60 YEARS

OF THE FACULTY OF MATHEMATICS AND PHYSICS
CHARLES UNIVERSITY IN PRAGUE

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faculty of mathematics and physics

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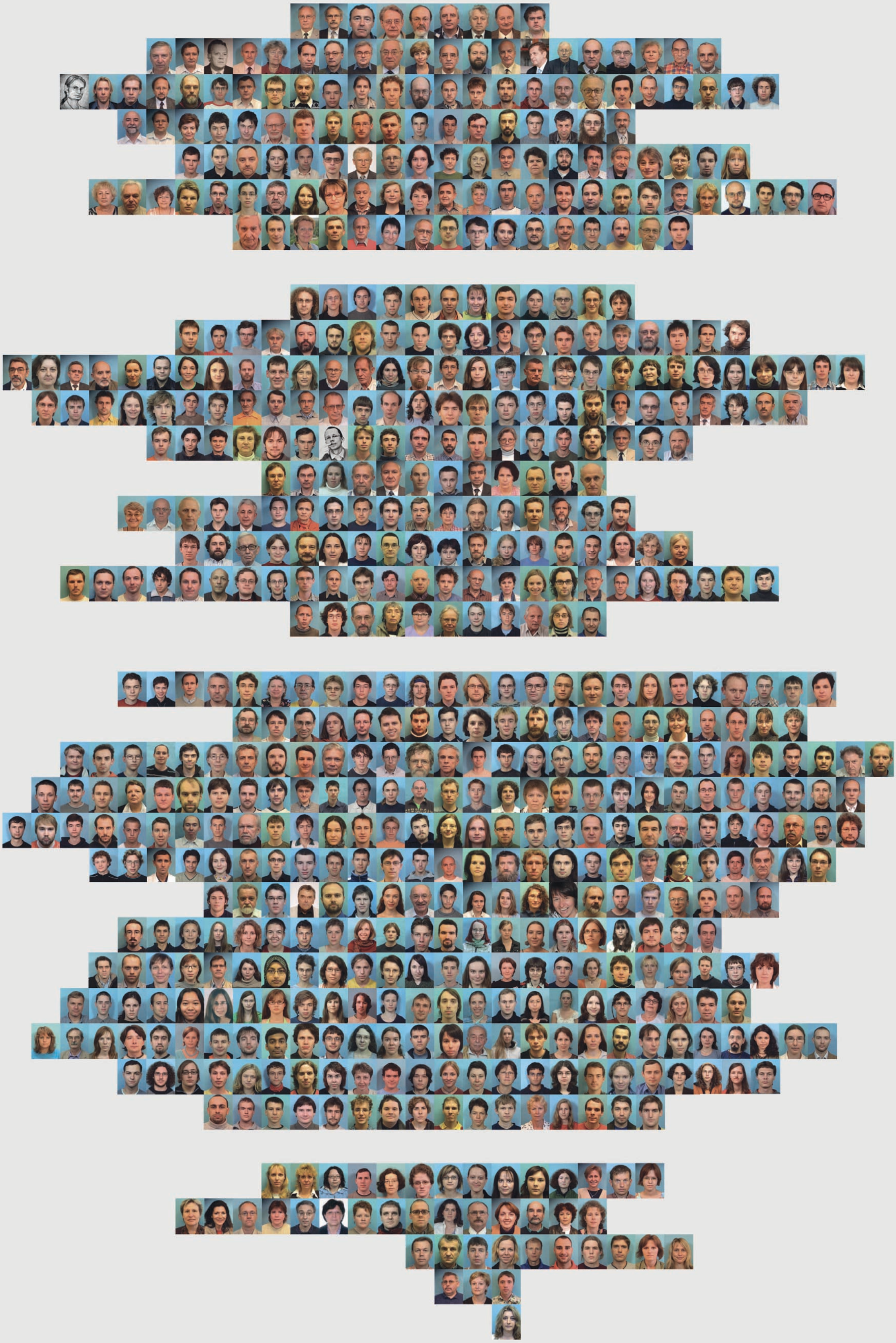

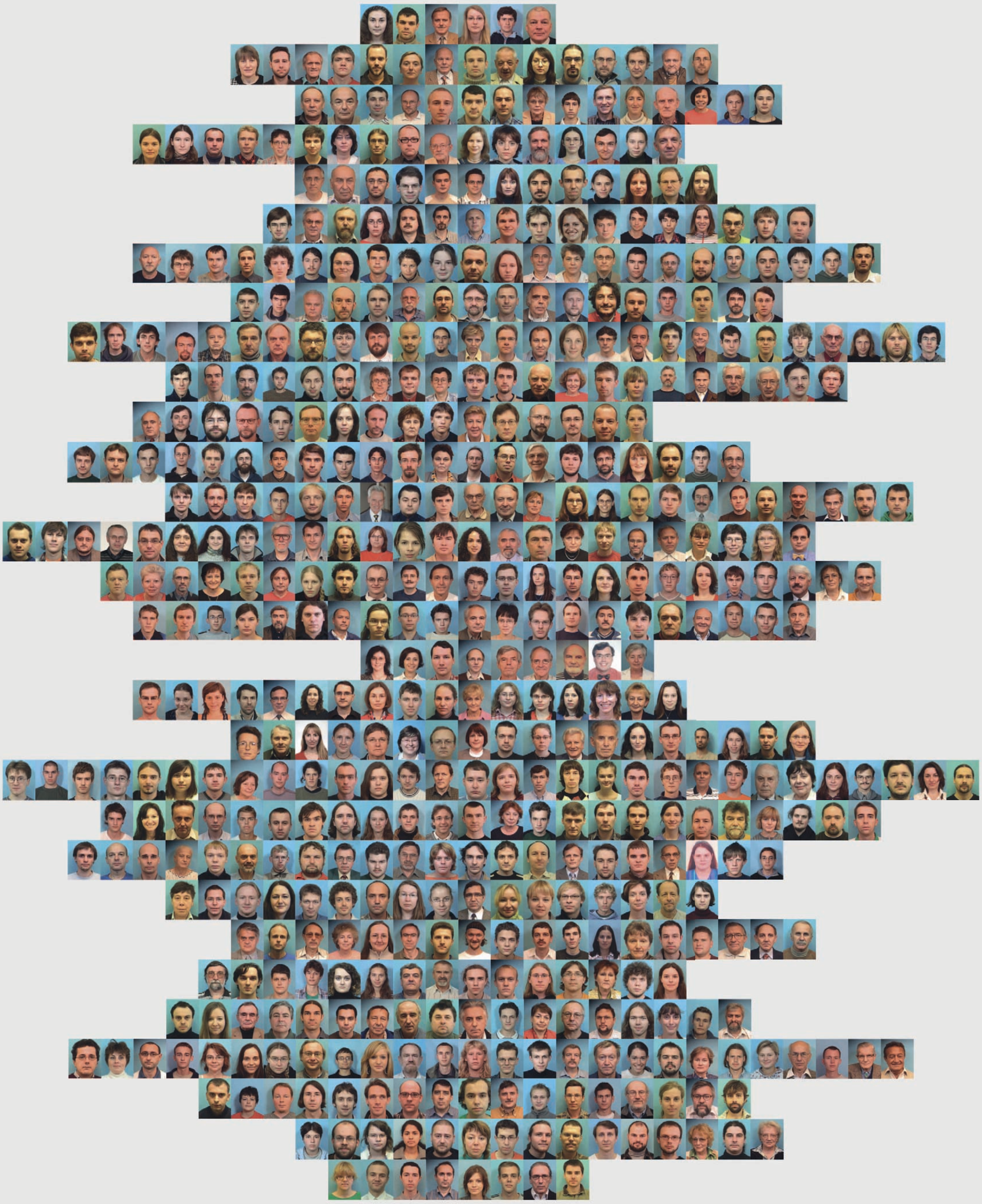

• About the Faculty of Mathematics and Physics and Its Management

Prof. RNDr. Zdeněk Němeček, DrSc. The Dean, after the election in the Academic Senate

The natural sciences have been a part of the research and teaching at Charles University since its founding in 1348. However, in the last century the explosive developments in the sciences called for, first, the establishment of the Faculty of Natural Sciences in 1920, and then the creation of a separate faculty for the pursuit of mathematics and physics; and on 1 September 1952, the Faculty of Mathematics and Physics was finally established by government decree. This Faculty was formed via the division of the Faculty of Natural Sciences, and the new Faculty of Mathematics and Physics was allocated in two buildings on Ke Karlovu street. The research and training program of the Faculty quickly expanded, and the buildings on Ke Karlovu soon proved to be inadequate. In 1960 the Faculty of Mathematics and Physics was given space in Malá Strana, and in 1961 took over a building in Karlín. The further development of the Faculty led to the decision to build a large-scale training facility of Mathematics and Physics in Prague 8, and in May 1968 its cornerstone was laid down. However, due to political developments construction was delayed until 1971, and in 1979 the part intended for physics was completed. At that time, it became clear that the bold plan to build a campus for the whole Charles University in Pelc-Tyrolka would not be realized, and only a few of the departments of physics were able to move to the new campus. The situation became static, new construction ceased and the most urgent needs for space were alleviated by emergency building conversions and extensions. In November 1989, after the velvet revolution and thanks to the unceasing efforts of the leadership of the Faculty, a beautiful loft conversion was made in the Karlín building and the building in Malostranské náměstí was completely reconstructed. These activities were impeded by floods in August 2002, when the newly reconstructed building in Karlín and some buildings in Troja were badly damaged. The affected buildings were quickly repaired and are now in even better condition than before the floods. Thanks to the assistance of the Ministry of Education, Youth and Sports, it was possible to move the helium liquefier and the new laboratories of low temperatures into the Cryopavilion on the Troja campus, which had been newly built outside the flood zone. Despite all these projects, which have gradually increased the usable space in our existing buildings by nearly 20%, the lack of space is still felt, particularly, in the mathematical part of our community. We, therefore, hope to start building a new pavilion on the Troja campus, which would solve space problems for some time.

From the previous text it would seem that the development of the Faculty was a mostly organic, constant growing of space for teaching and scientific work. I believe that the rest of the brochure, which you are currently reading, will show how much thought and research went into developing our Faculty. MFF UK has gradually evolved into a respected scientific institution, holding a leading place in our Republic. The word “matfyz” has become synonymous with excellence in science and education.

9 November 2011

prof. RNDr.
Jaroslav Pokorný, CSc.
Deputy-Dean and Vice-Dean for Research and International Affairs

prof. RNDr.
Vladimír Sechovský, DrSc.
Vice-Dean for Physics

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Vice-Dean for Computer Science

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Josef Štěpán, DrSc.
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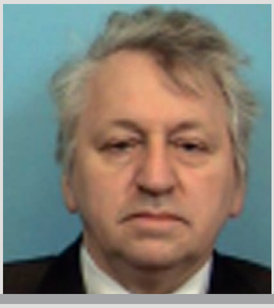

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Vice-Dean for Administrative and Academic Affairs

prof. RNDr.
Jiří Anděl, DrSc.
Vice-Dean for Students Affairs

doc. RNDr.
Pavel Svoboda, CSc.
Vice-Dean for Development

• Faculty Dynamics Since 2001

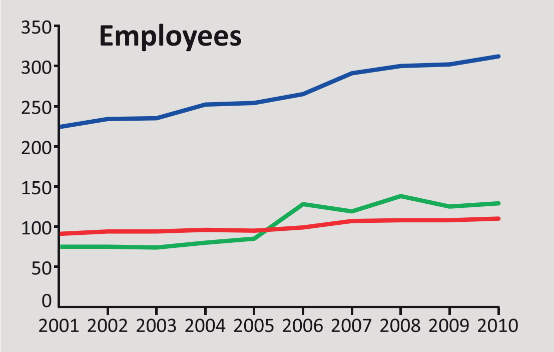
This page contains a quantitative view of faculty development over the last decade graphically illustrated.

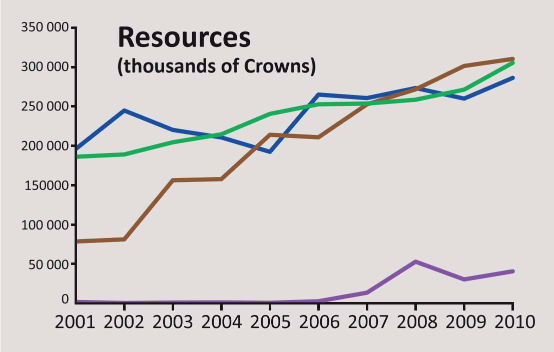
The first graph shows the **increase in the number of employees** in all sections: the physics section is represented by blue curve, mathematics by red and computer science by green. This pattern is used throughout the brochure.

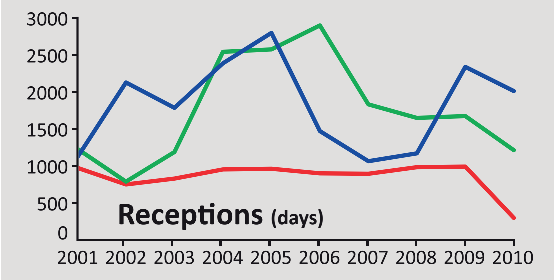
The second graph shows the **increase in financial sources** allocated to the faculty. Green stands for educational activities, brown for scientific and research funding (dependent on the scientific performance of the faculty), blue for special-purpose funds from the Czech Republic (grants), violet for special-purpose funds from abroad. About 1/3 of the total funds comes from the initiative of the faculty staff.

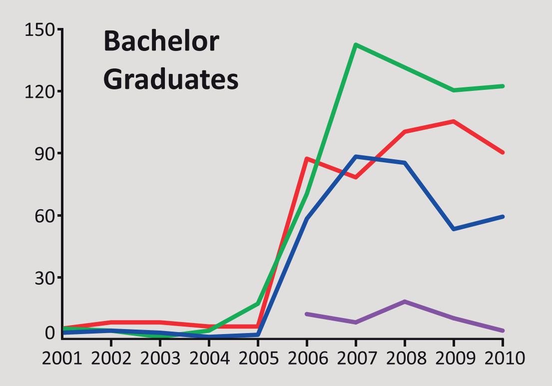
The mobility and quantity of international contacts is illustrated by the number of days for faculty employees at foreign institutes, as well as by the number of guests from abroad hosted by the particular sections of the faculty. The significant number of days physicists spend abroad corresponds to their work in foreign laboratories and their participation in international collaborations (experiments) common in the world of physics.

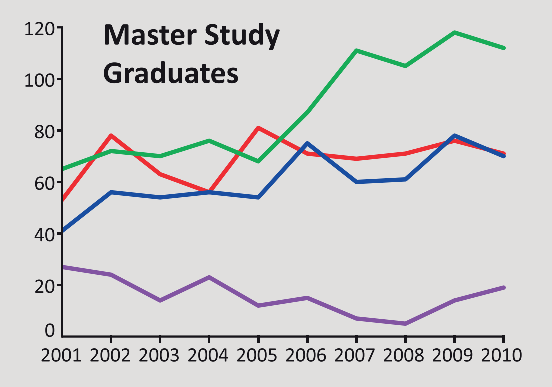
More detailed information about the function of the faculty can be found in the yearly faculty reports, see: **http://www.mff.cuni.cz/fakulta/tiskoviny/zpravy/.**

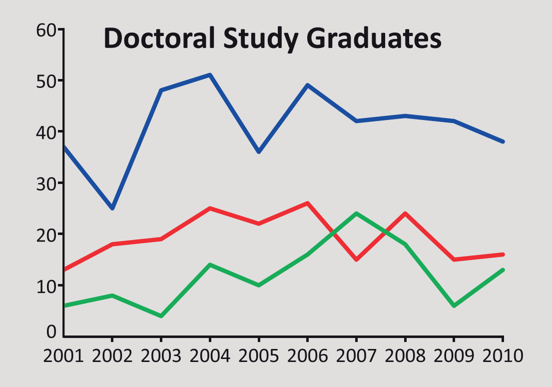


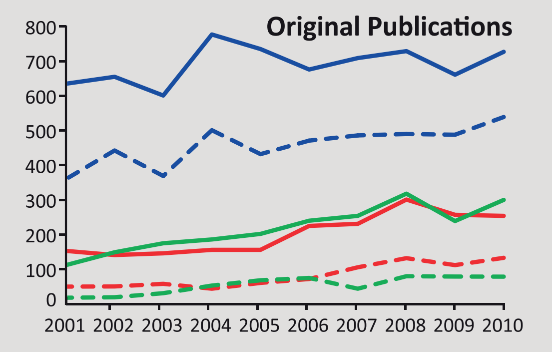












This page characterizes **faculty performance**. The first product of the faculty is its graduates.

The **number of bachelor graduates** rose rapidly in 2006. This was the first class of bachelor students who had graduated after the reform of university studies, in which university study programs were divided into bachelor study programs and follow-up master study programs. The color pattern is used as mentioned above (blue for physics, green for computer science and red for mathematics). Violet represents graduates from secondary school teacher education programs.

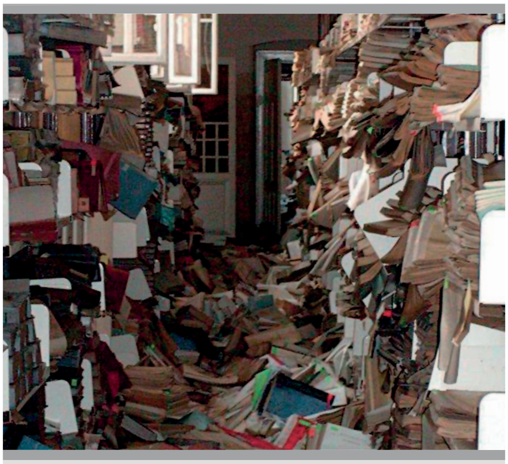
The number of graduates from master study programs rose only slightly in the last decade, the rise being most significant in the number of graduates from computer science. A lack of interest in teacher study programs is still apparent.

Apart from some minor fluctuations, the **number of graduates from doctoral study programs** remains stable. The significant number of doctoral graduates from the physics program visibly shows the tendency of physicists to proceed from bachelor, master to doctoral programs and then towards a scientific career in the Czech Republic or abroad. In contrast to the situation of bachelor and master graduates in mathematics and computer science, neither Czech industry nor other institutions seek bachelor and master graduates in physics.

The second product of the faculty is its original scientific results, which are quantified in the last graph displaying a rise in the **number of publications**. The dashes show the number of publications in journals with a non-zero impact factor. There is a slight but steady rise.

• The Development of the Faculty in the past 10 Years

Floods in 2002 – Troja campus
photo by V. Matolín



The consequences of the floods of 2002 – Karlín, library
photo by J. Antoch

In 2002 the Faculty of Mathematics and Physics, Charles University celebrated the 50th anniversary of its formation. At the same time the life of the Faculty was seriously affected by the consequences of the August floods. Two buildings of the Faculty (Sokolovská 83, Prague 8-Karlín; V Holešovičkách 2, Prague 8-Troja) were heavily damaged; most affected were the experimental physics laboratories, technological equipment and the libraries.

The total amount of the damage reached 141.5 million Czech crowns, of which 56 million represents the loss of library materials: the lending library for textbooks, the meteorological library in Troja as well as the mathematical-computer science library located in Karlín all experienced major losses.

About 13,000 books, 468 titles of magazines, 2,500 textbooks, over 4,000 higher education textbooks and 2,000 diploma master theses were destroyed; 6,000 titles were preserved in the Mochov refrigeration plants in Kladno. Ironically, the floods were a powerful impulse behind the new construction projects of the faculty that materialized through the following decade. Immediately, however, the damaged buildings were put into service on 15 October 2002; teaching started with only a two-week delay.

Reconstruction in 2002 cost almost 77 million Czech crowns; funding came mostly from the Ministry of Education, Youth and Sports, and from Charles University and the Faculty of Mathematics and Physics. The contribution of the Faculty was 10 million crowns.

The period following the floods was met with great solidarity from individuals, companies, institutions, etc., both domestic and foreign. By 31 December 2002 the Faculty had received 2.5 million crowns from financial donations, 2 million crowns of which went to the restoration of library materials. Of paramount importance to this effort were the many gifts of mathematical literature made to the University.

The first renovated physics laboratory, Laboratory of Karel Urbánek photo by P. Svoboda

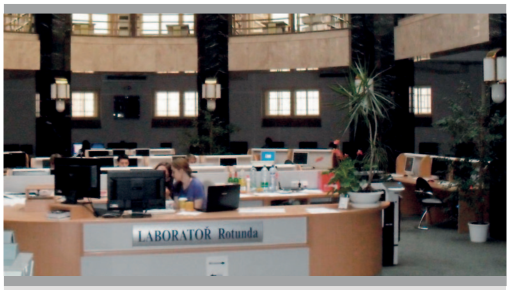
As years went by

2002

During the year 2002 the first period of reconstruction of the faculty building in Malostranské náměstí was completed. The sports complex and the tennis courts in Albertov were reconstructed.

2003

A significant part of the reconstruction work in 2003 meant not only cleaning up of damaged sites after the floods, but fundamentally changing the use of the affected buildings and significantly improving the work environment of staff and students.



Rotunda Computer lab photo by P. Svoboda

The year 2003 was quite exceptional in the fact that the Faculty managed to obtain and in large part to use many other financial resources, in particular for the initiation of two entirely new projects – the construction of the Pavilion of Cryogenic Techniques and the reconstruction of the hall of heavy laboratories.

With the significant contribution of the Foundation of Karel Urbánek, a former graduate of the Faculty of Mathematics and Physics and an important personality in the US semiconductor industry, the reconstruction of the physics laboratory in Ke Karlovu 3 began; now completed, it bears the name “The Laboratory of Karel Urbánek”.

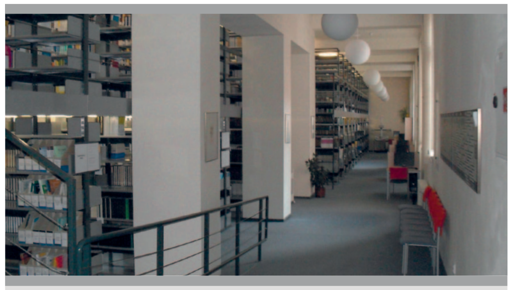
Meanwhile, during the reconstruction of buildings in Malá Strana frescoes in the refectory, and later the rotunda of St. Wenceslas were discovered which helped accelerate reconstruction of the building. At the end of 2003 the Rotunda computer laboratory was completed.

In Troja a photovoltaic power plant was installed on the building of heavy laboratories.

2004

In 2004, extensive reconstruction following the floods in the building at Karlín were completed (the mathematical section of the faculty library, a gym, and interiors were newly constructed), and the second stage of the reconstruction of the Malá Strana building (the computer science section of the faculty library, computer labs, and catering facilities in the basement) was completed.

