate Professor, and Full Professor (C4). Promotion at the same university is quite impossible, change to a different university is required; this increases mobility and avoids jealousy and judging of peers. The difference in the position affects the personal salary and the number of assistants: usually 0 or 1 for C2/C3, 3 for C4; this, and the psychological difference of status, varies from university to university. Rights and duties are usually the same across positions.[8] Still, the difference between several "kinds" of professors, "not-quite-professor" post-doctorals (similar to Assistant Professors elsewhere), and assistants may create quite a status of hierarchy; while this is to some extent natural, based on knowledge and experience, it can easily degenerate into a mere power structure and may, in effect, inhibit fruitful co-operation. This largely depends on the personalities involved, the particular university, and its possibly continuing prevalence of traditional hierarchical structures.

The Department Chairperson ("Dekan", "Fachbereichssprecher") is elected and has administrative duties, but little official power compared to the USA. All important decisions are made by elected committees, with attendance open to everyone; the group of professors has a majority of votes. Hiring of new faculty is also done by special committees. The hiring procedure takes a very long time: usually about two years to (re)fill a position for a professor. A new professor has to stay for at least 3 years, and stays for about 10 years on average. Every professor is entitled to a fully paid sabbatical semester every 7 semesters to do research at her/his home institution or elsewhere.

Research at Universities. For research, funding from outside sources is quite important. It is not unusual that a professor has 5 to 10 (or even more) research assistants on several projects, working for their PhD at the same time. Major funding organizations are the German Research Association (DFG; equivalent to NSF in the USA), the Ministry for Research and Technology (BMFT), the Commission of the European Communities (CEC), and private industry. Research projects are sometimes joint projects with an industrial partner. Most projects are only partially funded; the university is required to put up resources in terms of infrastructure, available faculty time and research assistants, and, sometimes, equipment.

Indirectly, the government is thus funding most of the research. Recently, there is more and more of a requirement in Computer Science to link to industry-related research. This is absolutely necessary to ensure fast technology transfer. But to a certain extent there is a danger here that influence by industry is too strong; it is usually governed by economic and short-term goals, possibly inhibiting more speculative long-term projects. On the other hand, prospective gains are better "technology transfer" of fundamental research results and, more importantly

[8] There are now 6-year Junior Professor positions, some of them tenure-track.

perhaps, the possibility to keep certain types of large-scale research at the university, which might otherwise totally migrate out of the academic domain due to lack of resources.

1.3 Recommendations for Computer Science Education in China

What then are the particular recommendations for China and, in particular, Peking University?

Integrated M.S. Program. There is no question that academic Computer Science education must be structured for different levels of qualification, in particular in such a vast country as China. There must be the well-trained specialist with good vocational training: the HW engineer and systems or applications programmer, below or at the Bachelor's level.

These should not be educated at the level of universities, but at colleges with a vocational training. I think most emphasis (and perhaps more emphasis than now) should be placed on the education of M.S. students. Computer Science is changing very fast, perhaps faster than any other engineering field. It has high demands on intellectual flexibility, creativity and, most importantly, a solid, comprehensive, high-quality education, balanced between theoretical and practical subjects. The demand for abstraction and well-founded formal (mathematical) methods in SW (and HW?) development will increase in the future as the demand on reliability or "correctness" increases (cf. the "5th generation computer" tendency). Students will have to be prepared now by a broad theoretical background. At the same time, they must be able to put their ideas to practice and train their abilities before they are working in industry. Graduates with a lack of potential for adaptation are in danger of becoming tomorrow's lay-offs.

The standard American B.S. graduate is not sufficiently trained for this challenge. On the other hand, the present Chinese M.S. seems to be over-qualified, at least as far as the length of study (4 years B.S. + 2.5 years) is concerned. Assuming that the number of places is limited (and will continue to be so for some time), this works against the foreseeable high demand.

