Computational Engineering Programs at the University of Erlangen-Nuremberg

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Abstract. The Computational Engineering Program at the University of Erlangen was initiated by the Department of Computer Science as a two year graduate program leading to a Master's degree in 1997. In 1999, a three year undergraduate program was added. As a peculiarity, the Masters program is taught in English and is thus open to international students who do not speak German.
The curriculum consists of approximately equal parts taken from computer science, (applied) mathematics, and an engineering discipline of choice. Within the current program, this includes material sciences, mechanical engineering, fluid dynamics, and several choices from electrical engineering, such as automatic control, information technology, microelectronics, semiconductor technology, or sensor technology.

1 Organisational Background

Computational Engineering (CE) at the University of Erlangen was initiated by the Department of Computer Science in 1997 as a two year postgraduate program leading to a Masters degree. Originally the program was funded by the *Deutsche Akademische Austauschdienst (DAAD)* within a project to attract more international students to Germany. Thus all core courses of the Master's program (but not the undergraduate program) are taught in English and are thus open to international students without knowledge of German.

The CE program is presently offered within Erlangen's School of Engineering (Technische Fakultät), which includes the Departments of Computer Science, Electrical, Chemical, and Mechanical Engineering, and the Department of Material Sciences. The mathematics courses of the curriculum are being taught by the Department of Applied Mathematics in the School of Sciences.

The Bachelor-Master structure of academic programs is still in an experimental stage in Germany. The traditional German Diploma degree still dominates and both faculty and (prospective) students view the new Bachelor or Master programs with considerable scepticism. Despite this, the CE program is currently accepting approximately 50 new undergraduate students and 40 graduate students annually.

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Formal Ph.D. programs are traditionally not offered within the German university system. However, sufficiently well qualified Master graduates are routinely being offered Ph.D. studentships and research assistantships by the faculty participating in the CE program.

2 Undergraduate Curriculum

The undergraduate curriculum consists of an approximately equal number of credits in computer science, (applied) mathematics, and an engineering discipline of choice.

Required courses consist of the traditional German four semester sequence in *Engineering Mathematics* which contains elements from calculus, analysis, linear algebra, and ordinary and partial differential equations(PDEs). Starting with the second year, students are required to take a two semester sequence in *Numerical Analysis*.

The core computer science courses are taken from Erlangen's standard computer science curriculum. CE students must take the two semester sequence *Algorithmik* that teaches the standard algorithms of computer science, data structures, programming languages, compilers, plus some elements of theoretical computer science. Additionally, students are required to take two semesters of *Organisation and Technology of Computers* and *Systems Programming* which include basic computer architecture and operating systems.

All students must choose a *Technical Application Field*. Presently, the program offers specialisation in

- Mechanical Engineering,
- Micro Electronics,
- Information Technology,
- Automatic Control,
- Thermo- and Fluid Dynamics,
- Material Sciences, and
- Sensor Technology.

Depending on the particular choice of the technical application, each student must take a sequence of 10 to 20 credits of application specific required courses. With specialisation in, for example, *Thermo- and Fluid Dynamics* the required courses are

- Elementary Physics,
- Thermo Dynamics (two semesters),
- Heat- and Mass Transfer, and
- Fluid Dynamics (two semesters).

Additional requirements are a 12 week internship in industry and participation in a seminar.

All courses listed above are taken from existing degree curricula. A new course, specifically designed for the CE program, is *Scientific Computing* (6

credits). This is the core required course in the second year and is aimed at teaching the specific techniques of computational science and engineering on an elementary to moderate level.

The specific emphasis of the present course is on practical and algorithmic aspects, rather than theory. Currently the contents are

- cellular automata (including lattice gases),
- solution of dynamical systems (initial and boundary value problems),
- basic visualisation techniques,
- elementary numerical PDEs, and
- iterative solution techniques.

Besides the core curriculum of required courses, students can and must select additional 10-20 credits from an exhaustive list of optional courses that can be taken either from the student's application field, Computer Science, or Applied Mathematics. Though any course from the conventional degree programs of the participating departments can be chosen, students are intensively advised and guided individually to enable them to find suitable combinations of courses. Any selection should primarily provide application oriented and practical skills. Typical courses for such a specialisation include

- Computer Graphics and Visualisation,
- High Performance and Parallel Programming,
- Pattern Recognition,
- Computer Networking,
- Advanced Numerical Methods (including numerics of PDEs),
- Finite Elements, and
- Optimisation.

Since the traditional German education system puts strong emphasis on independent, project oriented work, the final requirement is a project of three months duration and includes writing a short thesis.

3 Masters Curriculum

Graduate students are selected on a competitive bases from Mathematics, Computer Science, or a technical discipline. In a first *orientation semester*, students are required to take courses in

- Usage of Computer Systems and Operating Systems,
- Advanced Computer Programming and Data Structures,
- Computer Architecture,
- Numerical Mathematics,
- Scientific Computing, and
- an overview course according to the application field of choice.

These courses are designed to provide new students, who may come from quite different educational backgrounds, with a uniform basis of knowledge in basic CE techniques.