View from the Rotunda lab to the newly built library in Malá Strana, photo by P. Svoboda



The newly built library in Karlín, photo by P. Svoboda

The building of the faculty in Malostranské náměstí, photo by P. Svoboda

The Cryopavilion building in Troja, photo by P. Svoboda

Building reconstruction also took place in the premises of Ke Karlovu 3 and 5; in the Troja campus the reconstruction of the heavy laboratories hall, enabling an entirely new use of the original space, was completed.

A very important event in the life of the Faculty in 2004 was the opening of a completely new computer science section of the faculty library in the Malá Strana building.

2005

The most expensive project in 2005 was the reconstruction of the historical building in Malostranské náměstí including the reconstruction of a transformer station. At the same time the project documentation for the reconstruction of the interiors and the subsequent restoration work was prepared.

The most important building project of the year 2005 was the completion of the Pavilion of Cryogenic Techniques ("Cryopavilion"), where the new helium liquefier was installed and where the physics laboratories requiring a steady supply of liquid helium were moved. The original liquefier in the heavy laboratories building was completely destroyed in the floods in 2002, and the new location of the Cryopavilion was chosen outside the flood area.

In Ke Karlovu 3 the construction of new lecture rooms where former physics laboratories of didactics of physics had been located was completed.

2006

In 2006, work on the interiors began in Malá Strana. Repair of the building facade was completed in Karlín together with new insulation of the passageway.

In the Troja campus the temporary repair of the facade of the departmental building and the roofs of the developmental workshops was completed; and, as a number of workplaces in the departmental building and heavy laboratories building had been relocated, the opportunity was taken to reconstruct some of the floors. In Ke Karlovu 5 one of the lecture rooms and physics labs in the basement were reconstructed.

In 2006, the Faculty, with particular thanks to the efforts of Prof. Tichý and Doc. Svoboda, managed to obtain significant funding (over 20 million CZK) from the Development Programs of the Ministry of Education, Youth and Sports, which was used to install a wireless wifi network, allowing the use of the eduroam infrastructure in the Faculty buildings.

Thanks to the favorable situation at the Ministry of Education, Youth and Sports at the beginning of 2006 the Faculty was asked to promptly submit additional development projects, which made it possible to equip all lecture halls and lecture rooms of the Faculty with data projectors, and large lecture halls with audio technology.

Even the Study Department of the Faculty was equipped with new communication technology, which has led to the improvement of communication with students. A part of the funds from the Development Programs of the Ministry of Education, Youth and Sports was also used for the organization of events leading to the recruitment of talented young people for studies at the Faculty.

The reconstructed faculty building in Karlín, photo by P. Svoboda

The organ in the faculty auditorium in Malá Strana, photo by J. Šaroun

The reconstructed building Ke Karlovu 5, photo by P. Svoboda

The reconstructed building Ke Karlovu 5 – view of the courtyard, photo by P. Svoboda

The reconstructed lecture room of Čeněk Strouhal (F1) Ke Karlovu 5, photo by M. Vlach

2007

In 2007 there were intensive negotiations between the 1st Faculty of Medicine, the Faculty of Natural Sciences and The Faculty of Mathematics and Physics concerning the new form of the Albertov campus. Finally, it was decided to build two centers there – the Center of Global Changes and the Bio-Center, both of which count on the strong participation of the Faculty departments. At the end of the year Charles University commissioned the preparation of an architectural study.

The number of building projects, which the Faculty had undertaken in previous years, decreased slightly. However, the repair of the facade of the building Ke Karlovu 5 started, and a new parking lot in the Troja campus was built.

In 2007, the construction and installation of the organ in the auditorium of the Faculty of Mathematics and Physics (former "refectory") in Malostranské náměstí was completed successfully.

Reconstruction of the physics labs necessary for relocation to the Troja campus, and the building Ke Karlovu 5 were completed.

With the help of Development Programs of the Ministry of Education, Youth and Sports the installation of the wifi network and connection to eduroam infrastructure for the entire faculty was completed. In the summer of 2007, the wifi network was successfully installed in the University Training Centre at Albeř, where the entrance workshop of 1st year faculty students is traditionally held.

2008

2008 marked the 100th year since the opening of the building of the Institute of Physics, Charles University at Ke Karlovu 5. For this happy occasion the exterior appearance of the building was restored and a considerable part of the interior was repaired. Celebrations of 100 years of physics in Karlov, which took place on 30 September, opened the new academic year 2008/2009 with dignity.

Repairs at Ke Karlovu 5 were not the only building activities. In the Karlov campus an elevator was finally installed after much delay in Ke Karlovu 3, making the building accessible for people with reduced mobility. This was followed by the generous reconstruction of the courtyard behind the building, through which wheelchair access leads.

In Troja campus the long delayed reconstruction of the exterior mantel of the departmental building formally started. The project which spread over three years was completed in September 2010; the total expenses exceeded 150 million CZK.

The regular operation of the refectory (Auditorium of the Faculty) in the building in Malostranské náměstí started; since September 2008 the Bachelor's graduation ceremonies of all the University faculties have been held there.

In 2008, the repair of the roof and facade of the Institute of Physics building in Ke Karlovu 5 was finished. At the same time internal adjustments and repairs of the Institute of Physics building and reconstruction of the Institute of Physics workplaces and of the Department of Chemical Physics and Optics started.

In the building of the Mathematical section in Karlín a new study workplace – the Respirium, was built.

Within the framework of the Development Programs of the Ministry of Education, Youth and Sport in the year 2008 the project for a high capacity student's data storage started, continuing through the years 2009 and 2010.

The reconstructed refectory – Auditorium of the Faculty, photo by J. Šaroun

The elevator in the building Ke Karlovu 3, photo by P. Svoboda

The courtyard Ke Karlovu 5 after reconstruction serves as a parking lot, photo by P. Svoboda

Newly reconstructed Physics laboratory I, photo by P. Svoboda

New floors in corridors in the building Ke Karlovu 5, photo by P. Svoboda

2009

The most important building project in 2009 was the first stage of the reconstruction of the departmental building facade in Troja. Replacement of the mantel on the south side was inspected and passed in November. Furthermore, improvements of internal courtyards of Ke Karlovu 3 and 5, and Sokolovská 83 were also completed and inspected, as well as improvements of the basement and ground floor in Ke Karlovu 3 and 5.

Faculty development is, however, unimaginable without further construction. In this respect, the locations of Troja and Albertov seem to be the most promising. For the preparation of construction in the Albertov site a working group consisting of one representative from each involved faculty was appointed. The Faculty of Mathematics and Physics is represented by P. Svoboda. The use of University land in this location is complicated by the involvement of the Prague 2 city council, which states that all building-free areas are available to the public. With this in mind, a new land-use plan has been worked out. The Faculty of Mathematics and Physics, together with the Faculty of Natural Sciences raised objections against this plan within the relevant deadline.

In 2009, repairs and reconstruction of the lecture room F1 and physics laboratory in Karlov, and lecture rooms in Troja were carried out.

Repairs and reconstruction of technical and technological equipment of buildings, in particular in the Troja campus, were carried out through the year. The outdoor areas of Ke Karlovu 5 and Sokolovská 83 were completed.

2010

The favorable financial situation of the Faculty in 2010 enabled it to carry out a series of building modifications aimed at improving the working environment and the comfort of workers and students of the Faculty. Reconstruction of the building Ke Karlovu 5 was completed and new ceramic floors were laid in all the corridors of the building. The floor tiles were produced specially so as to respect the historical appearance of the building. In the same way the doors which had been in use for the past fifty years were replaced by replicas of the original doors. Improvements to the green areas around the building were completed by roofing the terrace.

Another significant event was the completion of the replacement of the departmental building's mantel in Troja. When the building was finally brought into service by the company "Unistav", all who had participated in the project agreed that the demanding construction, worth approximately 140 million crowns, had passed without problems and that the company had tried to meet the requirements of individual workplaces with a minimum of disruption. The result of the reconstruction from the point of view of staff comfort exceeded expectations; the energy savings will be calculated later.

Repair of the Physics Laboratory III was carried out. This action included not only extensive modifications, but also the installation of a walk-in closet with new workplaces and storage space.

2011

As the current space situation of the Computer Science and Mathematical section in the buildings in Karlín and in Malá Strana is fairly tight, and any building extensions at those places are not feasible, the Faculty is looking for alternatives.

In view of the fact that the construction of the Bio-Center and Globcenter in Albertov is not certain, the leadership of the Faculty has proposed another way out, namely the construction of the Pavilion for the Computer Science and Mathematical section (in the current premises) in the Troja campus.

New pergola in the garden part of the courtyard Ke Karlovu 5 as a place for informal discussions in a quiet environment, photo by P. Svoboda

The south side of the reconstructed mantel of the departmental building in Troja, photo by P. Svoboda

Visualization of the planned Pavilion in Troja, visualization: Ing. Arch. J. Jaroš

Albertov slopes after removing self-seeded shrubs, photo by P. Svoboda

Renovated tennis courts, photo by P. Svoboda

Physics laboratory IV, Ke Karlovu 3, just before the opening ceremony, photo by P. Svoboda

The development of the Faculty also includes the care of the campuses' environment: in the autumn of 2010 the Faculty was asked to help with the cleaning of the Albertov slopes; the slopes were covered with self-seeded shrubs and at the bottom of the slopes were spreading invasive fallopia.

In the winter at the beginning of 2011, it was decided to proceed with the first stage of the rehabilitation of Albertov slopes - to remove the shrubs and clean up the slope. The whole action took place after the agreement of the three faculties, the Faculty of Mathematics and Physics, 1st Faculty of Medicine, and the Faculty of Natural Sciences, in cooperation with the environmental division of Prague 2.

The politicization of discussions about the appearance of the slopes prompted the management of the Faculty to relinquish further care of the slopes to the Faculty of Natural Sciences.

Then, in the first half of the year attention shifted to repair of the tennis courts; the initial work in 2002 had not been completed owing to the consequences of the flood and the urgent need to act quickly. In spring 2011, the tennis courts, which the Faculty uses intensively, were repaired.

Work during the summer of 2011 was focused on emergency repairs of drain-pipes around Ke Karlovu 5 and in the courtyard of a building in Karlín, and also on repair of the dire state of the facade of Ke Karlovu 3.

One of the most important events of the year 2011 was the final period of reconstruction of the physics laboratory Ke Karlovu 3. The opening ceremony was 10/10/2011, and students of the physics disciplines can now use a laboratory at the elite level. It includes the basics of experimental physics, from historical apparatuses to up-to-date instruments and methods.

The reconstruction of the cooling system in the departmental building in Troja was the jewel of the maintenance projects in this campus. The repairs took place with the minimum disruption to work, and was completed within the planned budget and according to schedule in October 2011.

The reconstruction of the cooling system took place at the same time as the face-lift of the space around the non-functional cooling towers in Troja campus. As a protected monument they were incorporated into the park among the buildings according to the design of Ing. Arch. Jaroš.

In the second half of 2011 the Physics section initiated the preparation and partial implementation of projects aimed at long-term energy savings. The most important of these is the preparation of geothermal boreholes in courtyards Ke Karlovu 3 and Ke Karlovu 5.

These boreholes should serve for accumulation storage of heat waste into the subsoil during the year and allow for its use for heating buildings in winter. In the summer of 2011, in both areas a test drilling was made and an analysis of the thermal properties of the geological bedrock was conducted. On the basis of the results of this analysis the Physics section proceeded with the drilling at the end of 2011. The second stage, fitting the heat pumps, will follow in the first half of 2012.

Reconstructed courtyard of the building in Karlín, photo by P. Svoboda

Repaired facade of the building Ke Karlovu 3, photo by P. Svoboda

Cooling towers in Troja and their surrounding just before the completion of adjustments, photo by P. Svoboda

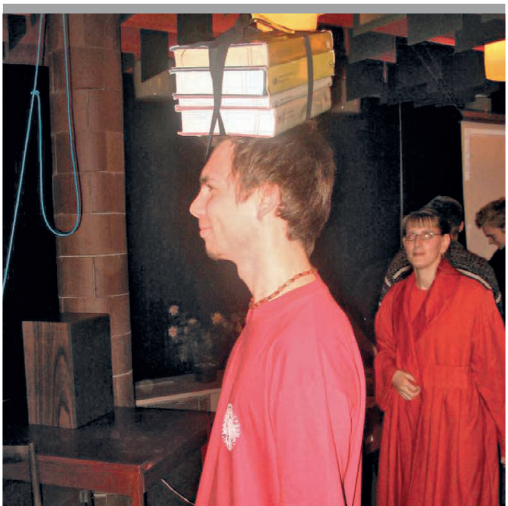
• About Our Students

"Beánie and Jarníkization"

The most important part of "**Beánie**", or the ritual to welcome new Math-Phys students by old ones, is the ceremony of "**Jarníkization**". Vojtěch Jarník was a significant Czech mathematician, and also the guru of our institution. Besides this he left a five-volume textbook of mathematical analysis for our times which, despite the somewhat archaic style and arduous precision of all his expressions, is still popular among some Math-Phys students, if not as a competent textbook then at least as a certain symbol of our status.

It is said that to be "Jarníkized" is a necessary condition for completing the Math-Phys faculty, but not a sufficient condition.

More at **http://spolek.matfyzak.cz**



This article is meant to complement the others, but instead of famous professors and scientists it will present a report on the largest part of the academic community, the students. However, capturing the essence of the "student of the Faculty of Mathematics and Physics" is really a hard nut to crack.

First I would like to focus on the environment that academics and other staff of the Faculty create for us. The first word in my mind is "expertise", the second "respect". Others will surely write here about expertise but to not mention this first is something I cannot do. The second is respect, which I encountered at every meeting I have had at the Faculty. In the first year, students often smile at being addressed as "colleague", which is usual among professors, but this respectful treatment certainly does not end with a salutation. Whether it is helpfulness, keeping one's word, or just common decency, the majority of faculty staff significantly exceeds the current standard at universities.

When professors of outstanding merit meet with young students, inequality of position and knowledge recedes before respect and equity. Associate Professor Emil Calda beautifully captured this sentiment with these words: "The road to mathematics is not royal, but on the other hand you won't get run over by a …" I shall leave it to the readers to fill in the missing word themselves.

I must mention here the activities directly related to the Faculty. The Association of Friends of the Faculty, our "Matfyzák", has many analogies at other faculties, but on closer inspection you will be amazed how successful its events are. Also, it is surprising how many students bought clothes with the faculty logo from our Association. At how many faculties can you meet students declaring support for their alma mater with their clothes?

There are also corresponding seminars of MKS, FYKOS, KSP, and others. These are annual professional competitions for students of high or elementary schools organized by students of our faculty. The oldest of the seminars has existed more than 30 years now and its former organizers can be found among the current professors. Perhaps this paragraph can be summarized by saying that our students are eager to be involved in something valuable apart from their studies.

But what is the student like as a person? Every university is mostly based on self-study, on the ability of students to work and educate themselves independently, voluntarily and beyond the call of duty. If we take this as the essence of education, then it is carried out at our faculty with great dignity. One of my fellow students wrote, for example, a very high-quality Bachelor thesis, accepted then as a professional article. Later she was laughing with us over a letter where the editor addressed her as “Professor”. Another of the students leads a mathematical seminar in his home-town high school, which raised a number of successful Mathematical Olympic competitors. Another in his spare time studies the philosophy of Professor Petr Vopěnka. I regret that there is not enough space to mention the merits and achievements of the many others. But what I cannot forget is the variety of specializations. Winners of the Olympics in physics or mathematics will probably not surprise you, but how about a junior player of the Czech national team in curling? At our faculty I have met musicians, conservatory graduates, organizers of cipher games, Sokol members, active members of different churches, young politicians, and top athletes. A large part of our student body studies a second university in their free time, such as economics, law, or art.

I hope I have described at least a bit the spirit of students at our faculty, which teaches us to learn and mainly to think. I do not know whether or not my friends and colleagues from the ranks of students will succeed in our dynamic society. I do not know how much of our knowledge will make it easier for us to get a job and ensure success. However, I can see so many great personalities that arose from our faculty, who were our former students! And when I look at the current students, I believe there will be others.

Tomáš Roskovec

A Math-Phys cookbook

In this cookbook you won’t find a recipe for lamb ragout, because it is too complicated. But there are recipes for survival at Math-Phys. We do not want to deprive you of the magic of discovering what it means to be a student of Math-Phys. On the other hand, instead of success it can bring you a lot of embarrassing situations and unnecessary loss of time. This guide to the Faculty of Mathematics and Physics, the dormitory of 17 November, the Prague public transport system, etc. therefore came into being for those of you who do not want to bother with finding out everything themselves.

See **http://kucharka.matfyzak.cz/**, **wiki.matfyz.cz**, **forum.matfyz.info**, **www.matfyz.info**

An **introduction to the Math-Phys student** can be found on the Internet: “…at first glance the Math-Phys student does not differ from other people. He/she has one head of normal size, two similar eyes, something around thirty-two teeth, altogether 20 digits evenly distributed along the body, washes his/her feet, and has regular bowel movements. But on closer examination you can find various differences…”

Sport and Albeř

A fundamental part of the 60-year history of the Faculty of Mathematics and Physics is sport. National champions in team foil fencing, a medal from the national championship in canoe slalom, the men's volleyball team in Extraleague, outstanding results of orienteers in the national rankings and a medal from the World Championship in orienteering – this is the inevitable culmination of the popularity of sport among students, employees and graduates of the Faculty.

But far more important than a random mention of the top results are the results on a basic level of sports. Thanks to the outstanding work of the members of the PE department, many students and staff including their families learned sports from scratch. And the level they have reached is not insignificant.

There have been, for example, hundreds of ski instructors trained, many students and staff had or have the possibility to experience the wonders of hiking and canoeing, the beauty of skiing, to participate in teams of basketball, volleyball, softball, tennis, table tennis and orienteering, to improve

Department of Physical Education

Physical education instruction at the Faculty of Mathematics and Physics is provided by the Department of Physical Education, which is housed in a newly reconstructed sports center in Prague 10-Hostivař. This is the location of most of the sports facilities where physical education takes place: a swimming pool, sauna, multi-purpose sports hall, fitness center, a gym for combat sports, and halls for teaching aerobics. There are also two inflatable halls where volleyball, tennis, basketball, and floorball are taught, and a special tennis hall. Outdoor sports facilities include tennis courts, a grass soccer field and a softball field. Physical education is also held at the Faculty's own sports grounds – tennis and volleyball courts on the Faculty campus in Albertov, and a table tennis hall and gym in Karlín.

their motion with competitive gymnastics, and one of the most praiseworthy achievements is that a lot of non-swimmers at the Faculty learned to swim. Among the very popular activities have been and still are hiker gatherings, canoeing courses, and skiing courses for both students and employees and their families. Also very popular are championships in basketball and volleyball in which teams of students from the same year compete (in this case also with the participation of teams from previous years), etc. In the early days sports at the Faculty were organized only spontaneously or as part of the sports club "Slávie Vysoké školy Praha". Gradually the number of athletes increased so much that in 1962 the Faculty founded its own sports club "MFF Prague". At the constituent's meeting the Czech Academy of Sciences member Kořínek, a passionate sportsman, even took part. Currently the Club has 12 sections and more than 400 members, all of whom with a few exceptions are students, employees, or graduates of the Faculty.

Of great significance for sports at the Faculty are the facilities it has at its disposal. These are innumerable, but two of them I consider most important. The first are the tennis and volleyball courts in Albertov. These sports grounds, back when the Faculty was still only in two buildings in Karlov, were for staff and students the closest and thus were thoroughly used. In particular, volleyball has become such a popular sport at the Faculty that, in the history of this sport, the faculty club VŠSK MFF is without parallel in the Czech Republic. Nowadays the club is represented in national competitions by 7 men's teams and 4 women's teams. The teams have always been purely amateur and all players consider as the main award the fact that they could play for Math-Phys.

However, the most precious sports facility, and not only for sports, is the summer training center Albeř. This camp was discovered by a five-member group of then university PE department members in 1959 (from MFF Jirka Adamíra and Kopal). Let me quote Jirka Adamíra on this significant moment:

"It was 6 May and a beautiful day. And so this site of the future camp made a great impression on the group. Back then there were no windfallen trees at the pond, and the pond was hidden from a distance. All the greater was our surprise and astonishment when we got to it. It looked like a Canadian lake in the middle of untouched wilderness. Then followed a thorough inspection of all adjoining areas which, when imagining the future camp, brought us literally to ecstasy."

Those who have experienced Albeř will fully agree with these words. In 1960 at the behest of the MFF, children's camps were organized for children of university employees , and family recreation for university employees, both predominantly with sports; and in September the assistant Zdeněk Malý organized the first week-long sports camp. All these events still take place today. At the Faculty the popularity of Albeř is huge, thanks in particular to the conditions it provides for sports. Let me quote my favorite saying: "The owner of Albeř is Charles University but it belongs to Math-Phys." The Faculty has even used this sports facility since 1983 for entrance workshops of future 1st year students, and since 1990 has been the site for registration of 1st year MFF students. Students thus get acquainted with the camp and a vast majority of them enjoy the place before they begin to study. It is true that the camp at Albeř in its 52 years of existence has changed beyond recognition from a "backwoods camp" to a place of sport, recreation and intense discussions.

The possibility to do sports for students and staff of the Faculty continues. The increasing number "VŠSK MFF" club teams and club members prove that these possibilities are widely used. Big credit for this goes to the Department of Physical Education, always employing top experts in various sports branches. Their qualities guarantee a high standard of events for students as well as for candidates from among the staff and their families. *(Jan Kašpar)*

• Public relations and publicity

The MFF helps arouse the interest of high school students, support a thirst for knowledge, develop talent, and take the first steps on the road to science through a system of promotional and PR activities.

Most of the activities involve both educational departments: the Department of Physics Education and the Department of Mathematics Education – for example, “Physweb”, Experiments in Physics for High Schools, Idea Fair for Physics Teachers, History of Mathematics, and a Seminar on Philosophical Issues of Mathematics and Physics. Other activities are offered by specialized workplaces such as the Institute of Theoretical Physics, which every year offers a course of Lectures in Modern Physics; the Department of Software and Computer Science Education organizes the School of Computer Science Teachers, and there are others.

The entire faculty is presented each year at the Open House; for 15 years now there has been One Day with Physics, and more recently One Day with Computer Science. These days are filled with lectures, excursions, experiments, presentations, demonstrations, tours of state-of-the-art equipment in scientific workplaces, and unusual encounters with physics or computer science in historical buildings in Karlov, Malostranské náměstí, or Troja campus.

Information about all public events can be found on the website:
http://www.mff.cuni.cz/verejnost/

Open House offers lectures and excursions and provides comprehensive information about studies at the faculty, where most of the departments introduce themselves and attract interested people.

Children and their parents or grandparents are the focus of the light and playful event called "Prague Playing with Science", usually held on Children's Day.

Robotic Day is full of contests.

Faculty staff organize several 14- to 25-day camps, summer or winter specialized camps or schools of mathematics and physics in which about 100 high school students and 25 pupils annually participate.