The advantage of an "integrated" M.S. study program (German style) without the B.S. in between is, that a high-quality student population can be assumed from the start; demanding (in particular theoretical) subjects can be integrated into the course of study from its start. Such a qualification should be achievable by an integrated study lasting one year longer than the present B.S. program of 4 years. At a university such as Peking or Qinghua University, where some students also study 5 years to acquire more knowledge, a slight modification to the B.S. program may in fact be sufficient. If a choice must be made, I would sacrifice a loss in the total number of Computer Science students (by eliminating the B.S. program altogether from the (top) universities) for an increase in average quality, at least in such a demanding field as Computer Science. It is not clear, however, that the total number of students must decrease, if 2.5 years times the number of Master's candidates were "distributed" as one additional year times the number of Bachelors at these universities.[9]

[9] I was told by my Chinese friends that about 10 to 15 years ago the Chinese Ministry Of Education established hundreds of so-called *Software Colleges*, specialized in educating software engineers, at most of the Chinese Universities, in parallel to *Computer Science Colleges*. These two alternatives

Critical and Co-operative Study. There should be more discussion and less "consumption" of material in class and, in particular, more review and tutoring sessions. Students should discuss among themselves and with tutors (graduate students) about alternative approaches, being critical with "worn-out" paths. Computer Science is changing so fast that one cannot afford *not* to have creative alternative solutions. Learning of constructive criticism and constant questioning of existing approaches is one of the most important qualities for the ability to change, adapt and be creative.

Students should be encouraged to work together in small groups of 2 or 3 to discuss, stimulate each other and learn a co-operative style of work. They must also learn to do technical presentations, on a regular basis, in study groups, pro-seminars (where they learn presentation style) and seminars. This is perhaps easiest in smaller groups at first, where everyone knows each other. They must be given the feeling that everyone has, at one time, learnt to give presentations, and it is no question of losing face when one tries. Similarly, it should be no question of losing face to ask questions of understanding in class; the psychological barrier is best overcome in tutoring sessions of small size (15 to 20 persons).

An important goal of any study program is also to get a broad overview of, and feeling for interaction between, the different (often narrow) subjects. Apart from frequent discussions, one way to achieve this is by "student projects", coordinated with appropriate supporting courses. These are presently done at Universität Bremen, Dortmund and Berlin in Germany. About 15 students work together with a professor and an assistant for one to two years, in groups of two or three. The intent of such projects is that students learn co-operation, appreciate integration of the various subjects they are taught, and have a little touch of the kind of project work they might be involved in after getting their degree. It is typical, I think, that such projects are done in an integrated M.S. program because they might take too much time otherwise.

Qualifications for University Teaching. In any case, the M.S. education should be geared towards employment outside the university, in industry, government institutions, etc., where graduates are needed in large numbers. Some of the M.S. candidates I met at Peking University seemed like "little PhD candidates" with a prospective tenured employment in university teaching. If university teaching is to be done by M.S. graduates, even at a "lower level only", it is a dangerous tendency. In the long term, this may have an adverse effect on the quality of teaching.

Permanent teaching positions, setting the quality standards of teaching at any level (as opposed to courses taught by T.A.s), should have the qualification of a tenured Associate Professor in the USA or, equivalently, require "Habilitation" in Germany. I am aware that the present situation (with few PhD qualifications) is due to the current state of transition; after all, the PhD degree in its present form did not exist until recently. Also, it is not the degree itself that is relevant, and not so much the extensive teaching experience, but more so the continued involvement in research and its influence on the contents of teaching. The present lecturers should

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are comparable to the German *Hochschule* ("University of Applied Science") educating application-oriented software engineers, and the *University* educating software scientists with a solid theoretical foundation and a more scientific approach integrating up-frontier research in the course of study.

not be exclusive teachers (at a particular level), but increase their qualifications and be continually involved in (co-operative) research.