For sufficiently well qualified students, their participation in individual courses of the orientation semester, or even the complete orientation semester, can be waived. This will be routinely done for students coming from a computational science or engineering undergraduate program that conforms with our curriculum.

The main part of the Masters curriculum consists of a total of 38 credits of elective courses which should be taken within two semesters. A minimum of 10 credits must be taken from a technical application where the list of choices for the application field is the same as in the undergraduate curriculum (though only a subset is offered in English).

Sixteen credits must be earned in courses of advanced computer science and 10 credits in interdisciplinary courses which may be taken from either the technical application, Mathematics, or Computer Science. Required courses depend on the application field. As example, the required courses for a specialisation in Thermo- and Fluid Dynamics are:

- Numerical Fluid Mechanics,
- Applied Thermodynamics,
- Numerical Methods for PDEs, and
- Special Topics in Scientific Computing,

while courses like Visualisation, High Performance and Parallel Computing, Non-Newtonian Fluids, or Turbulence, are recommended optional courses. Participating in a seminar is also required in the Masters program.

As in traditional German Diploma degree programs, a strong emphasis is put on project oriented, independent work. A full six month period is therefore set aside for work on a Master thesis. The thesis topic may again be chosen from either the student's technical application, Mathematics, or Computer Science. An excellent thesis is usually considered as the primary prerequisite to being offered a Ph.D. studentship.

4 CE Specific Courses

As described above, the majority of courses in the Erlangen CE curriculum are taken from conventional programs. One notable exception is the *Scientific Computing* class that is mandatory in the undergraduate program and is part of the graduate student orientation semester.

The remaining courses of the graduate orientation semester are also specifically taught for the CE program. Thus, for example, the computer architecture class for CE can put more emphasis on high performance and parallel computing than the standard classes taught for Computer Science students, where computer architecture would be treated in more generality and breadth. Similarly, the numerical analysis class for the graduate CE program is specifically tuned for the

audience and puts more emphasis on algorithms and program development than on analysis and theory.

At the more advanced level, we have also begun to create new classes with the goal to better bridge the gap between the disciplines. These courses are interdisciplinary and are taught jointly by faculty from the different departments.

One such course is *Numerical Simulation of Fluids* which is taught jointly by Chemical Engineering and Computer Science faculty. Using [NFL] as the basic text, the course guides students to develop an incompressible Navier-Stokes solver and to adapt and apply their code to a nontrivial application scenario. The first half of the course has weekly assignments that result in a core 2D fluid simulator. The method is based on a staggered grid finite difference discretisation and explicit time stepping for the velocities. When the students have completed the core program, they form project teams of up to three to develop some advanced extensions of their choice. Typical projects include extending the 2D solver for 3D flows, handling free surfaces, adding heat transport and simulating buoyancy driven flows, advanced flow visualisation, or parallelizing the pressure correction step. For more details, see [NFLW].

A second course, which follows a similar pattern is offered jointly by Electrical Engineering and Computer Science. Here the goal is to develop a finite element program for simulating electrical fields. The emphasis is on code development using modern object oriented techniques, data structures for handling unstructured grids, and solution by iterative techniques.

5 Future Development

The University of Erlangen's CE program is one of the first such efforts in Europe. Within the past five years, the program has grown to respectable breadth and is attracting a substantial number of students from Germany and internationally.

However, the program is still clearly in the experimental phase and will continue to be adapted and extended. The discussion about what makes CE different from a traditional engineering discipline, (applied) mathematics, or computer science is still continuing. We have learned that composing a curriculum by simply combining existing courses from the participating departments can only be a beginning. Both graduate students and undergraduates need systematic courses to integrate the different components and to teach them truly interdisciplinary work.

The SIAM white paper on CSE [SIAM-CSE] defines the field as being primarily oriented at developing *new and improved methods* for problems and applications. The novelty of the application is secondary. However, engineers or scientists from the potential CSE application fields are primarily interested in solving new and interesting *problems*, even if they can be dealt with using standard computational techniques and tools. For them, developing new algorithms and software is secondary.

This conflict of interest is also visible in our current curriculum, where some application choices are primarily oriented at developing new methods and exploiting new computing technology, while others are primarily oriented at teaching a broad range of existing methods and tools within their application field. From our experience, this is a core issue that will continue to be a source of interesting discussions.

References

[ER-CE] Erlangen Computational Engineering WWW-Site:
http://www10.informatik.uni-erlangen.de/CE
[Guide01] Erlangen CE Study Guide (2001 edition):
http://www10.informatik.uni-erlangen.de/CE/officialdocs/ce_study_guide.ps.gz
[NFL] Michael Griebel, Thomas Dornseifer, and Tilman Neunhoeffer: *Numerical Simulation in Fluid Dynamics: A Practical Introduction*, SIAM, 1997.
[NFLW] Numerical Simulation in Fluids Web Site:
http://www10.informatik.uni-erlangen.de/teaching/NuSiF/Project.html
[SIAM-CSE] SIAM Computational Science and Engineering WWW-Site:
http://www.siam.org/cse/index.htm