The Faculty has a very long tradition of correspondence seminars which are organized by faculty students for their younger future colleagues. There is a Correspondence Seminar in Mathematics (31st year), Correspondence Seminar in Physics (FYKOS) (25th year), Correspondence Seminar in Programming (24th year), a multi-disciplinary seminar M&M (18th year), mathematical correspondence competition for pupils in elementary school grades 6 to 9, and similar grades at multi-year grammar schools "Pikomat MFF" (27th year), as well as the most recent "Pralinka" (3rd year). Correspondence seminars also organize workshops for their participants where distance communication is supplemented with personal contact.

Correspondence seminars represent thousands of hours of collaboration over verbal tasks and thousands of hours of interpersonal and professional communication. Annually there are 11 one-week workshops for about 20 high-school students with 10-12 organizers; on average 35 series of about five mathematical problems and tasks, mini-schools of programming, and camps not only for participants in "Pikomat MFF". About 600 high-school students a year are involved in these activities. And in the competitions "Náboj", "Fykosí fyziklání" and "Maso" (teams of secondary and elementary schools) some 180 school and mixed teams are involved. Correspondence seminars offer contact with mathematics, physics and computer science to students from all over the country. This way our students contact and cultivate new potential students…

School of Physics

Physical research at the Faculty of Mathematics and Physics, Charles University is varied, ranging from the micro-world up to universe, includes basic research and applications, and produces high-quality work in all these areas.

The School of Physics has approximately 300 employees, of which 100 professors and associate professors, and 100 researchers. The breadth of the scientific concerns at the School is shown by number of keywords on the opposite page as well as the departments and subjects listed on the following two pages. The School publishes over 700 scientific articles per year, often the results of international cooperation.

In a number of physical specializations a fruitful cooperation exists between the physicists of the Faculty and colleagues from other universities and institutes in the Czech Republic, and the Academy of Sciences of the Czech Republic. There is a rich tradition of scientific cooperation; the participation of colleagues from the Czech Academy of Sciences in various examination commissions is quite common; and welcome, though unfortunately less frequent are the lectures they sometimes present.

Employees of the School spend about 14 thousand days a year abroad in intensive international cooperation, especially when going to do experiments in foreign laboratories. The time that foreign workers spend with us is almost seven times shorter.

Physics at the Faculty is studied by more than 300 students in bachelor's studies, around 150 students in master's studies and almost 400 students in doctoral studies (including those who the Faculty administratively takes care of and ensures their teaching, but who work in institutes of the Czech Academy of Sciences). Doctoral students and their work are annually presented during the Week of Doctoral Students.

modeling general theory of relativity plasma

amorphous materials the ATLAS experiment Mössbauer spectroscopy

neutron diffraction quantum chemistry metal-hydrides

low temperatures helioseismology climatic changes positron annihilation

magnetooptics excitations in condensed systems polymers

magnetic semiconductors the Belle experiment FyzWeb planetoids

molecular engines multiferroics physics of materials spintronics

high pressures synchrotron-radiation interaction with matter magnetic nanoparticles

geomagnetic storms biophysics nuclear magnetic resonance gamma flashes

nanocomposites geophysics multifunctional materials µSR spectroscopy thin films

photonic crystals quantum chaos optoelectronics high magnetic fields

electronic properties of materials optical spectroscopy Raman spectroscopy

magnetic multilayers infrared spectroscopy nuclei and particles superplasticity

molecular simulations electron microscopy the ELETTRA synchrotron

photovoltaics cryogenic dynamics of liquids phase transitions

photoelectron spectroscopy composites solar wind the LHC accelerator

magnetism and superconductivity neutron spectroscopy the ThALES spectrometer

physics for teachers, children and public catalysts X-ray spectroscopy

crystals shape-memory materials magnetocaloric cooling

ab-initio electronic-structure calculations quantum turbulence superfluidity

quantum critical phenomena electron diffraction X-ray diffraction

semiconducting detectors

• School of Physics

V Holešovičkách 2, Praha 8-Troja

Departments in the building:

Astronomical Institute of Charles University
Department of Physics Education
Department of Surface and Plasma Physics
Department of Low Temperature Physics
Department of Macromolecular Physics
Department of Geophysics
Institute of Particle and Nuclear Physics
Department of Meteorology and Environment Protection
Institute of Theoretical Physics

Topics:

• School of Physics

Ke Karlovu 5, Praha 2-Nové Město

Departments in the building:

Institute of Physics of Charles University
Laboratory of General Physics Education
Department of Physics of Materials
Department of Condensed Matter Physics
Department of Physics and Optics

Topics:

• Astronomy and Astrophysics

From the solar system via the Galaxy to cosmology

Astronomy found its place at Charles University soon after the University's foundation in 1348. Through the years many important personalities have worked there, including Johannes Kepler, Jan Marek Marci, Ernst Mach and Albert Einstein. The current Astronomical Institute of Charles University, established in 1886, is among the oldest of the university institutes.

The Astronomical Institute of Charles University cooperates with many other research and teaching centers in the Czech Republic (institutes of the Academy of Sciences, universities) and with significant observatories in Europe and throughout the world. The employees of the Astronomical Institute are involved in international scientific projects, represent our country in editorial boards of leading scientific journals (Astronomy and Astrophysics), educate talented students in doctoral studies, and they spend a considerable part of their time working at prestigious observatories and institutions abroad.

Students of bachelor and continuing master studies are given lectures and practical courses in the field of astrophysics, classical observational astronomy, cosmology and relativistic astrophysics. Particular attention is also paid to the physics of small bodies in the solar system. In addition to the standard instruction, lectures and seminars are often

Stellar astronomy

This specialization in the Astronomical Institute includes spectroscopic and photometric studies of binaries, multiple systems, hot stars and veiled stars. It uses data from telescopes in Ondřejov Observatory (diameter 2 m and 0.65 m), as well as from other observatories available within the framework of international co-operation.

Numerical models of the changes in the orbit of binary stars may reveal, for example, the behavior of a third body in a binary star, or the flow of matter between the components of a close binary, and the presence of an accretion disc around one of them.

Asteroids

Asteroids are the key to understanding the formation and evolution of the solar system, but at the same time threaten catastrophe if they collide with the Earth. The status of the rotation and the shape of asteroids can be derived from light curves by using sophisticated inverse methods, which are constantly being improved at the Astronomical Institute. Employees of the Institute manage the database of asteroid models DAMIT, cooperate with professional and amateur asteroid observers around the world, and will participate in the photometric projects PanSTARRS and LSST.

Other areas in the research of small bodies in the solar system concern the study of non-gravitational phenomena (e.g. pressure, direct and reflected solar radiation) on their movement. The consequences of the non-gravitational effects can accumulate over time and cause substantial changes in the trajectory of small bodies or in their rotation. They may, for example, lead to a small asteroid leaving the main belt between Mars and Jupiter, and moving closer to terrestrial planets, or to its rotational speed permanently increasing up to the critical level where the body tears into two or more components.

Helioseismology

This method of solar research is the only one that allows you to see under the surface of the Sun. Helioseismology uses the analysis of the shape of waves that spread inside the Sun to gain information about thermodynamic structure and the flow of plasma under the photosphere. This information is important for understanding the emergence and evolution of sunspots and other forms of solar activity. The Astronomical Institute is currently developing a fully consistent tomography method that performs three-dimensional helioseismic inversions for any parameters describing the solar plasma.

Flashes of gamma radiation

These flashes come from deep space. Their statistical analysis in the Astronomical Institute revealed physical properties and observed differences between groups of so called “short”, “medium” and “long” flashes. Important for understanding the evolution of the universe is isotropy, or anisotropy distribution of the sources of the flashes in the sky. Photometric and spectroscopic data from satellites, Compton, Shift, and RHESSI are used for the studies. The relationship of anisotropic relict radiation and the creation of structures in the early universe, and the relation between supernovae and cosmological parameters are also studied.

History of Astronomy

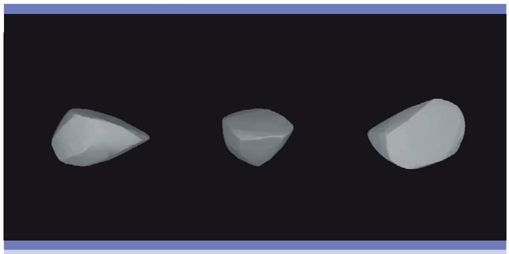
The history of astronomy offers many interesting and yet unexplored topics, including the circumstances surrounding the residence of famous personalities (Brahe, Kepler, Doppler, Mach, Einstein) in the Czech lands.

Website: **http://astro.mff.cuni.cz/**

visited by foreign visitors and researchers from other domestic institutions.

Foreign students are almost continuously in attendance at the university for one or two-semester stays, so some lectures and seminars are given in English or concurrently in Czech and English.

Graduates of the Master program almost without exception continue their studies in the doctoral program, both at home and abroad.



The model of the asteroid (1022) Olympiada, from whose light curve was this shape derived by the inverse method.

The model of the asteroid (889) Erynia calculated from its light curve. Both the asteroids orbit in the main asteroid belt between Mars and Jupiter. They turn in the space, so that the section of surface facing the sun and the observer continually changes and consequently its perceived brightness varies.

• Biophysics

Institute of Physics of Charles University

The Institute of Physics of Charles University belongs among the greatest physics centers at the Faculty. Its scientific aims move in two main directions: research in the optical and transport properties of semiconductors and other materials, and research in biologically important molecules and molecular systems.

Traditionally, the Institute of Physics is mainly a center for experimentation, importantly joining together differently focused research teams within five scientific divisions: Biophysics, Biomolecular Physics, Magnetooptics, Semiconductors and Semiconductor Optoelectronics, and Theoretical Division; the work carried out at the Institute emphasises the use of advanced optical and spectroscopic methods.

At the Institute of Physics there are currently 48 employees (including 4 professors and 14 associate professors), and also 27 doctoral students. The Institute of Physics significantly participates, in addition to scientific activities, in the education of students from bachelor to doctoral studies.

Within the master study program, the Institute guarantees the teaching activities for the Biophysics and Chemical Physics curriculum, and also participates significantly in the curriculum of Optics and Optoelectronics. In doctoral studies the Institute of Physics provides

Biophysics is an interdisciplinary scientific branch which uses physical methods, both experimental and theoretical, for the study of biological systems at different levels of their complexity: from individual molecules via cells and multi-cellular organisms up to complex ecosystems.

The teaching of Biophysics offered by the Institute of Physics builds on the basic physics education of bachelor study graduates in the field of General Physics, then deepens their education in areas of theoretical and experimental physics important for the description and the exploration of molecules, biopolymers, supermolecular systems and biological objects, and finally provides additional required courses covering selected areas in chemistry and biology.

Biophysics graduates will have received theoretical training, in particular of quantum theory, quantum chemistry, molecular modeling and molecular processes, as well as a knowledge of experimental methods in biophysics and chemical physics, specifically optical and other spectroscopic methods, structural analysis, and imaging techniques.

Scientific research in the field of Biophysics is done by the staff of three divisions: Biophysics, Biomolecular Physics, and partly also the Theoretical Division.

The Division of Biophysics has been involved in two research areas: problems of **transport processes in yeast and bacteria, and the dynamic and structurally-functional properties of proteins in solutions**. In the first, the yeast *Saccharomyces cerevisiae* and the bacteria *Escherichia coli* are studied, while standard fluorimetry that uses both fluorescent probes and genetically modified cells producing fluorescent proteins dominates the experimental procedures. An example of this is the study of the influence of chemical stressors on membrane potential and the activity of the MultiDrug Resistance pump in yeast.

Research in the properties of protein is possible owing to the fact that there are high-tech experimental facilities for nano- and picosecond time-resolved fluorimetry available in the Institute, which enable the monitoring of conformational changes, hydrodynamic properties and internal dynamics of biomolecules. This approach has managed to prove, for example, that the GRL loop of α-subunit of the mitochondrial peptidases is responsible for recognition of the substrate.

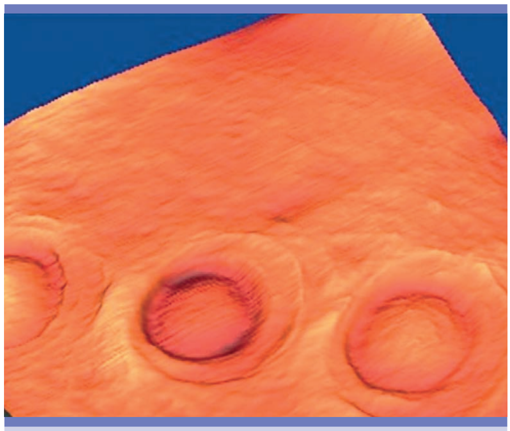
The Division of Biomolecular Physics focuses on the **study of the structure, dynamics and interaction of key biomolecules in an aqueous environment**, with the aim of explaining physico-chemical mechanisms of important biological processes, and offering possibilities of how to influence them.

This includes, for example, **structural stability and interactions of nucleic acids and their synthetic analogs** (significant as potential drugs) **and their activity in living cells**, **structure and biologically important interactions of proteins**, and **porphyrins and their specific interactions with nucleic acids** (porphyrins as structural probe of nucleic acids and photosensitizers). The experimental methods on which this research is based, in addition to absorption and optical emission spectroscopy, are spectroscopy of Raman scattering, including Raman optical activity, surface enhanced Raman scattering and Raman scattering microscopy. No less significant is the increasing role of computer modeling of molecules under investigation.

Research activity of the Theoretical Division in the field of biophysics focuses on the theory of single **molecular spectroscopy** and **multidimensional nonlinear coherent spectroscopy** of photosynthetic systems, and on an assistance in interpreting experiments carried out in the Division of Biomolecular Physics.

a supervised work area for study branches of 4F4 – Biophysics, Chemical and Macromolecular Physics, 4F6 – Quantum Optics and Optoelectronics, and 4F11 – Mathematical and Computer Modeling.

In just the last five years, 33 graduates of master studies and 50 graduates of doctoral studies have successfully completed their diploma or doctoral theses in the laboratories of the Institute. And, it is quite promising for the further development of the Institute that its former graduates return after long-term post-doctoral stays at top foreign universities and labs.



A cell-wall of the yeast S. cerevisiae *displayed by using the AFM, with the recognizable bud scars.*

• Optoelectronics

Institute of Physics of Charles University

The Institute of Physics of Charles University, introduced and described on page 34, is continually building on the traditions of the original Institute, which was founded in 1882 as one of institutes of natural sciences at the Czech section of the Philosophical Faculty of the divided Charles-Ferdinand University.

At different periods following its establishment however, many incommensurable institutions differing greatly both in size and mission carried the name of the Institute of Physics of Charles University.

But, in 1952, the newly formed Faculty of Mathematics and Physics of Charles University, which in 1956 included a renewed Institute of Physics with a statute similar to the scientific institutes of the Czechoslovak Academy of Sciences, became the successor of the first Czech Institute of Physics of Charles University.

The last major reorganisation of the Institute of Physics was on 1 January 1968, when Professor Jan Tauc was appointed the first Director of a reorganized Institute.

Professor Tauc directed the scientific focus of the reorganized Institute in two main directions – research into optical and transport properties of semiconductors, and research in biologically significant molecules with physical methods. These two paths, with, of course, sub-

The basic subject of optoelectronics is the study of the properties of solids, particularly semiconductors, insulators and magnetic systems through their interactions with radiation. The results of this research are used in the construction of electronic components, radiation sources, and detectors.

Optoelectronics can be studied in the master studies program in the specialization **Optics and Optoelectronics**, which is administered by the staff of the Institute of Physics and the Department of Chemical Physics and Optics. The graduates of this study program will have studied the theory of solids, quantum and nonlinear optics and photonics, technology of materials for optoelectronics, and construction methods of optoelectronic elements. Emphasis is placed on understanding the physical processes and laws which determine the qualities of systems being studied, as well as the principles underlying the operation of optoelectronic components. Graduates can work in basic and applied research at universities, institutes of the Academy of Sciences and industry.

Scientific research in the field of optoelectronics in the Institute of Physics is done by the staff of the Division of Semiconductors and Semiconductor Optoelectronics, Division of Magnetooptics, and partly also of the Theoretical Division.

The Division of Magnetooptics concentrates on the study of periodical magnetic structures, photonic crystals and scintillation detectors. Magnetic layered structures are used in the magnetic and magnetooptic recording of information, spin electronics, or as highly sensitive detectors **of scattering fields.**

Another area of interest is the micromagnetic theory of superfast magnetic processes, for example, in the magnetic nanodiscs (vortices). In the department highly sensitive methods of mag netooptical spectroscopy and ellipsometry have been developed for the study of such systems.

Thin epitaxial oxide films for scintillation detectors are prepared in the technological laboratory. Such detectors are useful in the detection of X-ray radiation or high energy electrons in 2D imaging systems of submicron resolution.

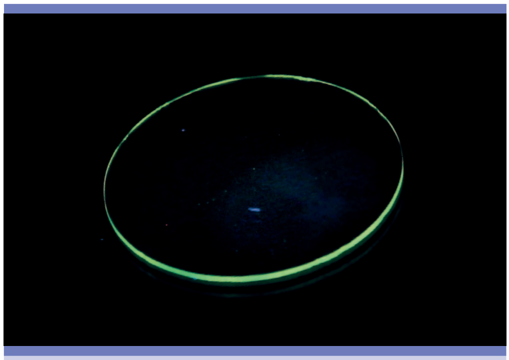
The research in the **Division of Semiconductors and Semiconductor Optoelectronics** is focused on two research areas, **preparation of X-ray and gamma radiation detectors based on (Cd, Zn)Te semiconductors** and **optical properties of quantum structures.**

In the first case the research is conducted on a unique material, which enables spectrally sensitive high-efficient detection of radiation without the need for cooling off the detector. The aim of the research is to find optimal technological processes in the preparation of the detectors. The Division has at its disposal the complete technology from the growth of single crystals up to preparation and characterization of detectors.

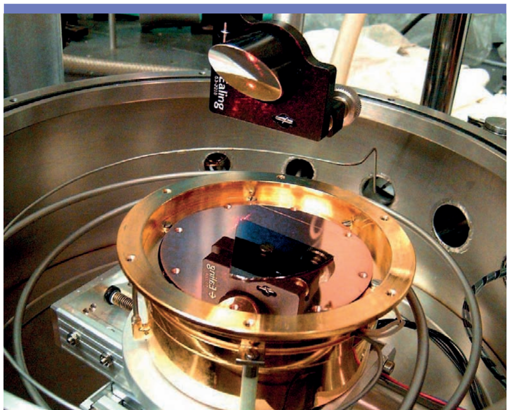
Quantum structures (nanostructures) are the basis for the modern series of optoelectronic components, which have no analogy in classical materials. The aim of the research is realization of experiments, which can verify the predictions of quantum physics. A rich selection of possibilities in creating various structures allows the preparation of devices on demand according to the particular requirements of the customer. Currently the properties of two-dimensional electron gas in CdTe/CdMgTe quantum wells and properties of the one-atom--thick sheets of graphite – graphene are being studied in the Division.

stantial modification in and expansion of specific research areas, in accordance with developments in the science, has basically persisted up to the present.

The Institute of Physics has traditionally been primarily an experimental center, and the current experimental equipment in the Institute laboratories is probably the best it has ever been.



Epitaxial thin film garnet scintillator Ce:LuAG excited by ultraviolet radiation.



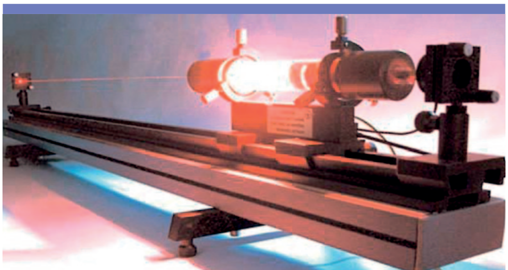
Helium-cooled optical cryostat for mapping photoluminescence of semiconductors

• Experiments in Physics Education

Laboratory of General Physics Education

The workplace responsible for the teaching of General Physics in the bachelor study program provides demonstrations of experiments during basic physics lectures. Students then verify their knowledge by independent work in basic practical courses in physics laboratories. The workplace also provides the experimental work in another two bachelor programs, i.e. Applied Physics and Education Focused Physics.

The Laboratory has also long been involved in computer-supported high school and university natural science laboratories. In 2002, integrated e-learning laboratories were opened as one of the first in Europe. The intention is to interconnect computer-supported distant and virtual labs.



The new task of the physics lab in optics – the HeNe laser.

The quality of physics teaching must be visual, therefore frontal experiments and individual experimental activity is a natural part of bachelor study specializations. This method of teaching demands technical equipment, since it is necessary to respond flexibly to the rapid developments of scientific disciplines in preparing university educated professionals.

Thanks to the continuous efforts to maintain a modern workplace the Laboratory currently offers more than 400 physics lecture experiments and more than 100 basic physics practical exercises completely covering all basic lectures, from elementary to advanced and financially demanding teaching areas.

In addition to demonstrations of experiments during lectures, students of physics at MFF UK take four courses in basic physics laboratory work during their studies where they can choose tasks according to their interest. In 2011, full reconstruction and modernization of all practical laboratories was completed.

Experiments are often performed on apparatus used for both basic and applied research. An appropriate complement to this is a range of selected practical courses dealing with the use of computing and measurement techniques and modern DAQ systems in physics experiments.

The knowledge and understanding of all such experiments and experimental methods enable graduates to find jobs in progressive fields of physics as well as chemistry, medicine and biology.

Photoelectron Spectroscopy Using Synchrotron Radiation

Modern research of materials plays an important role in creating materials with new properties. These include, for example, aluminum and/or magnesium alloys containing small amounts of rare earth elements, or polymeric networks and nanocomposites. New structural Al alloys are finding applications not only in the automotive industry but also as welded constructions in aviation. Magnesium alloys, moreover, in addition to transport applications are beginning to be used in medical sciences.

Medicine currently uses materials mainly for permanent implants. Their long-term presence is not desirable in some cases, and the implant should be taken out after the sick tissue heals.

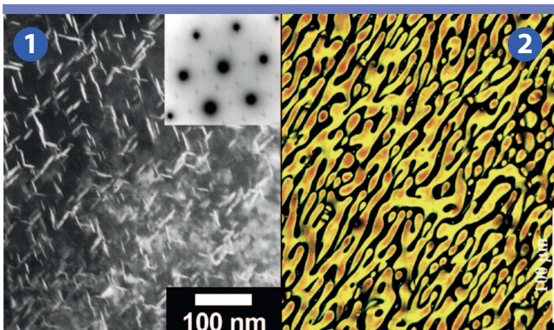
A general property of magnesium alloys compared to aluminum alloys is their reactivity and rapid corrosion in the physiological environment. These apparent disadvantages, however, may be favorable for biological use. Mg alloys with rare earths (RE) appear to be some of the best metal materials for degradable load-bearing implants to repair or replace bone tissue, or as cardiovascular stents.