Thus a very considerable number of PhD's is required (over those migrating into industry) who, after about 4 to 6 years of additional qualification through accomplished research as post-doctoral's, become tenured professors. These must be seen as particularly destined to create a snowball effect in education ("a little snowball creates a big avalanche"); they should go elsewhere for some time, some if not most abroad (see below under mobility).[10]

Even Quality of University Education. Personally, I am not fond of the mere concept of elite educational institutions. This is independent from a strong desire and definite efforts for excellence; but excellence can be achieved in other ways too, and really good people will always succeed provided the educational environment has certain minimal qualities.

I have stated above that I abhor the social side-effects of elitism in a society that is based on competition and individual success. This may not be so much of an issue in China. More important is perhaps the question, whether concentration or distribution of excellence creates a better effect in overall quality of education (let us focus on Computer Science education for the M.S. level).

My personal experience is that concentration of excellent individuals (at the level of university professors) does not necessarily lead to as much cross-fertilization of ideas as one might hope. Apart from personality problems and power politics, the size of the sample (10 to 15 professors) may just be too small to allow too many liaisons. University professors usually have little incentive to co-operate; a university is not a research center, where a large number of people work together on a particular problem (a national center of this sort is, indeed, a good idea).

Encouragement in research, mutual stimulation and exchange of information is much more effective in or at scientific conferences or working groups, including international meetings. These are, by nature, much more flexible in grouping the "right" people together. Meetings of people from different institutions require an adequate infrastructure and are costly. However, with the advent of electronic communication, teleconferencing systems etc., there may, to some extent, be a substitute for relocation. This sort of communication will become increasingly necessary (even in an elite university system).

Perhaps the most serious defect of (a hierarchy of) elite universities is their constant (upwards) drain of excellence of faculty as well as students, as described above. My vote is definitely for an even distribution of institutions of good quality and sufficient mobility between them, that is horizontal distribution rather than vertical drain of excellence. Chances are that there will be some excellent people at every university, who attract the good students (who are then also locally available) and

[10]My Chinese friends tell me that there are now two fast-track PhD careers in China after the Bachelor's degree, one combining Master and PhD as "continuous Master-PhD" (normally 5 years), analogous to the "continuous Bachelor-Master" (normally 6 years; cf. section 1.2), and the other the "immediate PhD" (normally 4 years, without Master's study). The difference is that, in case of failure in finishing a PhD, one can get a Master's degree in the "continuous Master-PhD" track, but not in the "immediate PhD" track.
In Germany, we have also been trying to establish a fast track "continuous Master-PhD" for excellent students after the Bachelor's degree, but the German academic system is slow and change-resistant – maybe we can learn from China here!

may even have a stimulating effect on their colleagues.

So the only reason that remains for elite universities (or research centers for that matter) is the concentration of infrastructure, in particular equipment. But it would, precisely, be a mistake not to provide every university with adequate resources for good education and research since this would necessarily mean inferior quality at all but the very best institutions, also in terms of not attracting good people. There are, of course, exceptions. There are certain areas of large scale research, where the necessary equipment is so costly that it can only be provided at very few institutions, for example VLSI manufacturing. However, this means concentration of a particular well-defined and confined research area at particular institutions and not (necessarily) all such areas at the same few institutions. High quality infrastructure should be made available to the very best researchers, no matter where they are.

Increased Mobility. High mobility in an academic career is an essential prerequisite to achieve high quality of education and research; its encouragement if not requirement should be institutionalized. In the Middle Ages journeymen were travelling around Europe on foot to learn new techniques, broaden their views, and expand and complement their personalities. The need for mobility and occasional travelling with increased personal contacts is perhaps as much true today in a fast changing field such as Computer Science, in spite of electronic communication.

China has realized the need for worldwide *international* communication and sends a large number of students abroad. I strongly concur with the seemingly prevailing view that students should receive their basic education "at home" before they are sent abroad. The earliest time should be (and is in current practice) the postgraduate level. I would even go further and recommend the level after the M.S. degree (not perhaps the "overqualified" Chinese M.S.); in any case at a stage, where course work is no more required, only recommended in some cases, and all efforts can concentrate on research. In Germany, in particular, an M.S. degree of a Chinese student avoids a lot of troubles in official recognition of other degrees, course work etc., since the B.S. does not exist and study programs are thus largely incompatible.

Postdoctoral research programs for a duration of several months to several years should also become possible.

Within an academic career, there should be at least one required move *"sideways"* to a different institution. If an elite system continues to exist, then at least one move could be *"down"* as well, for example after the PhD or as the first tenured appointment as professor at a less well known university, to gain experience in teaching and to do qualified research that may be stimulating for others. This way, at least some "snowball effect" is achieved before that person may eventually move *"up"* again to a different institution. Such a move "down" should obviously not be before the PhD level; only at this stage would the person (supposedly) be mature enough to be on her/his own.

Also, I believe it is no accident that both the American and the German academic careers have two major hurdles towards becoming tenured university professors: the PhD and tenure or "Habilitation". Both together require at least one move. More importantly, they also encourage moving out of the university for those, who are not suited for an academic career or, putting it positively, are better suited for industry, where quite a different set of qualities is required for success.

It would be a mistake to guarantee the "iron bowl" in the form of a tenured teaching position at a particular institution without the qualification of a PhD and additional accomplished research work. The danger, otherwise, is a perpetuation of mediocre and out-of-date views in teaching. I strongly believe in the unity of teaching and research at universities, particularly in the indispensable mutually beneficial effect of up-to-date research on up-to-date teaching and vice versa.

Lastly, one should not forget the mobility to industry and back again. This sort of flexibility is definitely a strength of the American system: people often leave with a B.S. and come back to work for an M.S. or PhD, possibly in a (slightly) different field. Such mobility must be strongly encouraged, especially if the B.S. continues to exist as an intermediate degree.

It should, of course, also be made possible for accomplished persons in industry or at a research institution to eventually come back to the university as professors. These must, however, have adequate qualification: in general, a PhD and convincing additional research achievements.

I realize the problems of increasing mobility in China, where practically all spouses have their own work and career, an employment "market" as such doesn't exist and housing is basically available from the employing institution rather than on a "market", and after a long waiting time. The problem of coordinating two careers of husband and wife is difficult enough, if not impossible, in "the West". Too often, one partner (and mostly, still, the wife) has to make sacrifices.

One solution is to organize mobility for both, that is to have an organization that finds employment for the other person, if one wants to go to a particular place. In no case must the demand for mobility be detrimental to the unity of the family (although the family at large will obviously be affected, at least temporarily). I personally regard the family as perhaps the most important "institution", and separation for a longer period of time to be quite harmful, in many respects. (Temporary?) loss of a circle of close friends is bad enough. One way might be to essentially limit high mobility to the period before marriage, equivalently, say, before the PhD, and to organizationally support further move(s) after long periods of time, let's say 5 years minimum.

I have no clear-cut solution for this unfortunate interdependence of problems, even in the West.

2 Recommendations to the Department of Computer Science, Peking University

In this section, I would like to make some specific recommendations to the Department of Computer Science, Peking University, apart from the general recommendations in section 1.3 above and from the proposals for co-operation in section 3 below. Many of these recommendations generalize to other institutions as well, of course.

2.1 Study Program

Students should get more programming experience. On the other hand, the study program should be a good blend between theoretical and practical subjects to ensure adaptability. It is very difficult to obtain a solid theoretical background after graduation. Students should work in groups of 2 or 3. There should be more tutoring sessions and seminars with open discussion and presentations by the students; also perhaps student projects of one or two years length as an integral part of the M.S. program.