The main objective of modern research on Mg-RE alloys is research leading to reliable mechanical properties of the material together with a tolerable toxicity, cytocompatibility and appropriate in vivo corrosion behavior.

Laboratory of General Physics Education and Science

Although scientific activity is not the main activity of the Laboratory, some employees are members of research groups currently focusing on the field of light metal alloys of hexagonal and face-centered cubic structure. Researchers study mechanical, electrical and thermal properties of metals; in cooperation with the Department of Physics of Materials they also study microstructure characteristics. There is also very close cooperation with major Czech and European institutions in research of metal materials and materials for medical purposes.

The second direction of research is connected with the cooperation with the Department of Macromolecular Physics and the Institute of Macromolecular Chemistry of the Czech Academy of Sciences, and with applied research in the field of ageing of rubber layers of conveyor belts. The research is focused mainly on liquid crystalline polymers, polymeric networks, and polymeric nanocomposites by dynamic mechanical and dielectric spectroscopy, polarizing optical microscopy and differential scanning calorimetry.



1) Triangular arrangement of prismatic plates, parallel to the planes {11-20} in MgTbNd alloy isochronally annealed up to 270 °C.
2) Microphotographs of the texture – the phase transition from nematic to isotropic state of the liquid crystalline polymer.

• Physics for Teachers, Children, and the Public

Physics Teacher Training

Among its other disciplines the Faculty also offers a program in the teaching of physics for secondary schools, both lower and upper grades, in combination with mathematics or computer science. The study program offers students a good foundation in specialized disciplines as well as extensive training in pedagogy and psychology, which enables them to pursue a teaching career not only in schools but also in various educational business centers. Our graduates are especially successful in positions where there is a need for good communicative skills and a high level of analytical thinking.

Via choosing optional subjects students form their specialization either towards work in physics or towards work with people. The study, besides basic theoretical background, includes

Electricity and magnetism step by step – elective seminar.

How can children and teenagers become familiar with physics? How can we develop their talents and support their interests in this field? These are the basic questions which staff at the Department of Physics Education tries to answer. Teaching at a high level is unimaginable without talented, qualified teachers. That is why the Department of Physics Education pays constant attention to the initial physics teacher training. The department also organizes a number of courses and seminars for those teachers who already teach. In addition, members of the Department seek to popularize physics. They run a web portal FyzWeb, participate in the production of educational TV programs, and organize shows and competitions in physics for children and adults.

Research

Physics education research concerns itself with a variety of topics. The Department of Physics Education considers especially the following questions:

What do pupils imagine about physics before they encounter the lessons of “natural science” or “physics” at school? How is the image changed by further education?

How do pupils perceive physics? How to motivate them to learn physics? Which field or topic of physics are interesting for them?

What does it mean good teaching of physics? What are the qualitative parameters of it? Who is a good teacher of physics?

Which cognitive processes arise when solving physics problems?

Resources for physics teachers

The branch 'Physics Education' also deals with the production of teaching materials and devices. Members of the Department are authors of a comprehensive series of textbooks and other methodological materials or e-learning modules for pupils and physics teachers. The Department of Physics Education Didactics of Physics also aids physics teachers practically with the actual experimentation. For instance, it provides them topics for simple demonstrations or for computer-aided measurements.

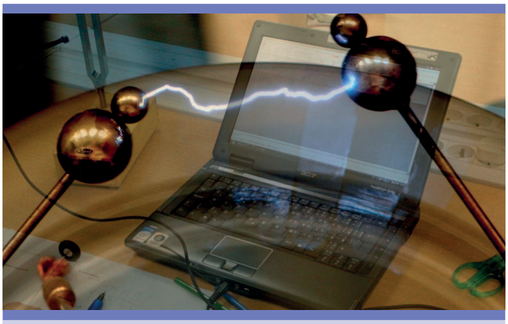
Moreover, DPE offers support for students and teachers experiments in the Faculty building. For example, a one-hour show of experiments from a chosen field of physics is performed every week.

The Department of Physics Education also gives methodological support to the Interactive Physics Laboratory (IPL). The purpose of the Laboratory is to enable high school students to do experiments with the help of more complicated devices not available at ordinary schools.

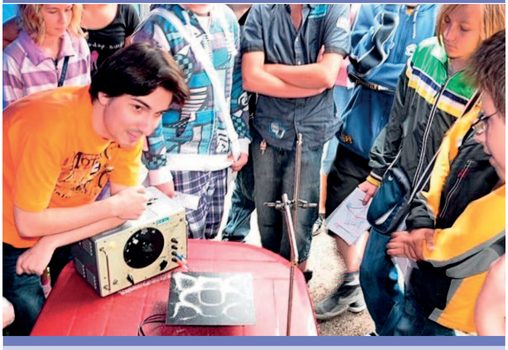
International cooperation

The DPE develops long-term cooperation with colleagues – educators in the field of physics not only in the Czech Republic but also throughout the world. It participates in the national and international preparation and evaluation of research in the field of natural science education TIMSS and PISA. To support teachers it cooperates with the 'Science on Stage' program. Members of the Department also participate in international projects focused on e-learning in the field of natural science, inquiry based science education or solving quantitative physics problems.

training of practical skills (work in laboratories, seminars, organization of events, etc.)



Photomontage from photos which were taken at "The Circle of Physics". http://www.krouzek-fyziky.ic.cz/



The profession of a physics teacher offers the possibility of working with young people and with new technologies, as well as being able to develop one's creativity and acting abilities.

http://kdf.mff.cuni.cz – website of the Department of Physics Education
http://kdf.mff.cuni.cz/heureka – the 'Heureka' project which supports heuristic methods in teaching
http://fyzweb.cz – the 'FyzWeb' portal which popularizes physics and supports teaching physics
http://talnet.cz – the TALNET project which supports gifted students in the field of natural science
http://kdf.mff.cuni.cz/ifl – website of the Interactive Physics Laboratory

• Plasma Physics, Knowledge of the Fourth State of Matter

What Kinds of Plasmas We Study

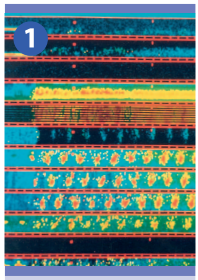
The term plasma was first used by Irwing Langmuir (1881-1957); the modern definition states: “Plasma is a quasineutral set of particles with free carriers of charges (electrons and ions) which behave collectively”. It is known that 99% of all matter in the universe is in plasma state.

Our planet belongs to that remaining percent of the universe where plasma exists sporadically. However, it is possible to find it in various and very different forms: in lightning channels, in fluorescent tubes, in electric arcs, in the ionosphere, in auroras, or in the magnetosphere of the Earth; in the solar system, plasma is contained in the solar wind, in the magnetospheres of other planets, or in tails of comets.

Depending on its different forms, plasma is created and studied in laboratories, or its parameters are investigated by spacecraft. Such studies are one of the important topics of research at the Department of Surface and Plasma Science (which deals with plasmas of the solar wind, the ionosphere and magnetosphere of the Earth, low-temperature plasma for technological applications, special plasma for thermonuclear fusion or for unique laser technologies, or, alternatively, particle interactions in tem-

Solar wind

Geomagnetic storms or substorms as a result of eruptions on the Sun can lead to changes in the Earth’s magnetic field which can induce a voltage in electrical circuits. Consequently, errors in data transmission can appear as well as breakdowns of the electrical network and gas lines, and finally, air traffic can be endangered. On the other hand, substorms can produce beautiful effects like the aurora.



The faculty researchers develop instruments for satellite measurements of plasma parameters in near-Earth space. These data are used for the so-called Space Weather prediction of consequences of strong explosions on the Sun that influence life on Earth. Picture (2) shows the instrument which was developed for the fastest in the world measurements of solar wind variations. At present, the instrument (1) onboard the Spectr-R project is monitoring interplanetary space. The data from such instruments, which were developed not only at the Faculty but also at other research centers around the world, are transmitted to Earth’s receivers and analyzed and, finally, compared with the theoretical calculations and numerical simulations of particular processes.

Research of plasma and its applications in laboratories

During the last 40 years of studying interactions among ions, neutral particles and electrons, a number of reactions which have taken place in the Earth's ionosphere and in interstellar space have been explored. However, the processes at low temperatures of a few Kelvin have not been explained yet. Here, besides interactions in the gaseous phase, important processes also take place on the surfaces of solid particles.

To study the reactions in plasma at very low temperature (10 K) it is necessary to catch and cool down ions and electrons. In the pictures below, you can see the experimental equipment with the low temperature trap (3) and magnetic electron spectrometer (4).

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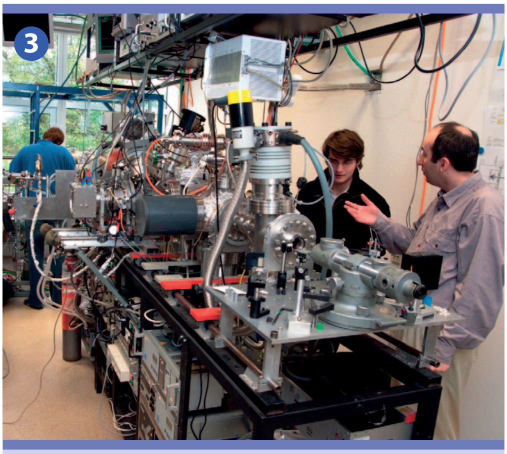

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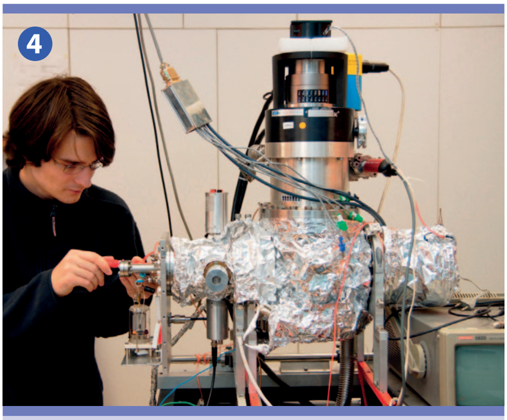


peratures close to absolute zero). Experimental studies are supported by numerical simulations and computer models which make the research more effective (see page 68).

Starting from the 2nd year, the students (see the picture in this column) participate in this research together with the faculty staff. They have the possibility to establish international contacts and to take a part in numerous conferences. Doctoral students regularly become full members of international research communities in the field of space plasma, or participate in ignition of the first flashes of thermonuclear fusion in tokamaks.

• Physics of Surfaces, Thin Films and Nanostructures

Surface in the Context of Physics

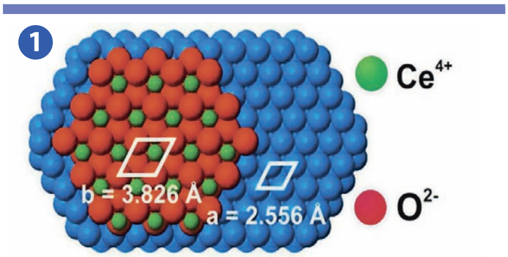
Surface properties of solid structures differ from their volume properties substantially. It is possible to imagine a surface as a structural plane which appears as a result of breaking bonds between atoms. Surface atoms have properties different from the bulk atoms thanks to the missing neighbors.

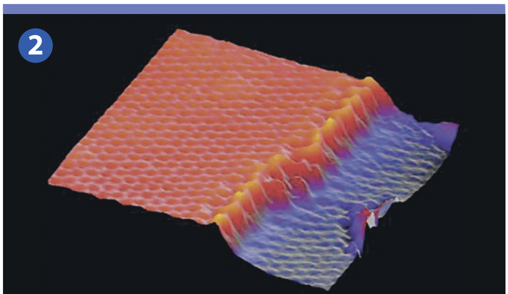
If we create a thin film of material the width of which equals only a few atoms, the differences in physical and chemical behavior of the film in comparison with the bulk will be even more significant because the proportion of surface atoms is large enough to give a material new properties. As we continue reducing objects by a transition from two-dimensional films to three-dimensional formations as small as tens of nanometers, we will produce *nanostructures*. The nanostructures may have properties which cannot be reached in bulk structures. Modern branches of nanoresearch and nanotechnologies use this for designing, and for modeling and preparation of new revolutionary materials. Such materials are already being used in a wide range of applications.

Applications of nanostructures can be found in various branches of animate and inanimate nature, in medicine, biology, and power engineering but, espe-

Cerium oxide (CeO_2) is an example of a compound with interesting catalytic properties which are used, for example, as a detoxification catalyst of exhaust gases of cars, or in the production of hydrogen from alcohol to be used in new sources of energy.

Basic research of CeO_2 nanostructures brings important information about the physical and chemical properties of materials, which can then be used for further research. In pictures (1) and (2) you can see the atomic model of a CeO_2 nanoisland and an actual image of it obtained by a scanning tunneling microscope (STM) with atomic resolution. Picture (3) shows oxide layers terrace with a thickness of 0.31 nm prepared on a single copper crystal substrate.



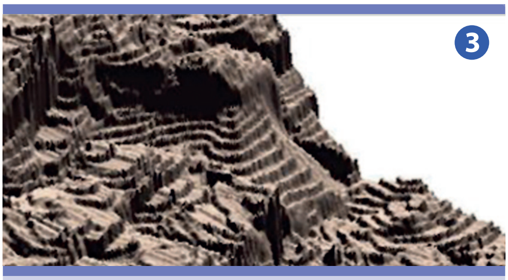


Photoelectron Spectroscopy Using Synchrotron Radiation

Synchrotrons are used mainly for the production of high-energy X-rays. They are particle accelerator rings in which the magnetic and electric fields are synchronized with the particles "flying by". The synchrotron radiation is produced in the last accelerator stage – in the accumulation ring – and is distributed into *beam-lines*, with laboratories located at their end.

Photoelectron spectroscopy may use a photo-effect caused by the absorption of synchrotron radiation of the material. The energy of electrons so emitted is analyzed, as it carries information concerning which atoms and in what states are present on the surface. The combination of spectroscopic and microscopic methods gives a complete picture of the physical and chemical structure of surfaces.

Picture (4) shows the beam-line spectrometer of the Material Science Beamline operated by the Faculty at the Elettra synchrotron in Trieste, Italy.



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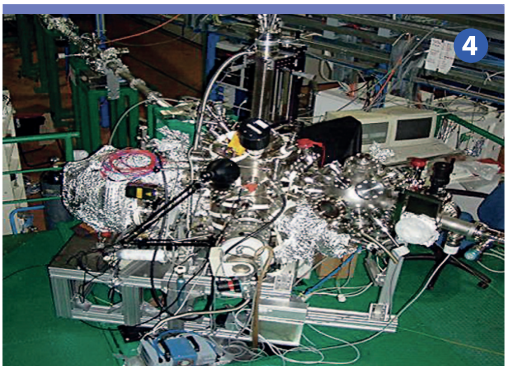

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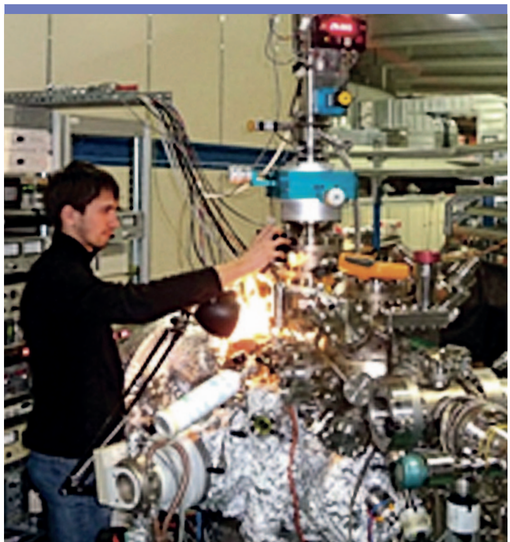
cially, in chemistry where nanomaterials have been used in catalysis for a long time.

The study of nanomaterials puts high demands on the experimental equipment in laboratories and on our ability to combine experimental and theoretical approaches to the research.

The Department of Surface and Plasma Science of the Faculty of Mathematics and Physics, has been studying surface properties of solids, thin films and nanostructures for decades. It can use its world-class equipment – microscopes and spectrometers which enable researchers to study surface properties down to atomic resolution. The instruments mainly used are scanning tunneling microscopes (STM), atomic force microscopes (AFM), and secondary electron emission microscopes (SEM).

Students have the opportunity to enter research on these world-class instruments not only at the Ph.D. level, but as early as with their Bachelor's and Master's theses work.



• Microstructure and Properties of Modern Materials

Department of Physics of Materials

The Department of Physics of Materials (KFM) concentrates on research into the microstructure and properties of modern materials to be used in construction and functional applications. Attention is paid especially to the relationship between the microstructure and mechanical and thermal properties of metals, alloys, and intermetallics, composites with the metal matrix and materials with fine-grained structure or nanomaterials.

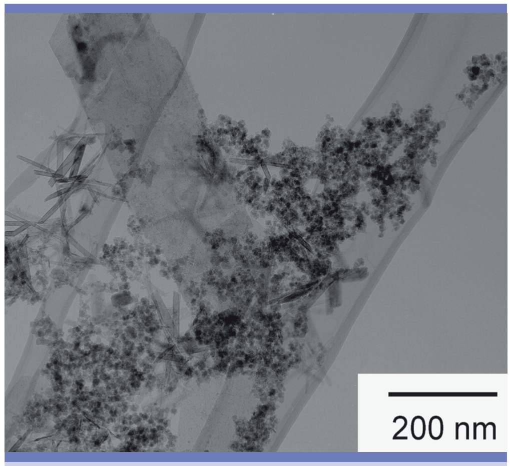
Comprehensive research into the physical aspects of plastic deformation, including theory, modeling and experimentation, and research of phase transformations in metal materials is done.

This scientific work has an impact on the process of teaching. Highly qualified specialists of the Department participate in teaching students in the bachelor program ‘Applied Physics’, and then the master program ‘Physics of Materials’.

The main parameters influencing the final properties of the materials studied are their microstructure and, especially, the possible presence and distribution of crystal defects in the material. Electron microscopy is a method without which

Not long ago the physics of materials was studied and taught at technical universities where the research was concentrated primarily on identifying properties of materials and their applications.

Increasingly, this field of physics is being studied at world-class universities. The key task of this research is to explain the physical nature of the properties which are studied. Researchers study relationships between the physical states and processes in the micro-, nano- and atomic world on one hand, and macroscopic properties on the other. Provided that a correlation between the properties and the structure is proved, it is possible to design changes in the preparation of the materials so that a particular property will prevail or be suppressed. In this way new materials can be invented.



Oxide nanoparticles displayed with the help of TEM.

Presently, researchers face increasing demands for materials which can be extremely strong, resistant to cracks, stress, and corrosion. Research is also motivated by attempts to simplify production processes (the number of technological steps), or to reduce excessive environmental impact and energy consumption (fuel consumption).

Research focuses on the following areas:

– Nano crystal and ultra-fine-grained materials

– Intermetallic materials for applications in the energy and car industry

– Light materials based on aluminum for the aerospace and automobile industry

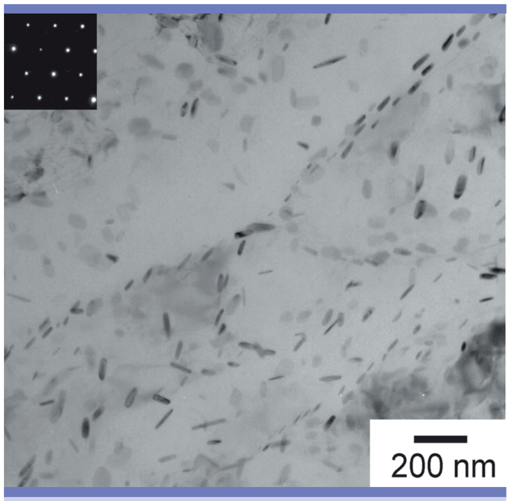
– Materials based on titanium and magnesium for biomedical applications

Emphasis is placed on close cooperation with partners from industry in the Czech Republic and abroad. In the past, for example during the 6th EU framework program, research was done on superplastic magnesium materials for applications in the aerospace industry together with the company Airbus. At present combined research into titanium materials for total endoprothesis of large joints with the company 'Beznoska' is ongoing as a part of the program 'Alfa TACR'. The Department of Physics of Materials participates in many such projects contributing its sophisticated instrumentation such as electron microscopy, thermo physical methods (DSC), or acoustic emissions and its expertise in the physical processes of materials such as thermodynamics of structure phases, crystal lattice defects and their influence on the properties and thermally activated processes (superplasticity), or plastic instability.

it is impossible to imagine current material laboratories.

The microstructure of inorganic materials can be displayed from a scale of a few millimeters to atomic resolution. Moreover, the crystal lattice can be investigated with the help of diffraction. If the equipment includes the necessary detectors, local chemical analysis can be performed. Contrary to other high-resolution methods (e.g. diffraction X-ray and neutron radiation) it can detect defects and structural changes in very small volumes.

The electron microscopy laboratory of the Department of Physic of Materials is equipped with a microscope working in both transmission mode and scan mode. These methods enable us to understand processes which take place in the materials mentioned above.



Precipitates in aluminum matrix and diffraction pattern of particles.

• Quantum Phenomena in Condensed Matter Systems

Department of Low Temperature Physics

The Department of Low Temperature Physics was founded in 1981 as a joint research center of the Faculty of Mathematics and Physics, Charles University, and the Institute of Physics, Czechoslovak Academy of Sciences. From the very beginning the Department has been interdisciplinary in character, ranging from condensed matter physics to nuclear spectroscopy. The research had its origin in the tradition of studying hyperfine interactions using nuclear magnetic resonance (NMR), Mössbauer spectroscopy (MS) and nuclear orientation at very low temperature.

These traditional problems were followed by: positron annihilation spectroscopy, high resolution NMR to study solutions of complex organic molecules, cryogenic fluid dynamics and quantum turbulence.

Several laboratories of the Department belong to the Joint Low Temperature Laboratory (JLTL) established between Charles University and research institutes of the Academy of Sciences of the Czech Republic.

Faculty students participate in research and are regularly sent on stays at top research centers like CERN (especially the COMPASS experiment), Aalto University in Helsinki, CNRS

Positron annihilation uses the positron – an elementary particle – as a probe to study the microstructure of solids. In solids positrons annihilate with electrons and the resulting gamma rays provide information about the annihilation process. If a sample under study contains defects connected with a loss of volume such as vacancies and dislocations, the positrons live longer and the parameters of the annihilation process change.

We use three complementary methods of positron annihilation spectroscopy (PAS), which are unique non-destructive methods of studying atomic defects, usually difficult to identify: (I) by measuring positron lifetime we identify them and determine their concentration, (II) coincident measurements of the Doppler broadening of the annihilation peak give us information about the chemical environment of the defects, and (III) with the aid of a slow positron beam with tunable energy we study the surface, thin layers and the depth profile of the defects.

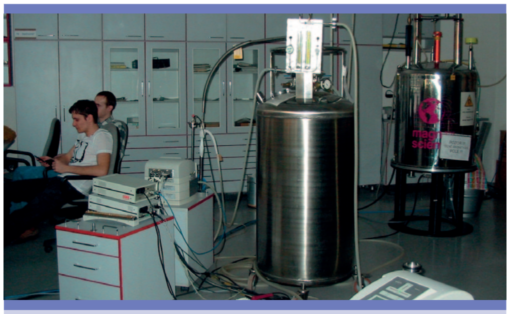
The problems under study involve microstructures of fine-grained and nanocrystalline materials; defects in intermetallic FeAl alloys; structures of quasi-crystalline materials; early-phase precipitation of reinforced Al and Mg alloys; hydrogen-induced defects and their interaction with hydrogen; defects and their impact on electrical and optical properties of ZnO and ZrO_2; and radiation damage of metals.

Radiofrequency Spectroscopy. Nuclear magnetic resonance (NMR) and nuclear quadrupole resonance are universal methods which use magnetically active atomic nuclei as local probes appropriate for studying atomic, electronic and magnetic structures and the dynamics of condensed systems. NMR spectroscopy enables us to understand connections between the microstructure and macroscopic parameters of studied objects. At the same time spectroscopy is very practical. Studies of magnetic materials, especially oxides of transitive metals, including intrinsic defects, contamination and substitutions of diamagnetic and paramagnetic cations, are unique.

We study materials with reduced dimensions (thin layers, nanomaterials); substances with structural phase transitions and magnetic reorientation transitions; and magneto-electric effects. Theoretical calculations of the electron structures of oxides are performed and compared with hyperfine parameters determined by NMR.

Much time is devoted to the study of dynamics and structures of organic molecules (calixarenes) and biomolecules (proteins, oligonucleotides) in solution, non-covalent interactions (hydrogen bonds) in supramolecular complexes, and to the study of the influence of paramagnetic ions and stable radicals on relaxation processes. One of the latest trends is the research of NMR applications to observe the diffusion of molecules in solutions and in structured environments (such as porous materials).

Grenoble, AGH University of Science and Technology Krakow, University of Applied Science Jena, Stockholm University, Osaka University, University of Leipzig, Institute for Physics of Materials Göttingen, Helmholtz Centrum Dresden-Rossendorf, TU Munich.



Mössbauer spectroscopy enables us to study hyperfine interactions of ^{57}Fe isotopes in condensed matter. The research is focused on magnetic nanoparticles, nanocomposite materials and low dimensional iron oxides, xerogels and zeolites doped with iron. Our Laboratory uses four spectrometers in a transmission arrangement. One of them can be used for cooling samples down to 4.2 K, others are modified to detect measurements on-site during the chemical reaction and for measurements using conversion electrons.

Cryogenic fluid dynamics, superfluidity and quantum turbulence. Cryogenic helium offers three substances that can be used in fluid dynamics - cold gas, normal and superfluid liquid. These working substances have unique properties such as tunable viscosity which has been experimentally modified over two decades down to the lowest of all known substances. Our cryogenic fluid dynamics experiments include the study of transition of selected classical and superfluid flows to turbulence, or cryogenic turbulent convection at ultra-high Rayleigh numbers. The quantum liquid – superfluid helium (He II) – enables us to study quantum vortex dynamics and quantum turbulence. It can be generated both mechanically and thermally, in the counterflow of the normal and superfluid components of He II and - detected by second sound attenuation, or with the aid of sensitive mechanical oscillators. Liquid helium flow in an optical cryostat is visualized by observing the motion of solid hydrogen and/or deuterium particles illuminated by laser and captured by a sensitive ultrafast camera. To study pure superflow at millikelvin temperature we use a powerful dilution refrigerator.

• Electronic Properties of Metals

Department of Condensed Matter Physics

At present the Department consists of three research groups: group of magnetic properties, structure analysis, and theoretical physics.

The Department guarantees the Master study program of '**Physics of Condensed Systems and Materials**', designed to follow the Bachelor level, and organizes the study called 'Physics of Atomic and Electronic Structures'. The program concentrates on studying properties of condensed systems, their microphysical interpretations and possible applications, especially with respect to the present state of materials research.

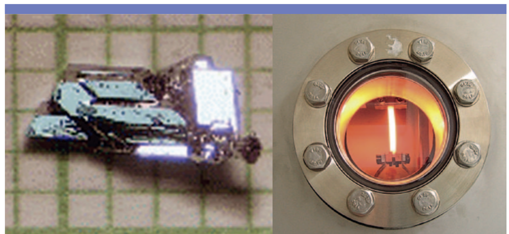
The Department also guarantees the Bachelor study program of '**Applied Physics**'. In this program Department staff not only teach in the basic courses but also cover the specialization 'Physics of Materials', which devotes special attention to acquiring knowledge of modern diagnostic methods in condensed matter physics, basic principles, possibilities and connections, as well as a basic knowledge of chemistry and electronics.

Do visit us at our website: **http://cmd.karlov.mff.cuni.cz/kfkl/index.php/**

Magnetism and other cooperative phenomena can be found in d- and f-transition metals. They result from pair interactions in a system of many electrons and can be described or predicted only approximately by calculations. Research at the Department of Condensed Matter Physics concentrates on properties of materials with 4f elements (lanthanides) and uranium as a representative actinide (5f).

The technology of ultra-pure materials and single-crystal growth is a necessary prerequisite for experimental research of metals, alloys, and intermetallic compounds. The method of Solid State Electrotransport Refinement cleans metals in an ultrahigh vacuum from impurities below the level of the purest commercially available metals.

Single-crystal growth by the Czochralski technique can be used even at very high melting



Single-crystal $GdCu_4Al_8$ prepared by the growth from an oversaturated solution. In this method the form of a crystal often reflects the symmetry of the crystal structure (left). Single-crystal UCoGe purified by the SSE method (right).

temperatures. Single crystals can be also grown from liquid alloys or can be produced in an optical furnace. High pressure of hydrogen is used for hydrogen absorption studies and tuning of properties by crystal-lattice expansion. This leads to the synthesis of hydrides, which are relevant for hydrogen storage.

Research programs include a wide range of materials with interesting functional properties, e.g. media for magnetocaloric cooling, permanent magnets, materials with huge magnetoresistance relevant for information storage and spintronics.

Other research programs deal with issues connected with the phenomena of electron-electron correlations on the verge of 4f and 5f electron localization, such as the mechanism of unconventional superconductivity and its possible coexistence with ferro- and antiferromagnetism, the actual formation of magnetic moments and various types of magnetic ordering.

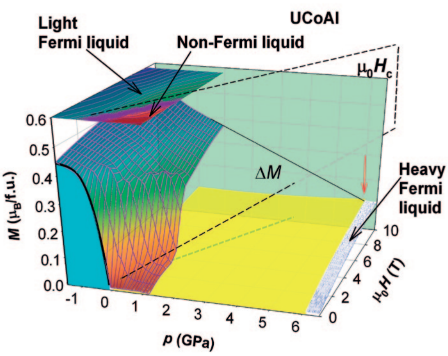
The synthesized materials are characterized by means of X-ray diffraction techniques; magnetic structures are determined by neutron diffraction at large facilities (e.g. ILL Grenoble). Magnetic, transport, and thermodynamic properties are studied in a wide range of temperatures and magnetic fields up to 14 T. The reaction to lattice compression and consequent increase of the overlap of electronic wave functions with the center in neighboring atoms are studied at high pressures (over 20 GPa).

Condensed Matter Physics

Condensed matter consists of ions in crystals bound with well-defined periodic positions, and electrons, which under specific conditions (e.g. in metals or semiconductors) can travel throughout the crystal and influence other electrons in similar situations. Condensed matter physics provides a quantum mechanical description.

The behaviour of electron sub-system is the key to numerous fundamental and functional properties. Electrons obey the Fermi-Dirac statistics and are affected by electrostatic interactions between positively charged ions. In addition, there are spin-dependent correlations between electrons with a negative charge.

Magnetism and superconductivity appear as a result of pair interactions between electrons, i.e. in a system of many particles and only on a quantum level. It is therefore impossible to obtain an exact quantitative description by ordinary calculations. Advanced theoretical methods are necessary to be combined with sophisticated experiments, often performed at very low temperatures and in high magnetic fields.



Disappearance of magnetic moments opens the degrees of freedom that lead to so-called emergent phenomena. In the case of the compound UCoAl tuned so that the ferromagnetism is suppressed by external pressure, band metamagnetism, which has a non-magnetic ground state, appears. However, the state corresponding to ferromagnetism is induced by external magnetic field.

• Crystal and Magnetic Structure

Crystallography and Structural Analysis

Crystallography studies the structure of crystals, i.e. regular arrangements of atoms in various materials, including the failures of these arrangements, and nanostructures of polycrystalline materials. It also deals with the relation of the structure to preparation conditions and properties of materials.

Crystallography nowadays represents a typical interdisciplinary branch on the border of physics, chemistry, biology, material sciences and mineralogy.

The main method used to study crystal structures – **structural analysis** – is the diffraction of X-rays, neutrons or electrons. It is possible to obtain a great deal of structural information from the placement, intensity and form of diffraction maxima on the diffraction pattern.

At the Faculty teaching crystallography and structural analysis has had a long tradition and is a dominant part of the Master study program called ‘Physics of Condensed Systems and Materials’ as well as the ‘Applied Physics’ Bachelor study program, and partly in other programs such as ‘Optics and Optoelectronics’ and ‘Physics of Surfaces and Ionized Environments’.

Knowledge of the crystal structure of materials is essential for studying their various physical properties and especially their directional dependency – anisotropy, which is typical for crystalline materials.

X-ray Diffraction

This method provides a great deal of information. Besides information about crystal structures, there is also for instance the possibility of determining phase compositions, textures, sizes of crystallites, and microscopic and macroscopic tension for polycrystalline materials. From the reflectivity of thin films we can obtain their thickness and roughness of surfaces, electron density and correlation of surface nanostructures.

The research group dealing with structural analysis is involved in many projects. Recently this has included complex structural analysis of thin polycrystalline layers with interesting photocatalytic (especially TiO_2), ferroelectric and magnetic properties, which also includes in-situ measurement of temperature stability. Among other scientific problems, they deal with structural analysis of nanotubes and nanowires, nanocrystalline powders, submicrocrystalline materials prepared with the aid of an intensive plastic deformation pressing method (ECAP) and high pressure torsion.

Structural properties of magnetic semiconductors such as GaMnAs, GeMn, and GaFeN are studied within the framework of European and other projects. Special methods of anomalous diffraction and standing waves have been used to establish the concentration of Mn ions in various positions of the crystal lattice of GaMnAs.

High-resolution diffraction and reciprocal space mapping are used to study, for instance, stress relaxations in various epitaxial layers, the contents of dislocations and other defects (GaN layers). We also study the structure of semiconductor quantum dots and the structure of semiconductor nanoparticles in an amorphous matrix. The laboratory is equipped with modern X-ray diffractometers with new X-ray optics enabling users to do experiments on a very high level. Some experiments are performed on synchrotron radiation sources in Grenoble, Karlsruhe, and Trieste.

Small Angle Scattering of X-ray Radiation

This measures distribution of non-homogeneities in electron density. This method can be used to study positions and shapes of Ge nanoparticles in an amorphous glass matrix. Picture (1) was taken by transmission electron microscopy and shows the nanoparticles as dark spots. Pictures (2) and (3) present the measured and calculated direction distribution of the diffused radiation. Comparing the measurements with the calculations, we study the processes during which the Ge nanoparticles self-organize in the direction of their deposition. The measurements were done on the ELETTRA synchrotron in Trieste in cooperation with the IRB institute in Zagreb.

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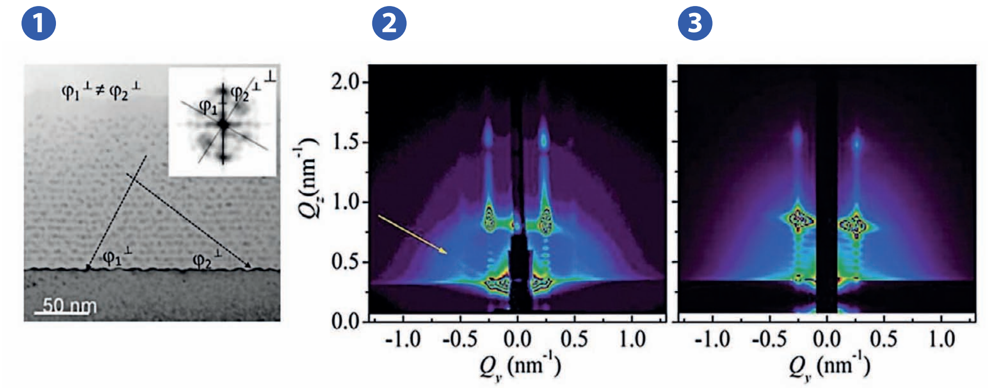


*The information about the crystal structure of material obtained from **neutron diffraction** is comparable with the same information received from X-ray diffraction. The main difference between both of these methods is that the first one gives much deeper information and, moreover, it studies scattered radiation primarily on the nuclei of atoms, not on the electron shell as in the case of X-ray diffraction. An important aspect is also the relatively strong possible scattering on magnetic moments, which leads to the creation of new diffraction maxima connected with magnetic arrangements, and enables researchers to determine the magnetic structure of a crystal.*

Elastic neutron scattering is also used to study excitations in solids – e.g. phonons. Neutron experiments are usually done in foreign research centers, especially at ILL in Grenoble and HMI in Berlin. However, some of them can also be performed in Řež near Prague.

• Physics of the Earth and Planets

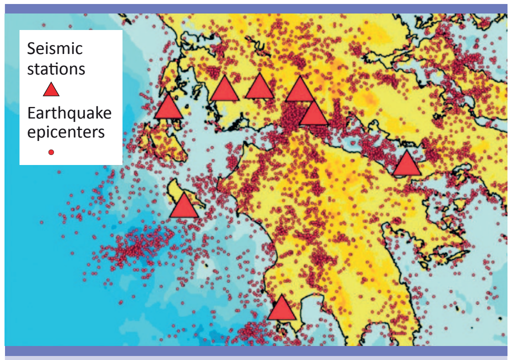
Department of Geophysics

Geophysics is one of the oldest branches of physics studied at Charles University spanning two centuries. The study and research in this branch, as they are organized at the Faculty of Mathematics and Physics nowadays, include both traditional and newly created geophysics disciplines.

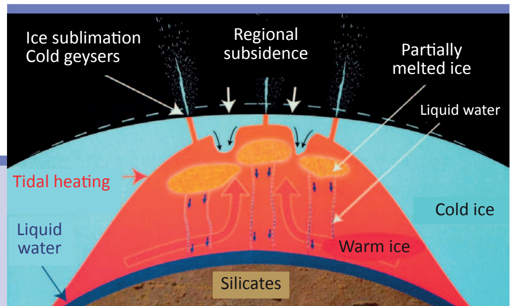
Research in the field of theoretical seismology is connected especially with the name of Prof. Červený, whose innovative work on the problem of elastic wave propagation is to this day an important basis of computational methods used at numerous research centers all over the world. Basic research performed in this field at the Faculty is also supported by international industrial companies.

An important part of seismological research is the study of earthquake sources and threats in seismically active areas of the world. The Department of Geophysics conducts its own network of seismic stations in Greece and also participates in the development of early warning methods in Italy.

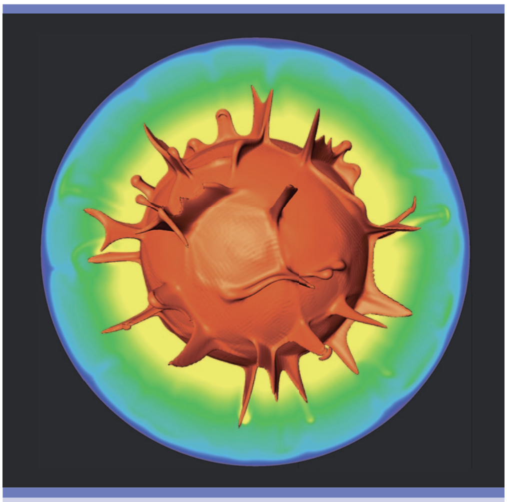
During the last ten years the Department of Geophysics has participated in several projects supported by the European Commission. The Department has become one of the European geophysical research centers, which are regularly visited by many foreign students and significant researchers.



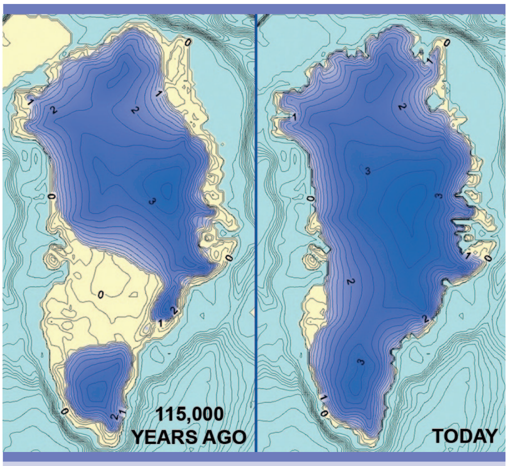
Faculty seismic stations in Greece enable staff of the Department to study earthquakes in the seismically most active areas of Europe. Their research has not only scientific motivation but also tries to save the lives and possessions of people living in these high-risk areas.



Model of thermal activity of Saturn's moon Enceladus designed by Faculty staff in cooperation with LPG in Nantes.



Example of a computer simulation of temperature evolution in the Earth's mantle. The red color shows anomalously rising warm currents which lead to cooling the Earth. The emphasis placed on numerical modeling is typical for geophysics at the Faculty.



Computer simulation of Greenland glacier evolution based on paleoclimatic measurements.

These kinds of simulations are important for understanding present climate change.

The Department achieved important results in the field of computer simulations of long-term processes inside the Earth. This research is directed towards, among other things, understanding the mechanisms which enable heat transfer inside the Earth and which take part in forming the Earth's magnetic field.

The study of gravitational and magnetic fields at the Faculty makes use of satellite measurements. The Faculty takes part in a wide range of international cooperation (with ESA and NASA, e.g., projects Swarm, Grace, and Goce). The cooperation also includes creating models of these fields and their interpretation with respect to the inner structure of the Earth.

The department members also study questions connected with global climate change. They design computer simulations of glacier development, surface deformations in connection with the appearance and disappearance of the Earth's ice cover, simulations of ocean currents and estimates of sea level fluctuations.

In recent years much attention has also been paid to celestial bodies (Mars, icy moons of large planets, exoplanets) especially in connection with the search for liquid water in the solar system and with thoughts about the possible existence of life in the universe.

Geophysics graduates usually find good self-realization in research institutions both at home and abroad. Thanks to having good skills in numerical modeling they are also welcome in applied research centers and can also work in companies dealing with technology and economics.

See more: **http://geo.mff.cuni.cz**

Chemical Physics and Quantum Chemistry

Department of Chemical Physics and Optics

Research activities of the Department cover both experimental and theoretical directions of chemical physics and optics. The research includes the following topics: molecular and biological complexes and their theoretical and computational modeling (quantum theory, quantum chemistry, molecular simulation); the experimental study of semiconductor nanostructures and the development of modern spectroscopic methods (high-resolution low temperature optical spectroscopy, spectroscopy of individual molecules, femtosecond and picosecond spectroscopy) and their applications (photosynthesis, semiconductor nanostructures, optoelectronics and spintronics, etc.).

The Department cooperates with numerous institutions in the Czech Republic (institutes of the Academy of Sciences, universities and firms) and top universities in Europe and other parts of the world. The experience of the researchers at the Department is highly evaluated and used in applied studies of photovoltaics, chemical sensors, the environment etc. There is a group of applied research in chemical physics (food production and a part of the Center of Nanotechnologies and Materials for Nanoelectronics).

The 'Quantum and Nonlinear Physics' group has a long tradition in studying the fundamental concepts of quantum mechanics and in high-precision calculations of the properties of atoms and molecules. Its research activities also include theoretical investigations of small and large molecular systems with many practical applications in material science, biology and medicine. Teaching activities of the group cover all of the theory of the physical properties of atoms, molecules and molecular systems.

Several interesting results contributing to the understanding of quantum mechanics have been achieved. These are based on the standard Copenhagen interpretation of quantum mechanics and principles of mathematical statistics. The following results rank among the most remarkable ones: derivation of several quantum mechanical equations of motion from the Fisher information theory and the derivation of new uncertainty relations that are stronger than the usual Heisenberg uncertainty relations.

Other notable results include formulation of the first perturbation theory for anharmonic oscillators converging for all physically interesting values of the binding parameters, or the derivation of Hamilton's principle using a statistical description of measurement results.

Modern very precise methods are used to study **interactions between atoms and small molecules**. Potential energy and dipole moment surfaces of small molecules obtained by state-of-the-art quantum chemistry methods can be used to study stationary states of molecules. Collisions of molecules with atoms at very low temperature or radiative association of atoms are then studied by quantum dynamics methods. Results of these calculations give invaluable information about the processes of molecular cooling (e.g. a pioneering study on possibilities of sympathenic cooling of molecule NH) or about the processes of molecule formation in interstellar space. (e.g. a detailed study of molecular ion LiHe+ formation by radiative association).

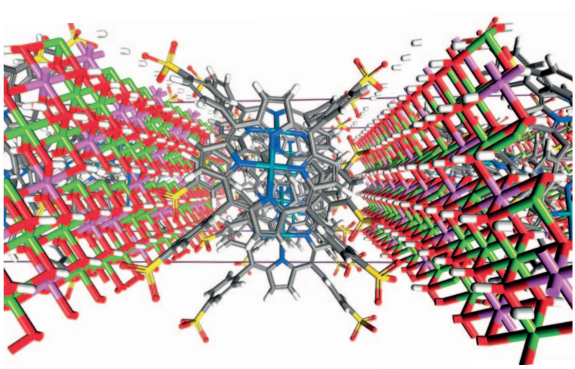
The Department guarantees the Physics master study program 'Optics and Optoelectronics' and is also responsible for the study program of 'Biophysics and Chemical Physics'.

In postdoctoral studies the Department is responsible for the programs of 'Biophysics, Chemical and Macromolecular Physics', 'Quantum Optics and Optoelectronics', and 'Physics of Nanostructures'.

There are four research groups at the Department: 'Quantum and Nonlinear Physics', 'Optical Spectroscopy', 'Optothermal Spectroscopy', and 'Quantum Optics and Optoelectronics'.

In **quantum chemistry** organometallic complexes of platinum, rhodium and ruthenium are studied. One example are the calculations of the activation of ruthenium (II) compounds, which are very promising complexes for cancer treatment. Comparing two very different classes of Ru (II) complexes from various research laboratories we come to the conclusion that although both of the classes undergo spontaneous hydration and are structurally similar, they have different reaction mechanisms. Not long ago the method was developed to calculate reactions in solutions with constant pH and constant concentration of chloride ions (pCl) – the model system of the cellular environment. This model was applied in studies of platinum complex hydrations.