An integrated M.S. program (without intervening B.S. degree, see 1.3 above) of about one more year's length than the present B.S. should be offered, possibly at the expense of the present B.S. program. The present "over-qualified" M.S. program should be given up in favor of the integrated program and more PhDs.

M.S. theses may be collaborative (several people as authors) as long as the advisor can discriminate individual contributions. PhD theses should be individual; a possibility for "cumulative" qualification (accumulation of (published) research papers, possibly some jointly with others) should be installed.

All tenured professors should be entitled to advise PhD candidates; the degree being conferred by committee. PhD candidates should do their research work in close co-operation with a professor, possibly in a research group.

2.2 Faculty Structure

Teaching of courses completely under one's own responsibility should only be done by persons with a PhD qualification. PhD candidates should be allowed to teach specific courses, but as the exception and upon special assignment.

Only lecturers with the qualification of "tenure" or "Habilitation" should have permanent positions, as professors.

There should be more mobility for (post-doctoral) lecturers and professors ("upwards", "downwards", "sideways"). It should be possible to go to some other university in the country for several years (apart from foreign exchanges) with the possibility, but not guarantee, to come back for a tenured position. Qualified people from elsewhere should have the possibility to be hired as professors at Peking University.

2.3 Infrastructure

Rooms. The lack of space for the Department of Computer Science is obvious; I am sure the administration of Peking University already has made plans for rapid expansion. Nevertheless, I would like to emphasize here how important the availability of adequate rooms is.

For classroom teaching it is obvious and can most easily be quantified. There must also be rooms for laboratory teaching, including software development, with ample room for terminals and small computers to make the best use of the equipment. There should be secluded terminal rooms for graduate students and faculty research.

I would like to make it a particular point that seclusion (and this means one or two people per room) is not a luxury, but a necessity for concentrated, creative research. There must be a sufficient number of (individual) offices for the faculty members including PhD students. It cannot be underestimated to what extent infrastructure in terms of rooms and equipment actually supports and enables particular research.

2.4 Equipment

There should be a hierarchy of different kinds of computer equipment with different power for various needs in teaching and research.

Mainframes. At the top there should be one (or several) mainframe(s), whose purpose is to supply the peak power for applications that cannot be done (or would require an excessive amount of time) on smaller equipment. This is typically the case in "number crunching" applications in Mathematics/Theoretical Computer Science, Numerics, Simulation, Graphics and Computer Aided Design/Manufacturing etc.

For reasons of availability of widely used software (see also below), in particular the relatively easily accessible SW from universities, a Digital VAX 780 or 750 is presently almost a "must". UNIX should be the standard operating system on the mainframe, if possible.

Workstations. With the decline of hardware cost it is now generally recognized that most applications will, however, be done on workstations or personal computers in the future; the distinction between the two is largely a matter of power and price. This is also, and already, the case for most of the undergraduate teaching; it should be done in a decentralized fashion with a small number of users per computer or, even, on strictly personal computers, depending on the power needed (see below).

A "workstation" is characterized by a powerful yet inexpensive 16 or 32 bit processor (e.g. Motorola 68010) with HW support of virtual memory access; this will be required by more and more applications in the future, for example by new-generation programming environments. A distinctive feature is the availability of a fast, large, high-resolution graphics display (preferably non-interlaced, that is one full screen image per cycle) for use in graphics, CAD etc., but also advanced human-user interfaces with windows, icons etc. (see also Apple Macintosh below). Moreover, it should be connected to a high speed net (a 10 MBaud Ethernet, say) for SW exchange, for access to a central file server, possibly even to realize virtual memory swapping. One should realize that today's workstations are tomorrow's personal computers and their study and extensive use now is an absolute necessity for future-oriented research.

Unix is the standard for workstations today. Support of virtual memory over the net is important here also for economic reasons since a local hard disk may be dispensable; Berkeley Unix 4.2 and (the apparent forthcoming industry standard) System V, coming versions, support it.