Molecular simulations are focused on the structural organization of various clay minerals that are intercalated by organic cations, especially by dye cations, and by neutral polar molecules. We study the properties of anionic clays intercalated by organic anions, especially by porphyrins. The effectiveness of molecular simulations is illustrated by calculations of energetic materials (explosives), identification of interactions between the parts of the system and the possibility to simulate their explosions. Phase transitions of liquid crystals and cocoa butter triacylglycerides have also been calculated. Molecular simulations are very helpful in characterizing powder structures and predicting their resultant properties.



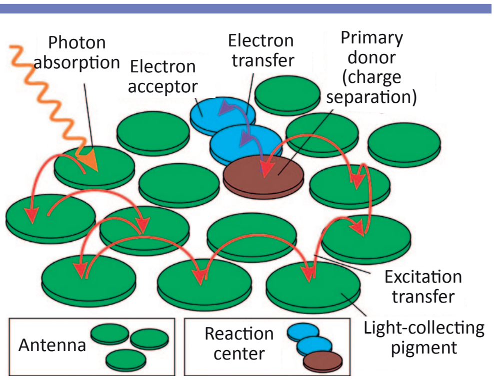
Molecular simulation of Pd-5,10,15,20-tetrakis(4-sulfonato-phenyl) porphyrin in MgAl layered double hydroxide.

• Modern Optical Spectroscopy

Towards Artificial Photosynthesis

It is important to study the first steps of **photosynthesis** (i.e. the absorption of photons by pigment molecules and fast energy transfer in light-collecting antennas to reaction centers, where the excitation energy is used to separate electrons) as various photosynthetic complexes represent model systems to study the **mechanisms of exciton or electron transfer**, or **manifestation of intermolecular interactions**.

The development of nanotechnologies enables us to mimic some of their functions. Chlorosomal bacteriochlorophyll aggregates studied at the Department may be used in developing artificial light-harvesting complexes, sensors, solar cells etc. The main task of the field is to achieve artificial photosynthesis, which means to create a complex that will use the energy from solar radiation to split water into oxygen and hydrogen.



Laser Spectroscopy with High Spectral and Spatial Resolution

Optical spectroscopy is a powerful tool in physics and is being quickly developed by new technologies – light sources (laser diodes and LEDs), photodetectors (photomultipliers and CCD cameras) and optical imaging. State-of-the-art technologies such as **laser spectroscopy with high spectral resolution** (known as spectral hole-burning spectroscopy), and more recently **microspectroscopy of individual nanoobjects** (nanocrystals, nanowires, molecules etc.), have been developed at our Laboratory over the past decades. These extreme techniques are complemented by a host of other spectroscopic techniques, e.g. measuring transient absorption by the pump and probe method, measuring the fluorescence quantum yield or absolutely calibrated spectroscopy – radiometry.

Newly developed techniques are applied to study many problems in the field of biophysics, biomedicine and nanotechnologies. For instance, we study natural and artificial photosynthetic complexes, or semiconductor nanocrystals and nanowires. These materials are partly produced or modified at our laboratories.

Another prospective direction of research is the **spectral- and time-resolved study of singlet oxygen** photogeneration using both porphyrin dyes in photosynthesis and photosynthesizers for photodynamic therapy. For this purpose we have built several state-of-the-art apparatuses allowing parallel **detection of fluorescence and phosphorescence of dyes and phosphorescence of singlet oxygen** of **in vitro** and **in vivo** materials, from microscopic resolution of cell constituents to on-line monitoring of laboratory mammals.

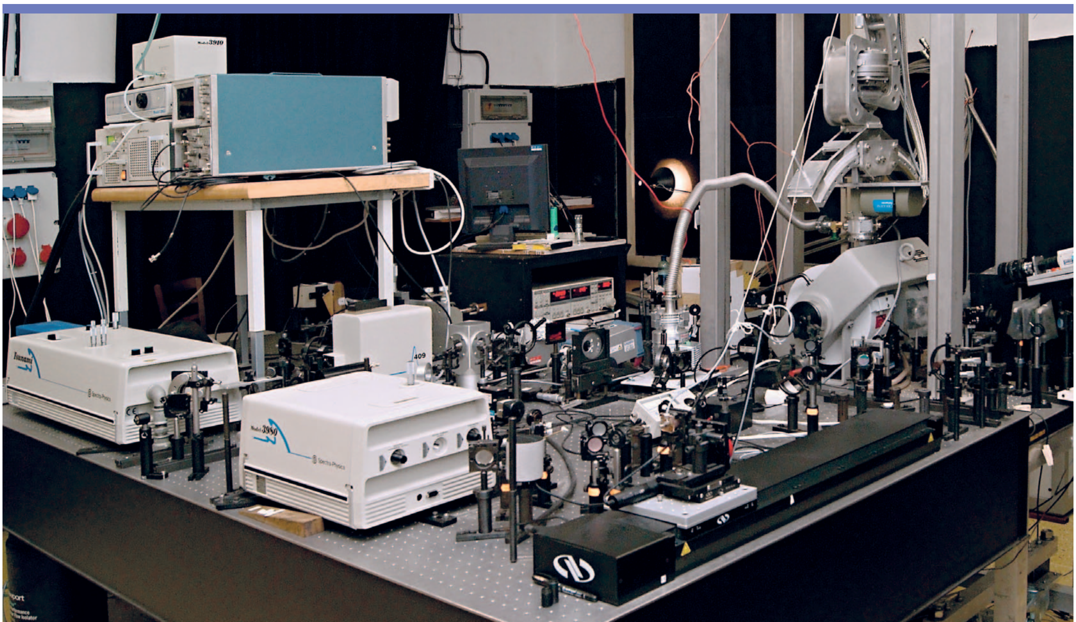
Ultrafast Laser Spectroscopy

The quantum optics and optoelectronics group at the Department of Chemical Physics and Optics is focused on experimental research in the field of ultrafast (picosecond and femtosecond time resolution) laser spectroscopy. This follows on the tradition of laser spectroscopy and nonlinear optics developed at the Department starting in the 1960s. During the last fifteen years the group has developed optical methods to study ultrafast processes in matter. At present the research is focused on **spintronics** and on fast electron processes in **semiconductor nanocrystals** (Si, CdS, CdSe, diamond, type III-V semiconductor quantum dots), which are important for modern photovoltaics, optoelectronics and photonics.

Spintronics is quickly developing as a modern part of electronics where electronic processes can be controlled by spin or a magnetic field. When the processes are combined with light signals, for instance to change the spin state of electrons or to control the magnetization of materials, one can speak of optospintronics. At present the **Joint Optospintronics Laboratory** is being built in cooperation with the Institute of Physics of the Czech Academy of Sciences.

In the field of **electron dynamics in nanocrystals**, relaxation and recombination channels of photoexcited charge carriers are studied. One important task is to achieve control that will enable us to optimize the radiative recombination to develop a laser with an active medium consisting of silicon nanocrystals, or to ensure optimum separation and transfer of a photoexcited charge when nanocrystals are used in photovoltaic elements. The studied influence of the ambient conditions on the ultrafast electron processes in nanodiamond is used in sensoric applications. In order to further develop optics with high light fluences it is necessary to know the nonlinear optical properties of materials, which are studied intensively in our laser laboratories.

Much attention is also devoted to the **theoretical study of light interactions** with nanostructures, especially to the microscopic description of phenomena that are studied experimentally.



Femtosecond laser laboratory at the Department of Chemical Physics and Optics

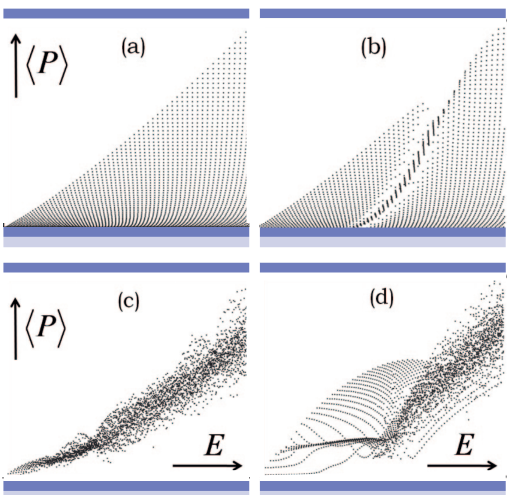
• Nuclei and Particles

Institute of Particle and Nuclear Physics

Nuclei and particles are studied at the Faculty of Mathematics and Physics in the **Institute of Particle and Nuclear Physics**, which was created in 1999 by the merger of the Department of Nuclear Physics and the Nuclear Center.

Atomic nuclei are unimaginably small, yet their structure and behavior are remarkably complex. The theoretical study of nuclei at the Institute is devoted primarily to chaos in nuclei and collective excitations of nuclei. Experimental work is focused on the study of electromagnetic decay of nuclei.

Website:
http://www-ucjf.troja.mff.cuni.cz/



Ordered and chaotic vibrations of nuclei

The atomic nucleus is a quantum object with discrete energies of excited states. Energies of nuclear vibrations, i.e. common oscillations of all (or most) particles inside the nucleus around an equilibrium shape, also form a discrete vibrational spectrum.

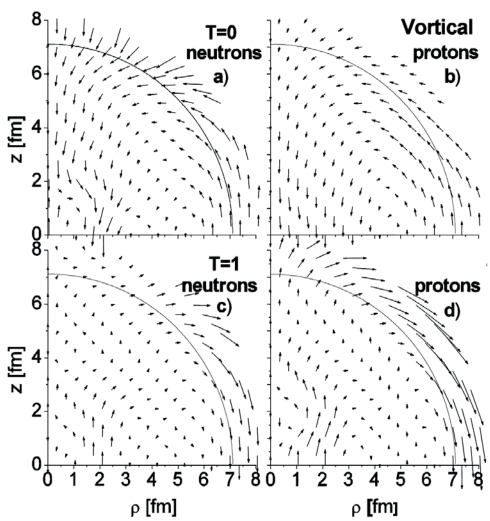
The picture shows the energies of nuclear vibrations (E) calculated within the Bohr liquid drop model of the nucleus. Each dot represents one vibrational state characterized by the energy E and another quantity <P> (the mean value of "squared seniority"). Panels (a) – (c) represent the spectra for various choices of model parameters. Dots in the pictures form ordered lattices in some cases and random clusters in others. Regularly grouped dots correspond to vibrational states in which the nucleus vibrates in an ordered manner. Chaotic states, whose vibrations are irregular and hardly predictable, appear as randomly scattered dots. Panel (a) shows the spectrum for the exactly solvable model with ordered vibrations. Even a very small change in parameters of the model leads to a break-down of the lattice, which is seen in panel (b). Chaos finally affects almost the entire spectrum (except states of lowest energy), see panel (c). With different parameters, however, new and unexpected areas of the regular dynamics appear, also very far from the mode of solvability, as shown in panel (d).

The method of spectral lattices belongs to a specialization called "**quantum chaos**". Besides nuclei, its statistical procedures are used in other complex systems containing a large number of mutually interacting particles such as molecules, atomic clusters, optical cavities, quantum capacitors, etc.

Collective states of nuclei

The collective behavior of hundreds of strongly interacting nucleons, in particular so-called giant resonances, is studied by another group of nuclear theoreticians. Giant resonances are a nuclear collective motion with high excitation energies, reached for example by the absorption of a photon in the nucleus or the inelastic scattering of protons, alpha particles, or electrons. According to the type of process and characteristic moment of mobility we distinguish different types of such resonances (e.g. magnetic dipole M1 resonance, electric dipole E1 resonance, electric quadrupole E2 resonance, etc.). Comparing measured data with theoretical calculations is a source of new knowledge and the means to develop theoretical models.

Arrows in the figure show the velocity field of neutrons and protons in the (ρ,z) plane (in cylindrical coordinates) in the ^{208}Pb spherical nucleus for two excited states of the E1 type with 8.3 MeV of excitation energy (one of the so-called isoscalar T = 0 states) and 9.1 MeV (one of the so-called isovector T = 1 states). The picture shows the vortex nature of nucleon motion in these states (in three-dimensional space these vortices form a toroid).



The Institute educates students in a master’s program specialization **Physics – Nuclear and Subnuclear Physics** and a doctoral program **Physics – Subnuclear Physics** and **Physics – Nuclear Physics**.

Candidates usually choose their bachelor thesis in the Institute and thus have a chance to get a taste of the specialization. Master studies provide students a background in quantum field theory and provide the current theoretical perspective on the world of elementary particles and atomic nuclei. Students also become acquainted with basic experimental techniques.

Thesis advisors are Institute staff along with their colleagues from the Institute of Physics and the Institute of Nuclear Physics of the Czech Academy of Sciences. The thesis is associated with research work and is the student’s first real entry into contemporary physics and the scientific world.

All of our scientific activities take place under closer or, more likely, broader international cooperation. For students this means that even during their master studies they visit some of the foreign laboratories, such as CERN in Geneva, and report on their results at international meetings. They often write their thesis in English so that foreign colleagues can understand.

• Nuclei and Particles

Institute of Particle and Nuclear Physics

Experimental particle physics requires very complicated and expensive equipment that exceed the human and financial capacities of individual countries. For this reason international cooperation has been established in this field a long time ago. In 1954, the European Organization for Nuclear Research (CERN) was founded in Geneva.

In the Eastern bloc a modest parallel of CERN was the Joint Institute for Nuclear Research in Dubna. Czech particle physicists intensively used the Dubna Institute until the Velvet Revolution, when they moved most of their activities to CERN (the Czech Republic has been a member of CERN since 1992) and elsewhere in the world. “At home” at the Institute of Particle and Nuclear Physics, we develop and test detectors and prepare the experimental program what is often associated with simulations of the expected processes. To perform the experiments we go to CERN (Geneva), FNAL (Batavia, USA), KEK (Tsukuba, Japan) and other laboratories. We then analyze the data in our Institute.

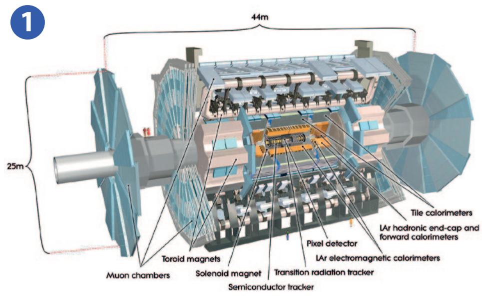
Theoretical particle physics in the Institute is focused on the development of methods of quantum field theory and theoretical models of particle interactions, again under international cooperation.

The ATLAS experiment at CERN

At the European laboratory for particle physics in Geneva (CERN) the new accelerator – the Large Hadron Collider (LHC) – has been in operation since the end of 2009. The collisions of accelerated protons or lead nuclei are recorded by ATLAS, CMS, ALICE and LHCb detectors.

Staff and students from the Institute of Particle and Nuclear Physics have been participating in the preparation, construction and installation of the ATLAS detector since the early 1990s (especially a semiconductor tracking detector and hadron calorimeter (fig. 1)). At present they serve shifts operating the detector and analyze the collisions (fig. 2). ATLAS not only searches for new particles such as the Higgs boson and supersymmetric particles but also contributes to our understanding of the micro-world. We also have our hopes set on unexpected discoveries.

1



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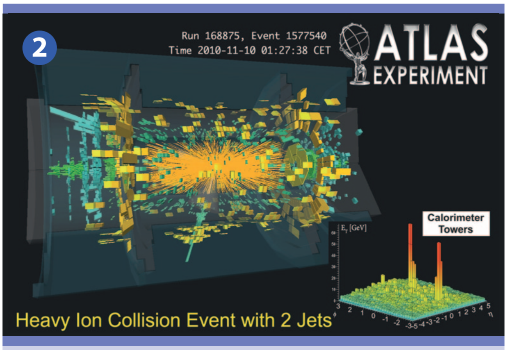
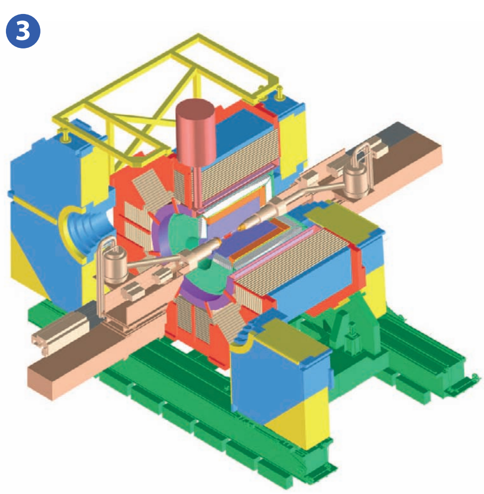
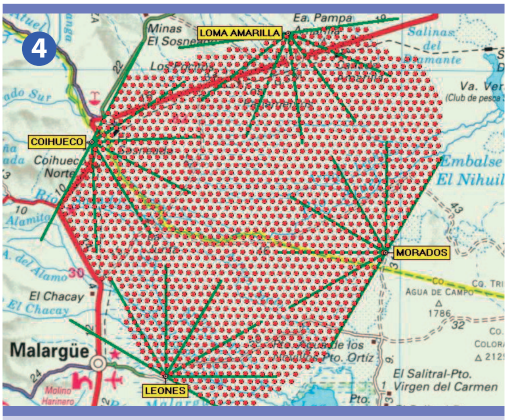




BELLE (and the future BELLE II) – fig. 3

Belle is an experiment specialized in so-called B-physics, the study of processes in which the b-quark plays a vital role. It uses beams of electrons and positrons on the accelerator in the KEK laboratory in Tsukuba, Japan. One of the key themes of this experiment is to study fundamental symmetries and their violations, in particular the violation of so-called CP-symmetry.



Auger and HESS astroparticle experiments – fig. 4, 5

Both experiments are focused on detecting high energy particles arriving from space. The Auger experiment (fig. 4) detects showers induced by protons or heavier nuclei by using fluorescent radiation of atmospheric nitrogen and shower particles that reached the ground, where 1600 aquatic Cherenkov detectors are located on approximately 3000 km^2 of pampas near the Argentine city of Malargue.

In the HESS experiment in Namibia the atmosphere also works as a substantial part of the detector – an incoming photon initiates an electromagnetic shower which appears as Cherenkov radiation (weak blue light) on the Earth's surface. This is detected by 4 telescopes (fig. 5).

Analysis of the results of these experiments in combination with other astrophysical measurements advances our knowledge of the mechanisms of particle acceleration in the universe and the structures of such exotic objects as black holes and supernovae.

• Climate, Weather and Atmospheric Physics

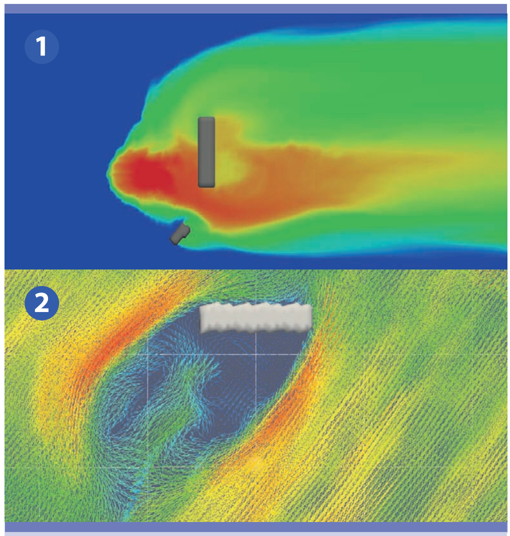
Department of Meteorology and Environment Protection

The subject of meteorology and climatology at the Faculty of Mathematics and Physics currently stems mainly from atmospheric hydrodynamics and thermodynamics using a wide range of knowledge of the other branches of physics. It focuses on the study of a variety of atmospheric processes including atmospheric optics, acoustics and electricity, radiation in the atmosphere, cloud microphysics and precipitation physics.

It specializes in the application of atmospheric dynamics, energetics and circulation in the field of meteorological forecasting using the latest methods of numerical mathematics as well as current air pollution problems linked with ecological issues. These problems include the anthropogenic influence on the atmosphere, climate modelling methods, studying climate changes and problems of both stratospheric and ground-level ozone.

Another topic being studied relates to the atmosphere as a complex non-linear dynamic system including the influence of chaotic processes focusing on the basic questions of the atmospheric processes' structure and predictability.

The main branches of research, in which the Department of Meteorology and Environment Protection achieves significant results, are represented by problems of climate and climate change, atmospheric chemistry and atmospheric quality modelling, not forgetting small-scale airflow modelling. The Department of Meteorology and Environment Protection (KMOP) has formed and still forms an important part of various international and domestic research projects.



1) The field of average surface activity (Bq/m^2) outside an obstacle after immediate leakage of a radioactive substance (99 Tc).
2) The field of airflow velocity around an obstacle. Both calculations have used the CLMM model (Charles University LES Microscale Model).

The particular state and behavior of the atmosphere in a given location is also determined – except the large-area distribution of state functions (temperature, pressure, humidity) – by specific local conditions. The final weather in a given location is thus a superposition of a number of factors. The higher the resolution we get in atmospheric models, the more the local factors apply.

One of the problems the KMOP MFF UK members deal with is the airflow interaction with non-flat ground surfaces and objects (e.g. urban environments) which appear on the ground and significantly influence the structure of the airflow field including small-scale processes and turbulence. All of this substantially influences the behavior of the part of the atmosphere where most of terrestrial life proceeds – the atmospheric boundary layer (ABL). The state of ABL also refers to the transport and dispersion of pollutants in the atmosphere and directly influences the quality of life in a given location.

Another important part of KMOP research is the issue of climate change with special attention to regionalization with the purpose of evaluating the consequences in central Europe. This is connected with the analysis of model outputs indefiniteness, climate changeability and evaluating the share of natural climate variability and changes caused by human activity. The Department operates high resolution regional climate models, which are suitable tools to study local climate changes in our complex topographic conditions. To study the interaction of a climate system and the chemical processes in the atmosphere, the model may be connected to a chemical model; this model system is then used to study the consequences of climate change air quality and vice versa.

Teaching and research at the Department of Meteorology and Environment Protection also includes studying modern conceptual atmospheric models, their application in prognostics, interpretation of numerical prognostic methods outputs as well as methods of remote sensing of the Earth's atmosphere.

From the historical point of view, meteorology and climatology have been incorporated at Charles University since the end of the 19th century. In 1902, František Augustin was appointed as the first professor of meteorology at the university.

In the following decades professor Stanislav Hanzlík published world-famous works about the structure of cyclones and anticyclones.

After World War II, the department was managed by professor Stanislav Brandejs and its activity was mainly concentrated to the field of numerical methods of meteorological forecasting and also took a leading position among universities in the former Czechoslovakia.

In the 1970s and 80s the department gained a leading position in the area of modeling the dispersion of anthropogenic air pollutants. In the early 1990s the Department of Meteorology was the first Czech scientific workplace to take part in climate change and climate modelling research.