ICL's PERQ (own unix version, no virtual memory yet), the SUN workstation (Berkeley Unix 4.2), and the PCS Cadmus workstations are examples of the range of machines.

Personal Computers. At the bottom of the hierarchy, there should be a large number of personal computers (PC's), whose price is now less than twice that of a terminal (and can be used as a terminal if necessary with appropriate SW); therefore it is, at least in the "West", much more economical to buy these than mainframes, say. Moreover, students become acquainted with the "personal computing" style of work. Many universities in the USA and also in Europe (although at a slower pace) are now starting to make such PC's available to every student in the university, not just Computer Science, in a "computer literacy" campaign.

A typical PC has a 16 bit processor (INTEL 8086/80186/80286, Motorola 6800 or the like); 8 bit processors are not future-oriented enough. It is a good idea to link the PC's in a low cost network, not only for better communication possibilities, but also for economic reasons: the PC's in a cluster can share disk space in a central file server and high quality printers in a printer server. Moreover, the need for a second (or even first?) floppy disk drive per PC goes away and a local hard disk is only necessary for advanced applications.

An excellent example for such a net is the AppleTalk Net for the Apple Macintoshs (50$ per PC) with print-quality LaserWriter as printer server and file servers forthcoming. This net will also be available for IBM PC's this year. There are a number of low cost nets for IBM PC's and compatibles.

For reasons of SW compatibility, the variety of IBM PC compatibles is probably best now, although the Intel 8088 chip is now out of date (there are compatibles with the 8086 etc., for example Olivetti).

A most interesting development is the Apple Macintosh because of its brilliant high-resolution graphics possibilities at a low price. It should be very easy to incorporate Chinese characters both on the screen and in print (on the LaserWriter); it can even "speak" through its SW programmable sound generator. I can highly recommend to study it closely, in particular because of the enormous amount of very interesting SW that is now becoming available from many (sometimes very small) companies. Such a (SW business) development is only possible because of the de facto standard of the equipment: companies can invest in SW development because of a great market. I see a distinct possibility for China in such SW development as well, marketing worldwide.

Software. A consideration that is becoming more and more dominant for the purchase of equipment is the widespread availability of standardized software. In most cases this is the deciding factor since nobody can afford to do customized developments on a large scale. This is particularly true for universities to have access to experimental SW that is produced elsewhere as soon as possible.

Standardization starts with the use of standard programming languages such as Pascal, Modula2, Ada; it continues with operating systems like Unix (System V seems to be the coming industry standard) or MS/DOS (CP/M seems to be fading out) to SW with standard interfaces like the Macintosh Toolbox containing graphics, window manager and OS primitives. A similar and very important stream of development of (de facto) standards is that of environment interfaces like the Ada-oriented Common Apse Interface Set (CAIS) and the European, more ambitious, Portable Common Tool Environment (PCTE).

In the purchase of equipment one should be careful to actually test promised compatibility as much as possible. For example, an IBM PC compatible computer with MS/DOS, floppy disk compatibility and compatible programming languages may not be fully SW compatible if its screen control is different; then non manufacturer-supplied application programs will not work unless extensive modifications are made.

2.5 Research

Research should be structured and linked to ensure co-operation and maximum efficiency. There are various levels according to qualification.

Student Projects. M.S. students should work in student projects of about 15 students for one to two years in groups of two or three (see section 1.3 above). Emphasis should be placed on learning effect; therefore, it would be a mistake to expect or ask too much in terms of innovative research content. A similar argument applies to M.S. theses. Other qualities than academic excellence are required in industry; and M.S. graduates are needed fast.

Research Projects. Research for PhDs must be individually measurable. This does not exclude, however, collaboration in research projects under the collective guidance of a professor, quite on the contrary. Typically, post-doctoral research is more isolated, with a looser connection to ongoing research projects, to pursue one's own highly specific research interest.