Further information about the subject of meteorology and climatology, the department (KMOP), and courses of study may be found on our website:
http://kmop.mff.cuni.cz/

• Theoretical Physics

From the Smallest to the Biggest

Thanks to the interesting combination of the two main topics we pursue at the Institute of Theoretical Physics (ÚTF) – the general theory of relativity and collisions of electrons and ions with atoms and molecules – we can honestly say that we study the entire universe from its smallest to its biggest constituents.

Additionally, we also popularize physics by giving lectures for both high school students and the public, translating relevant popular science, and organizing public tours of the ÚTF.

The ÚTF closely cooperates with foreign institutions including University of Cambridge, Harvard University, Loughborough University, Albert Einstein Institute, Heidelberg University, University of Alberta, Universitat de les Illes Balears, Perimeter Institute for Theoretical Physics, Institut d'Astrophysique de Paris, Université de Toulouse, Technical University Munich, and Friedrich Schiller University in Jena.

Naturally, we also cooperate with our colleagues from the Czech Republic, who work at the Institute of Physics AS CR, Institute of Mathematics AS CR or Silesian University in Opava.

Our website:
http://utf.mff.cuni.cz/

There are two research teams at the ÚTF. One deals with the general theory of relativity (GR), i.e., Einstein's theory of gravity, and its applications in astrophysics and cosmology. The team was founded in the 1970s by Professor Jiří Bičák. Today, his students work not only at MFF UK but also at other universities and research institutes across the former Czechoslovakia. They have established their own successful GR groups, e.g., at Comenius University in Bratislava, Silesian University in Opava, and the Institute of Mathematics AS CR.

The difficulty with GR lies in the fact that Einstein's equations determining the character of the gravitational field represent a set of non-linear, partial differential equations and it is extremely complicated to find their solutions. Thus, we study the character of the solutions we already know and, based on them, we are able to generate new ones. One topic we are interested in is the propagation of gravitational waves, which promises to open a completely new window to the sky and universe as a whole. We also study the asymptotic characteristics of space-times, black hole horizons, influence of non-homogeneities in cosmological models on the interpretation of astrophysical measurements, chaotic motion of particles in gravitational fields, and behavior of thin disks around black holes. Another interesting GR application is also the so-called gravitational lensing, an effect which distorts the appearance of objects lying behind a massive body.

In addition to exact solutions, we also pursue another vital topic of modern GR, i.e., numerical relativity, which analyzes the character of GR models using approximate numerical methods running on computers. Further, we study GR extensions and their properties under the assumption there are more than four dimensions.

The other field of research we pursue at the Institute of Theoretical Physics are collisions of electrons and ions with atoms and molecules. Our team was established by Professor Jiří Horáček. The main topic the team works on is development of numerical methods in quantum scattering theory and their application to particular problems in collaboration with foreign institutes in Heidelberg, Munich, and Berkeley. Former students from the research team now work in Japan, USA, and the UK.

Recently, the team has managed to anticipate and explain the existence of long-lived states of hydrogen anion, resonant structures in cross sections of inelastic electron collisions with molecules, excitation energy transfer in atomic clusters, and a number of other phenomena.

Currently, Professor Horáček calculates resonant parameters of polyatomic molecules while his colleagues work on other issues of atomic and molecular physics. Martin Čížek applies scattering theory to calculations of charge transfer through molecular bridges, which may behave as molecular engines. Karel Houfek studies nuclear dynamics of resonant electron collisions with polyatomic molecules and Přemysl Kolorenč works on a new subject, interatomic coulombic decay of molecules and clusters.

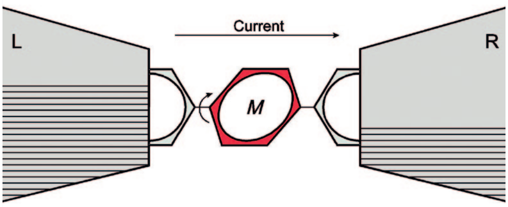


Diagram of a molecular engine. A molecule connected to two electrodes is spun by the current passing through. The detailed description of the system is a highly non-trivial issue of non-equilibrium quantum statistical physics.

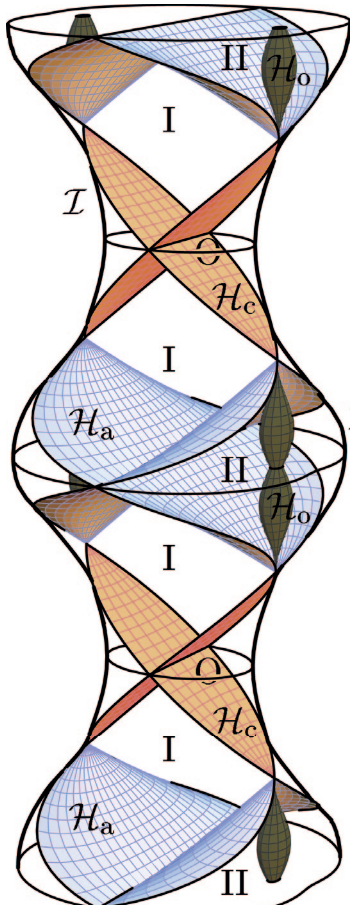


Image of the causal structure of spacetimes with accelerated black holes and a ***negative cosmological constant****. Time passes along the vertical axis, horizontal directions represent space.*

The black areas symbolize black-hole horizons, the outer surface corresponds to infinity.

• Modeling in Physics and Technology

Mathematical and Computer Modeling in Physics and Technology

Mathematical and Computer Modeling in Physics and Technology is a relatively young and demanding interdisciplinary subject in both the mathematics and physics programs. The discipline was founded by Professor Jindřich Nečas (Theory of Partial Differential Equations), Professor Jan Kratochvíl (Continuum Mechanics), and Professor Ivo Marek (Numerical Mathematics) with the vision of offering a study that combines modern top-level mathematics and physics, especially with regard to continuum mechanics. Students of this subject are in close contact with students of the analogous subject within the mathematics program (see page 120).

Besides training in classical physics, our students are led to use actively some modern mathematical methods that do not belong to those applied commonly in these particular fields of physics. Mathematical modeling is not a large-scale subject; it is based on personal approach and attempts to involve students in active scientific work. For instance, we closely cooperate with the Department of Geophysics; however, we also deal with problems from other fields of physics, for example in coopera-

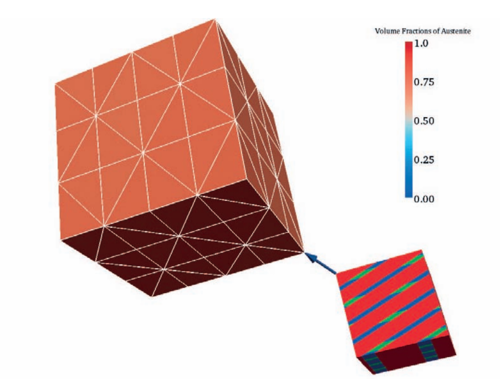
Mathematical Modeling, both within the Mathematics and Physics programs, focuses mainly on the problems within continuum mechanics; for an example of a particular problem, see the section on modeling from the mathematical point of view, page 120. Continuum mechanics deals with models of ‘continuous’ environments and, at the same time, relies on the ideas of classical Newtonian physics as well as modern phenomenological thermodynamics.

Analysis of Partial Differential Equations

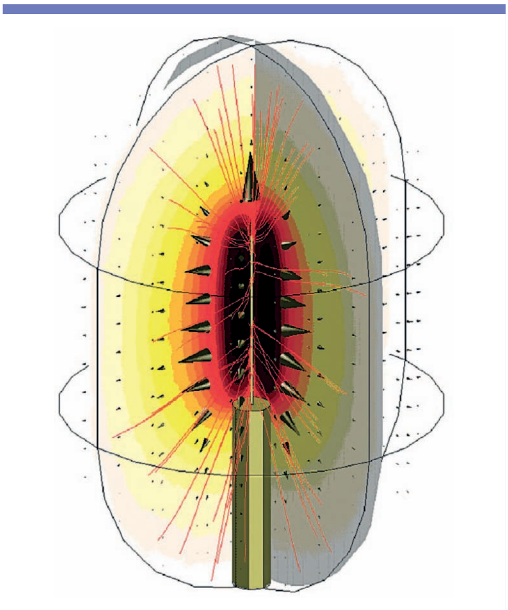
Models in continuum mechanics lead to systems of partial differential equations. An important step is to prove that there are solutions to these equations. This is also essential for computer simulations; we have to know that our effort to find a numerical solution is not doomed to fail in advance. We also study the quality of solutions without finding them first. The focus on high-quality mathematical preparation, which enables you to use and develop modern mathematical methods, represents the added value provided by mathematical modeling in comparison to an approach focused solely on physics.

Computer Simulations

Predicting the behavior of a particular material also comes down to computer simulations. However, it is not enough to load the task into commercial software and wait for the results. We also have to choose an algorithm suitable to solve the given task – the algorithm must respect the physical characteristics of the problem. It is necessary to prove that the selected algorithm is a reliable lead to a solution and then implement the algorithm in a high-quality manner including parallel computing. Combining the physical point of view of the issue and deep knowledge of modern numerical methods will enable you to design your own robust methods to solve any unsolved problem. Therefore, you will not depend on previous approaches only, which may not be suitable for the studied problem.

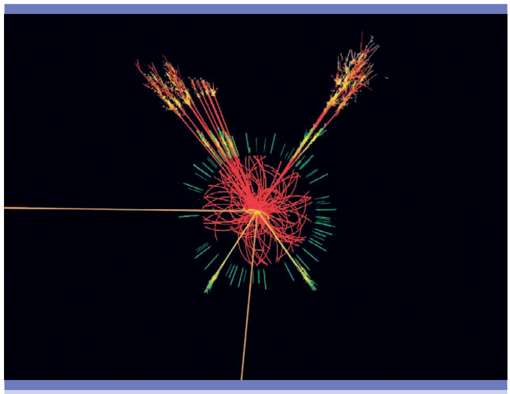


Simulation of a material with shape-memory, the NiTi alloy. Examples of variational inequalities.



tion with the Department of Physics of Materials or The Institute of Organic Chemistry and Biochemistry AS CR.

Computer simulations form a common part of work in a number of fields of physics and they are mentioned in the individual disciplines. Many physical systems cannot be described adequately by a set of equations that could be solved analytically or numerically but we can write and implement an algorithm describing the behavior of the system reliably. Some currently used computer models resulted from the work of Faculty departments, e.g., the above-mentioned model of plasma (see bottom left). Likewise, we often use and modify simulation programs applied by international teams in the individual fields of physics.



The picture represents an example of a decay simulation of Higgs boson produced in proton collisions at the LHC. It is a simulation of a theoretically predicted process including a simulation of detector response (ATLAS). Such simulations enable researchers to prepare searches for unknown phenomena.

• The History and Prospects of the School of Computer Science

Introduction

The SCS at the Faculty of Mathematics and Physics includes seven prestigious teaching and scientific workplaces. The quality of their graduates is widely recognized. Among them are a number of top experts working as computer program developers and technological innovators. Members of the SCS achieve outstanding scientific results in discrete mathematics, especially in graph theory and its application in intelligent systems, optimization, databases, programming methods, semantics and building large software systems, processing natural language and many others.

Achieving these results was not easy because the program of study in computer science at the faculty developed gradually and was established in accordance with world trends. Within the conditions of the faculty the program also had to become independent from the subject of mathematics. It was also necessary to overcome various prejudices. The main problems have actually always lain in computer science itself and in its impact on our society.

Computer performance, memory capacity and other hardware efficiency parameters had until recently doubled and in a way, using networks and parallelisms, are still able to double in approximately 18 month's time (Moore's Law). Within fifty years it means the performance will increase with the ratio being that of 10^{10} to one. This represents a proportion of several years to one second. What was infeasible at the beginning of the 1960s may be integrated in interactive systems today.

Therefore, it is no wonder that in computer science half of the knowledge becomes outdated within five years. It is even more important to note that approximately once in ten years there is a change in basic paradigms as well as in basic aims of their applications. Nowadays, the systems using the web work completely different and offer entirely different possibilities than mainframe computers did forty years ago. In the realm of computer science, it is necessary to become familiar with a vast amount of information that may, to a certain extent, create a new subject area in which very specific skills must be mastered. These skills are often only acquirable through practice.

Computer science has a deeper and deeper impact on social processes and on new fields of human activities and depends more and more on political and economical conditions. The meaning of these non-technological aspects gradually increases over time. The systems become bigger, more open and much more interactive. Distributing both systems and data all over the world has become standard, rather than exceptional.

Rapid ICT (Information and Communications Technology) development brings rapid changes of current research topics as well as the need for permanent modernization and optimization of teaching computer scientists. Some parts of computer science are used and developed for application fields. Some areas that have nearly been forgotten, e.g. the programming language FORTRAN, are currently being used and developed by other areas of science and technology, as well. However, let us go back to the beginnings.

Building a New Discipline; The Pioneering Era

Computer Programming at MFF started to develop at the end of the 1950s, and as a result, the gradual development of teaching and researching of computer science also emerged. At the beginning it was used mainly for the purposes of numerical mathematics. In 1961 The Center of Numerical Mathematics (headed by F. Nožička) was established, which also provided teaching numerical mathematics. In 1964, with the increase in the number of students, the Department of Numerical Mathematics was set up and it was soon possible to study computer science in more detail under the subject name Non-numerical Computer Applications. It was not until the 1970s when The Ministry of Education approved Numerical Mathematics and Theoretical Cybernetics as study subjects. Numerical Mathematics had one of its three specializations called Mathematical Basis of Information Technology. Between the years 1975-81 computer science was cultivated partly at the Department of Cybernetics and Operational Analysis (headed by M. Vlach), and partly at the Department of Mathematical Informatics (headed by K. Najzar). Theoretical Cybernetics (as visioned by Petr Vopěnka) has combined logic, computability and probability with basic understanding of programming. The year 1981 brought us a department "with a long name", i.e. the Department of Cybernetics, Informatics and Operations Research (headed by M. Vlach). In 1987 the Department of Cybernetics and Informatics (headed by M. Vlach, and later M. Chytil, A. Kučera) was created at the faculty.

Many great programming protagonists are connected with the beginnings of computer science at MFF, including: L.Koubek, J. Raichl, and E. Kindler. The last two came from the oldest computer science center in Czechoslovakia, The Research Institute of Mathematical Machines. They started the tradition and educated the following generations of computer scientists. Similarly, there were others to come later including: J. Demner, J. Hořejš, J. Pokorný, F. Plášil, P. Vojtáš and others.

The key part was played by J. Raichl, one of the computer science legends in our country. He excelled as a lecturer who could relate all of his knowledge and skills to his students in extraordinary ways. His books became fundamental in computer science as a subject itself. It is especially due to his impact that MFF graduates are still outstanding programmers and developers today. Students have always had to practice their abilities of team work, as well. J. Raichl's pedagogical results and approaches have also been followed by other lecturers such as R. Kryl and T. Topfer.

In the early 1960s, at the so-called "Raichl's seminar," the language Algol 60 and its methodology were referred to. It was soon proved that with good practical results it is possible to use the concepts of mathematical linguistics to define programming languages and that the results of computability theory (O. Demuth) and mathematical logics (P. Vopěnka, P. Štěpánek) have entirely practical consequences. As an example we can mention various database implementations or the Travelling Salesman Problem. This can be seen as a key contribution of J. Nešetřil.

Experience with using mathematical linguistics in defining programming languages later contributed to the fact that the leading center of mathematical linguistics, the current Institute of Formal and Applied Linguistics – ÚFAL (E. Hajičová, P. Sgall) became a part of the faculty. Apart from the above mentioned subjects, outstanding results have also been achieved in operational analysis (M. Vlach) and discrete simulations.

A great contribution to the success of the new subject was organizing the conference, or winter school, called SOFSEM, which has been run since 1974 by J. Gruska with the help of experts from all important centers in Czechoslovakia, including MFF. The six-hour lectures presented at SOFSEM could well be used as cores of semestral lectures. SOFSEM significantly contributed to the development of computer science in Czechoslovakia and is still valued as a distinguished international conference. The seminar "Modern Programming" founded in 1980 by R.Kryl also represents a considerable contribution to programming development in our country.

The Following Twenty Years

After 1970, computer scientists at MFF became well aware of new paradigms and developmental tools of the era, including mainframe computers with terminals, mini-computers and later micro-computers and PCs. Systems to support project and developmental works started to be used. Over the course of time, computer science activities at MFF have been divided into new departments.

The oldest department of the SCS is the Department of Applied Mathematics (KAM) which under the leadership and vision of J. Nešetřil developed since 1986 into one of the key departments of the whole faculty. In the last two decades the scientific work and activity of its leaders (Nešetřil, Pultr, Kratochvíl) and other core members (Loebl, Matoušek) together with their students which are active both abroad (Kříž, Thomas, Vondrák) and home (Z. Dvořák, Klazar, D. Král, Šámal, Valtr) formed one of the most important groups, internationally recognized in the areas of discrete mathematics, combinatorics and theoretical computer science.

In 1993 the Department of Cybernetics and Informatics was replaced by the Department of Software Engineering (headed by J. Pokorný), the Department of Theoretical Computer Science (headed by A. Kučera, and later V. Koubek), and the Department of Software and Computer Science Education (headed by R. Kryl). In 1994 the Network and Labs Management Center was also established. The Institute of Formal and Applied Linguistics (ÚFAL) was set up in 1991 (headed by E. Hajičová) and soon became a world-famous center for computer linguistics.

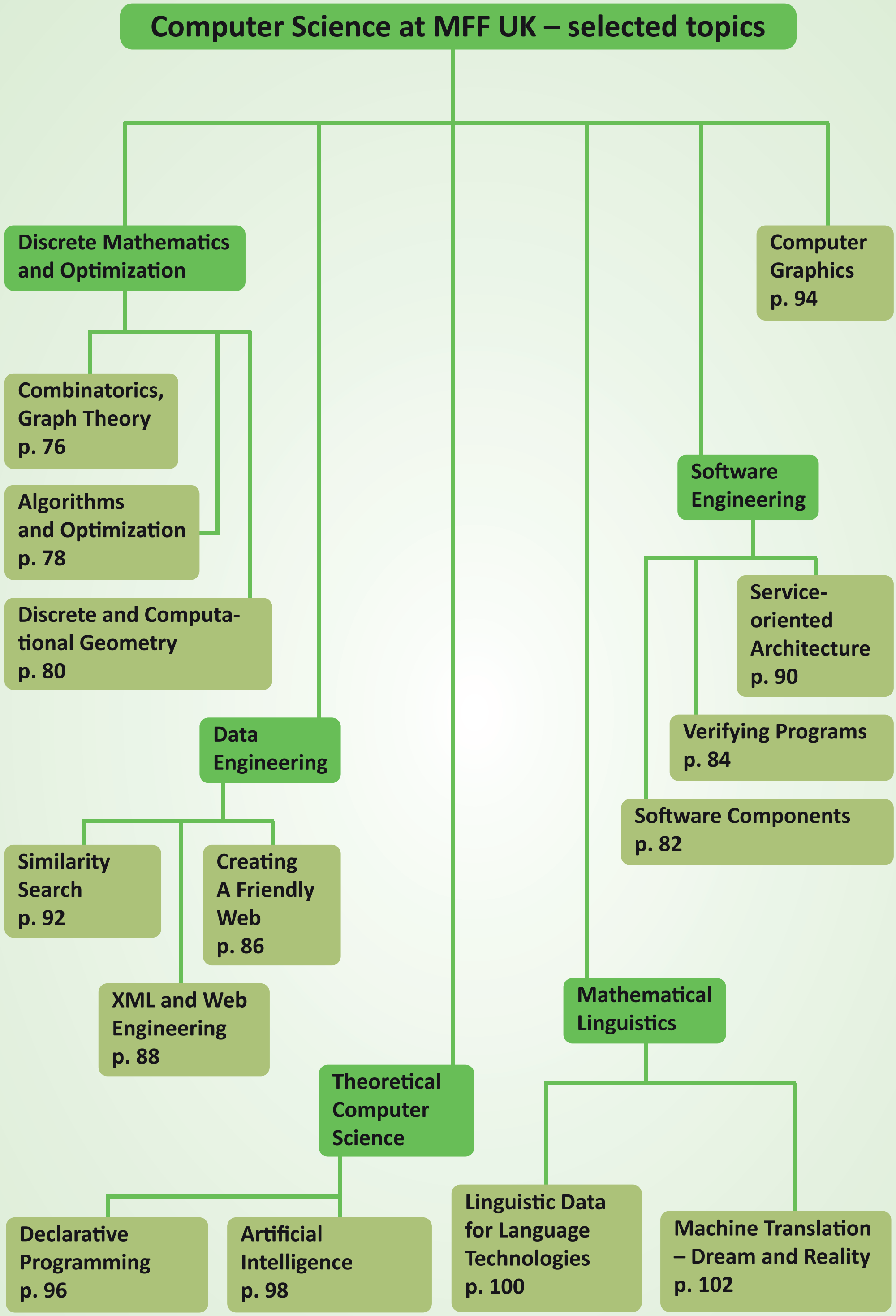
Teaching the foundations of computer science, especially the basic skills called programming, was of a high standard. Gradually, teaching system programming and team projects were added, with special thanks to J. Demner and J. Král. It is significant that teaching computer science has always responded quickly to new streams and technologies within the realm of computer science including fields such as data mining, data protection, web engineering, and XML.

It is important to take into account the fact that computer science is primarily a technical and engineering subject. To create large systems it is important to use a considerable amount of different approaches, paradigms and other tools than in the case of individual applications. Engineering procedures should also be used. This approach was stabilized by creating the Department of Software Engineering, whose teaching methods were modernized including the use of advanced hardware and leading commercial software products. The main success was thus achieved in the fields of database systems (J. Pokorný) and research and support systems of the object approach and component architectures (Fr. Plášil).

The Present and Future Overview

Scientific activities of KAM resulted (in 2000) the in creation of the Institute for Theoretical Computer Science (ITI) which has been repeatedly awarded and supported by Czech government funds as one of the very few scientific centers of excellence. ITI is now coordinated by the recently established Computer Science Institute of Charles University (IUUK). KAM, ITI and IUUK provide a link between computer science and mathematics.

Concerning computing, the members of SCS have mastered the latest changes in software paradigms very well and have achieved high quality results in engineering and technological aspects of computer science. It is necessary to cope with the issues of user response and the response of social environments like social networks, data protection and the impact of large companies. The developments of computer science itself, and especially the issues of what to research in computer science, are also influenced by the research in big companies accompanied by new product development. A lot of computer science applications today require very detailed knowledge of the particular area. This all should also be reflected in a certain form in teaching computer scientists.