Research Areas. It would be presumptuous to suggest areas of research. However, I will summarize here, what areas of research seem, to me personally, to be most interesting and promising: Formal Methods for program development: based on formal definitions of programming languages and concepts, formal specification (axiomatic/algebraic; of concurrency), verification; Programming Environments: data base issues, user interface; Distributed Computing: concurrent computations, Local Area Networks, Open Systems Interconnection standards; Embedded Systems: SW / computer HW embedded in an industrial process HW. All these areas are difficult if not impossible to tackle without large resources; international co-operation seems logical and necessary.

3 Proposals for Co-operation between China and the European Community

Evidently, there is mutual interest in strengthening the professional ties that have been established during my stay in Beijing. In the following, I shall describe possibilities for closer co-operation with the intent of formally proposing such co-operation both to the respective Chinese bodies and to corresponding partner organizations, in particular, the Commission of the European Communities (CEC).

Actually, my stay initiated a lot of co-operations and visits by colleagues from China; they are listed below, including the successful Chinese PhDs in my group, funded by European and German organizations, and Universität Bremen. I am extremely grateful to my Chinese friends to recommend such excellent candidates, who significantly contributed to my group's research as a "side-effect".

Prof. Wu Yunzeng (Peking University, Department of Computer Science and Technology) visited Universität Bremen in 1985. He was instrumental in preparing a Co-operation Agreement between *Peking University, Department of Computer Science and Technology* and *Universität Bremen, Department of Computer Science*, which was signed by the Rektor (President) of Universität Bremen (and Prof. Wu Yunzeng and me), but could unfortunately not be honored by Peking University due to lack of funds.

Prof. Tang Zhisong (Chinese Academy of Sciences, Institute of Computing Technology) visited Universität Bremen many times. His student *Qian Zhenyu* became the first international PhD candidate of my group and received the Dr. rer. nat. (1991, summa cum laude) *and* Habilitation (1995) from Universität Bremen. He became in turn an advisor of *Wang Kang*, who received his Dr. rer. nat. (summa cum laude) in 1994.

Prof. Lu Ruqian (Director, Department of Computer Science, Institute of Mathematics, Chinese Academy of Sciences) visited Universität Bremen many times (funded by DAAD, the German Academic Exchange Service). He stayed for a total of one year as a distinguished visiting professor, in a special program funded by the

German government, helping out teaching Artificial Intelligence (in German!). He also initiated and organized (with *Prof. Zhou Longxiang* and *Prof. Lu Weiming*) another 6 week visit to China in 1986 by Prof. Bernd Krieg-Brückner and Prof. Manfred Broy (Technical University of Munich, Germany), teaching Ada and Formal Methods (resp.), invited by *Prof. Li Changming*, Department of Mathematics, Guizhou University. At a resort near Guiyang, ca. 50 PhD candidates from all over China were invited to attend these lectures. Apart from enjoying Guizhou Province's beautiful nature, the visit was concluded by a very memorable boat journey back from Chongching to Wuhan along the (then still existing) gorges of the Yangtze River. A participant of these lectures from Xi'an, *Liu Junbo*, later became a member of my group and received the Dr. rer. nat. from Universität Bremen in 1994.

As an indirect effect, *Shi Hui* became a member of my group and received the Dr. rer. nat. from Universität Bremen in 1994. She stayed at Universität Bremen as a Senior Researcher and Lecturer, became the advisor of *Jian Cui* who received the Dr. rer. nat. in 2013, and now *Tao Wang*, who has a scholarship from China.

Prof. Dong Yunmei's student *Liu Jun*, recommended by Lu Ruqian to me, received the Dr. rer. nat. from Universität Bremen in 1998.

Prof. Li Wei (Beijing Institute of Aeronautics) spent a year at Universität Bremen as a distinguished scholar, co-operating with my group in a European project. Until recently he served as President of Beijing University of Aeronautics and Astronautics, now called *Beihang University.*