Computer Science at MFF UK – selected topics
Discrete Mathematics and Optimization
Combinatorics, Graph Theory p. 76
Algorithms and Optimization p. 78
Discrete and Computa-tional Geometry p. 80
Data Engineering
Similarity Search p. 92
Creating A Friendly Web p. 86
XML and Web Engineering p. 88
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Computer Graphics p. 94

School of Computer Science

Malostranské náměstí 25, Praha 1-Malá Strana

Departments in the building:

Department of Software and Computer Science Education
Department of Applied Mathematics
Department of Distributed and Dependable Systems
Department of Software Engineering
Department of Theoretical Computer Science and Mathematical Logic
Network and Labs Management Center
Institute of Formal and Applied Linguistics
Computer Science Institute of Charles University

Topics:

• Combinatorics, Graph Theory

Department of Applied Mathematics

http://kam.mff.cuni.cz/

Important Projects:
EU project Graph Drawings and Representations (2011-2013)
http://kam.mff.cuni.cz/gradr/

Topic: Graph Visualization
EU project Classes of Combinatorial Objects – from Structure to Algorithms (2010-2015)
http://kam.mff.cuni.cz/ccosa/

Topic: Structure of Combinatorial Objects
The Institute of Theoretical Informatics (2000-2011)

http://iti.mff.cuni.cz/

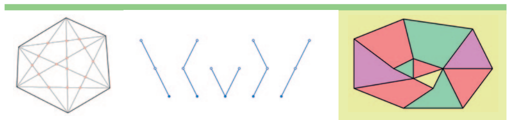
Students are our partners
kam.mff.cuni.cz/prezentace

Involvement in Science and Research
Students are regularly involved in working on research projects. Some of them manage to publish articles in prestigious journals and take part in international workshops and conferences even during their bachelor's studies.

Spring School on Combinatorics:
Regular event for our students.
Non-traditional Tuition:
youtu.be/PEBUYt8LgkY

Let us introduce our discipline by means of five "puzzles" or as short little problems you can think about. Combinatorics and graph theory is a lucky discipline in which there is a short distance from such puzzles to solving real challenges. Would you like to try that? Experience shows us that it is not only fun, but that it is also good practice for a number of careers.

Diagonals: Let us draw all diagonals in an irregular (convex) polygon. As the polygon is irregular, no three diagonals intersect at one point. In the picture there is a hexagon in which we can find 15 points of intersection (red points). How many points of intersection can we find for a 20-gon?



Counting Trees: In the picture there are all the five "binary trees with three vertices". How many binary trees with four, five, ... vertices can be found? Can we find out without drawing all the possibilities?

Ramsey Numbers: In each group of six people either some three of them know each other or some three of them are mutually unacquainted. Why? For a group of five people this is not true. Why? We shall record this as R(3) = 6. It is much more complex to show R(4) = 18. No one can determine R(5). However, we know that the numbers R(5), R(6), … do exist.

Coloring Graphs: Every map where each country has a connected area may be colored by four colors so that the neighboring countries have different colors (neighboring “over the corner” does not count). Mathematicians took almost 150 years to produce a correct and widely recognized explanation. One of the authors of this proof, Robin Thomas, is a former student of our faculty. Can you find explanations for easier versions with five (six, …) colors?

A Prison Story: In a jail in the town of N, the warden plays a cruel game with the 100 prisoners. He has placed their names into 100 lockers in his office, one in each locker, and, one after the other, he calls the prisoners in. Each of them may check any 50 lockers, then they are locked and the prisoner has to leave the room. The prisoner is not allowed to talk with the others. Provided each prisoner finds their name in an open locker, they will all be released. However, if one of them fails to find their name in the fifty open lockers, all the prisoners shall be executed. Can the prisoners agree on a suitable procedure that would give them at least a chance to survive?

Prisoner A: “We will all open the first fifty lockers, it makes no difference.”

Prisoner B: “Then we’ll all be surely executed!”

Prisoner C: “We all randomly open any 50 lockers. There is a 50% chance to find our name. Totally, the chance to survive equals (1/2) times (1/2) times … times (1/2) (100 times) because mutually independent chances multiply. The approximate result is 0.00 … 07 with thirty zeroes after the decimal point. It’s not very much, but it’s better than nothing…”

Prisoner D: “I know the procedure that will provide us all with more than a 30% chance to survive. It is not 100% as that is impossible but still better than zero point zero nothing. We shall proceed like this…”

Try to think over some of the questions and answer them. Easy ones first. Why does the proposal made by prisoner A give a zero chance of survival? Why did prisoner C multiply the chances? Would you believe prisoner D if he promised a procedure with a 70% chance to survive? And now the most difficult and most interesting one – what procedure then gives the 30% chance to survive?

Some of the mentioned puzzles are easy, some are difficult and some extremely complex. Solutions may be found online at **http://kam.mff.cuni.cz/resenihadanek**.

Combinatorics and graph theory study structures which model the relationships between a finite number of objects. A good example of this would be roads between towns. It has a wide range of applications. These include looking for the shortest way to get to a destination (as in GPS navigation devices or searching in public transit timetables), making schedules for classes at schools, and assigning variables to particular registers in computer processors. It also helps with analysis of data structures (frequency of memory access, expected time complexity), and so on.

Combinatorics and graph theory belongs among disciplines where paper and a pencil suffice.

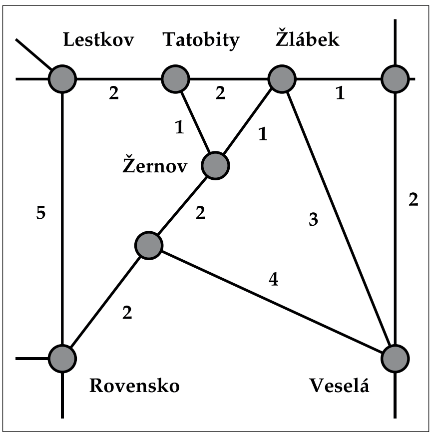
Therefore, we can organize lectures in unusual locations. Our student Jan Hladký lectures at the Spring School in Vysoká Lípa.

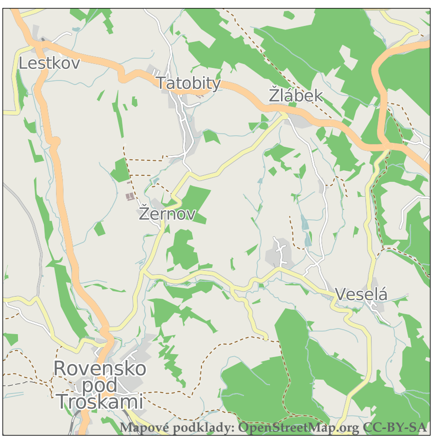
Algorithms and Optimization

Department of Applied Mathematics

http://kam.mff.cuni.cz/

For detailed information about the department see page 76:
combinatorics, graph theory.





Unlike geometry, which has enjoyed great attention for centuries, if not millennia, the science of studying algorithms is still quite a young subject. However, its results surround us every day – the core of each computer program, whether it controls a spacecraft or wrist watch, is an algorithm.

The roots of studying algorithms, however, date back to ancient times. Developing the exact procedures to solve tasks of the same type, known as algorithms, interested people more than two thousand years ago. For instance, let us remember the Euclidean algorithm for computing the greatest common divisor of two integers. Nevertheless, almost all historical algorithms were carried out by a person, or by more or less sophisticated mechanical machines, which significantly limited their possibilities.

The golden era of algorithms did not arrive until the 1960s with development of computers. Computers soon became universal machines, which could process a vast amount of information according to any algorithm. Since their potential is determined by our ability to design algorithms, studying algorithms has obviously become a centre of interest within the field of science known in English as "computer science" and in Czech as "informatics".

Let us have a look, for instance, at today's car navigation systems. They usually contain a GPS receiver measuring the current position of the car and a small computer with a digital map and software for finding an optimal (that may mean the fastest or the most economical) route between two given points. The algorithm for finding the route does not usually work directly with the map but rather with its abstraction in the form of a so called graph. A graph consists of vertices (representing the towns and crossroads) connected by edges (road segments). Each edge has some cost – its length, time or cost. The algorithm then finds the edges connecting the given points with the minimal cost.

What are we doing?

Our example of transforming a real-world problem to a question dealing with graphs is quite common. Many other tasks can be described through graphs – for instance transporting liquid through a system of pipes, creating a timetable, solving Rubik's cube, or allocating frequencies to transmitters within mobile phone networks. All such problems are being studied at the Department of Applied Mathematics. Not only do we deal with particular practical questions but also with more general theory of graphs and graph algorithms. It then serves as a kind of background for solving individual tasks.

Optimization

Route planning is, from the classical mathematics point of view, an unusual setting. We do not ask if an object exists (for example, a limit of a sequence or a route in a graph) because that is usually obvious. When working with algorithms, we are usually interested in finding a given object or, if there are several, in finding the best object (shortest, fastest, cheapest, …). Such searching for the best possible results is the core of a mathematical discipline called optimization.

Because of the limitations of our computers, optimization algorithms must be able to work within limited time and memory. That is sometimes easy, for example when looking for the shortest route. However, if we altered the question a bit and searched for the shortest route visiting all the towns, we would immediately face a challenge with no known efficient method of solution.

For hard problems like that we also study algorithms that quickly find a solution, which might not be the best possible but always almost the best one – for example a route at most 10 % longer than the shortest one. Such algorithms are called approximation algorithms.

On-line algorithms

Sometimes the optimization algorithm does not know its entire input in advance. The input comes in parts and the algorithm has to immediately respond to the already read input parts. These on-line algorithms are well illustrated by the following example.

Let us consider a flat pasture divided into two half-planes by an infinitely long straight fence. There is a cow grazing in one half-plane and it would like to get to the other side of the fence, where the grass is greener. However, there is only one gate in the fence.

If the cow knows where the gate is, it moves in the right direction and obviously walks the shortest possible distance. If the cow does not know the right direction, it must follow a more involved strategy and switch both directions. Try to find a strategy. We reveal that there is a strategy in which the cow walks less than ten times the initial distance to the gate.

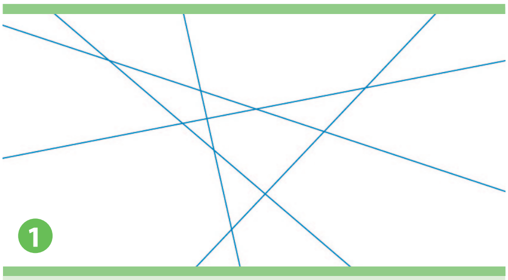
There are also more practical questions within the field of on-line algorithms, for instance lift control (where we learn the passengers' requests one by one) or even the stock market (where we continuously respond to the price development).

• Discrete and Computational Geometry

Department of Applied Mathematics

http://kam.mff.cuni.cz/

For detailed information about the department see the section on *combinatorics and graph theory* on page 76.



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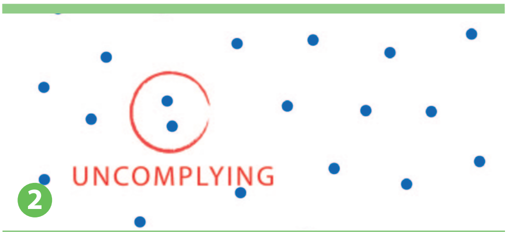

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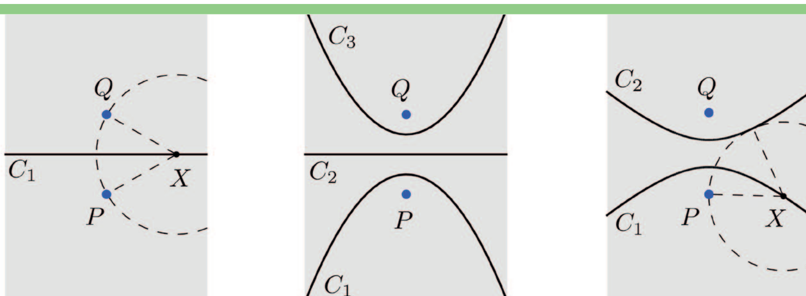
Geometry is one of the oldest branches of science, and so it might seem that everything about simple geometric objects such as points, straight lines, ellipses or rectangular boxes has already been discovered. However, the much younger fields of discrete geometry and computational geometry ask new questions about these basic geometric objects, and they contribute to the development of modern technologies.

Let us start with an example of an easy question in discrete geometry. What is the maximum number of pieces we can obtain by cutting a rectangle along n straight lines (see Figure 1)? The picture shows that for $n = 5$ we can get at least 16 pieces. This problem is often given as an assignment to freshmen at the Faculty of Mathematics and Physics, and many of them manage to solve it. Usually they get a hint – how does the number of pieces increase by adding another straight-line cut? The reader is invited to try as well.

What problems are considered in computational geometry? Here is a small illustration: a computer program receives n points in the plane as an input (as in Figure 2), and it should check whether the points have sufficient spac-



3

ing; namely, it should test whether each point has distance at least 1 from all others. How can this be done so that the program can process a large point set, say with a million points, in reasonable time? Some cleverness is needed, because directly checking the distance for each pair of points would be hopelessly slow.

What about the Department of Applied Mathematics? In the areas of discrete and computational geometry, the department focuses mainly on basic research. We are going to describe concretely one of the topics investigated by our researchers and graduate students.

A New Curve

Hiroshi Murata, a Japanese engineer working in VLSI design, raised the following geometric problem. Given two points P and Q in the plane, we want to place k curves $C_1, C_2, \ldots, C_k$ between them that are "equally spaced". This means that each point X, the distance from X to P equals the distance from X to C_2, each point of C_2 has equal distance to C_1 and to C_3, etc.

The case $k = 1$ is easy – the solution is the straight line drawn in Figure 3 on the left. For $k = 3$, the problem is also solved by well-known curves: C_2 is a straight line and both C_1 and C_3 are parabolas, as shown in Figure 3 in the middle. However, for $k = 2$ we obtain curves as in the right picture, which apparently have never been studied before. Actually, it is only one curve, since C_2 is a mirror reflection of C_1. It is called the distance trisector curve (not to be confused with "trisector" as a medical diagnosis; this word is often used for a person who obstinately tries to solve the ancient problem of trisecting an angle by ruler and compass, which was proved to be unsolvable almost 200 years ago).

What is the equation of the distance trisector curve? Probably there is no equation, in the sense that it is probably impossible to describe the curve using the usual functions such as power, sine, logarithm, etc. However, two Japanese researchers in collaboration with the Department of Applied Mathematics managed to prove that the distance trisector curve exists and is determined uniquely (this is not as easy as it might seem), and that the points on its graph can be computed fast and with arbitrary precision. However, for $k = 4$ or larger, analogous results are still unknown.

What can I do after growing up and studying all of this?

Computational geometry has been applied in architecture, biology, chemistry, medicine, mechanical engineering, textile industry, and a number of other areas – whenever one needs to process large geometric data sets. Discrete geometry constitutes a mathematical foundation for computational geometry.

You can, for instance, seek a job at a company like Geomagic; see http://www.geomagic.com/, whose products include, e.g., software for creating digital models of three-dimensional objects. A three dimensional scanner scans the position of many thousand points on the object's surface, and then the software needs to analyze the shape of the object – for example, we may want to obtain a reasonable surface made of little triangles (the resulting model can be used to create a faithful copy of the original object by a 3D printer). Our choice of Geomagic as an illustrative example is not accidental; its founder and CEO, Herbert Edelsbrunner, is a top-level researcher in computational geometry.

If you are enthusiastic and materially unassuming, you also have the chance to stay in the academic sphere and do basic research. Obviously, you can also become a securities trader, an artist, or a more or less successful politician, similar to many other former students of the Faculty of Mathematics and Physics: the strength of the graduates of this school lies not only in specialized knowledge, but also in a well-developed ability of thinking clearly and analyzing problems in depth.

• Software Components

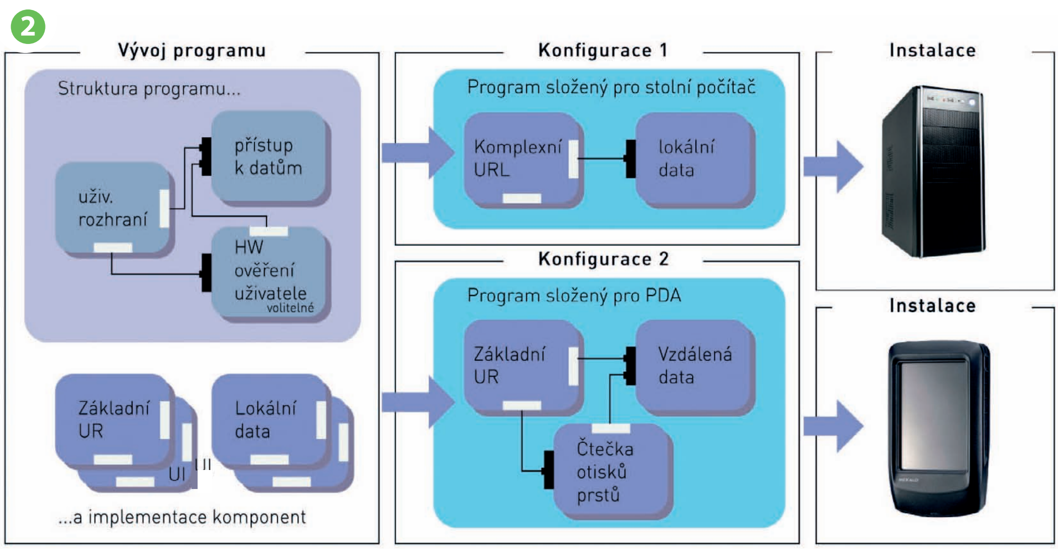
Department of Distributed and Dependable Systems

http://d3s.mff.cuni.cz/

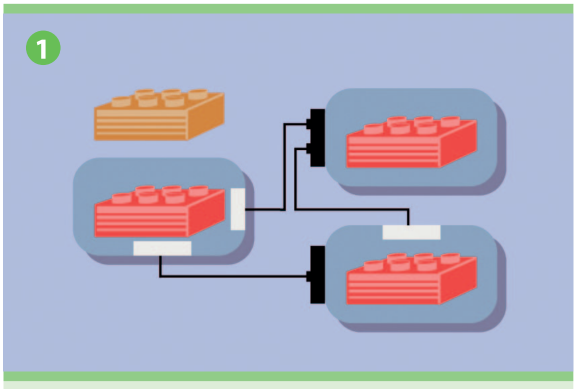
One way of designing software is using software components. Components should be easily usable by developers and they should enable functional verification as well as measuring and prediction of their performance.

Research topics solved in international projects include:
The performance predication, composing applications from components and services, and component system facilitating development of software for space satellites

Most likely everyone has seen the inside of a computer and knows that it consists of a processor, memory and other components. Many also know that a regular desktop PC is assembled from these components like a puzzle, i.e. individual components are produced by different manufacturers and those are the retailers or even end-users who put a computer together. This kind of assembly usually means simply connecting the parts together. Considering that this way of hardware assembly has worked well for years, it is only logical to try to use a similar way for creating software. In the field of software, this is called component-based development. A developer composes an application from existing software components and creates from scratch only the components specific for the given program.



Software components may be perceived as lego building blocks. On one hand they provide some services, this can be likened to the side with pegs of lego blocks. On the other hand they require other services for their operation, which is like holes of the lego blocks. The components connect together via both provided and required services, just like the lego blocks. A couple of connected components can form another component, so called composite component, which may be further used as a dedicated building block; see Figure 1.



Software components provide lots of advantages. Especially their use shortens the development time (compared to development without components). Components also facilitate testing and functional verification. This comes from the fact that components may be tested and verified in isolation, which is much faster than doing so for the whole application.

Testing and functional verification is especially important in the area of embedded systems, i.e. computers that operate within cars or planes, control production lines and power stations or are built in TV sets and other electronic devices. In fact, as surprising as this may be, a vast majority of computers are embedded systems. For example, if you disassembled a modern car, you would find dozens of these systems. The same holds for other vehicles, modern plants, power stations and so on. While an error in a word-processor or firmware of a TV sets results typically only in angry users, an error in software controlling a plane, space satellite or power plant may have fatal consequences.

Another advantage of components, again very important in the area of embedded systems, is inherent support for software product lines. A product line may be perceived as a template of a particular application into which particular components are inserted based on actual requirements. Software for cars may serve as an example. It is quite common that one car model is offered with different equipment, such as the engine type, air conditioning, type of radio, and navigation system. The structure of the software for these variants is the same – it differs only in the selection of particular components reflecting the actual equipment present. Another example may be an application designed to run on both desktop computers and smart phones, where different user interfaces must be taken into account; see Figure 2.

Related to this is measurement, testing and prediction of software performance. The performance may be understood as the time period needed to satisfy a user request, for example how long it takes for a browser to display a web-page. This is very important for applications which simultaneously serve a large number of people. When being developed, an application is tested only for a limited number of requests; thus it is not rare that when deployed to production environment, it collapses not being able to manage the real load. A simple solution of using more computers does not work because some of the application's functionality can be performed only sequentially.

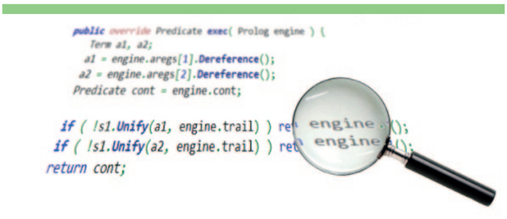
• Verifying Programs

Department of Distributed and Dependable Systems

http://d3s.mff.cuni.cz/

To get a better understanding as to why a computer program behaves as it should, testing and formal verification may be used. Our contribution to this area is represented by the Gimple model checker, which verifies properties of programs written in the programming language C/C++, and the Web badger, which verifies the source code of active web pages in PHP.

Research topics solved in international projects:
The prediction of program efficiency, and component and service-based software applications



Motivation

On September 21, 1997, while on maneuvers off the coast of Cape Charles, Virginia, the US battle ship Yorktown CG-48 unexpectedly stopped and stayed inactive for nearly three hours.

As it turned out later, the reason was an error in the operating system – an operator entered zero into the system by mistake. Division by zero caused an exception that was not caught. The error propagated throughout the ship computer network and caused the engine shutdown.

Nowadays, computer programs are everywhere and errors in them may have much worse impact than shutdown of ship engines on maneuvers. The examples include avionics, medical devices used for surgery, and software for internet banking. In all these cases it is very important that they do not contain errors.

Testing and Verification

Testing is a basic means for searching errors in programs. The developer (creator of a program) repeatedly runs the program and simulates the behavior of real users. This way it is not possible to reveal all errors – the number of various user behaviors may be enormous. Therefore it is necessary for the programs to be **verified**. To verify a program means to formally prove its correctness; a mathematical proof is used to show that the program is error-free. To verify the program, its **model** is to be created in a mathematical system.

Model and Specification

The program and its specification, the description of program properties and desirable or un-desirable behavior in a formal language, are then processed by a special program called a **model checker**, which evaluates whether the program satisfies the specification or not. Should the program not comply with its specification, the user is provided with an error description.

Challenges

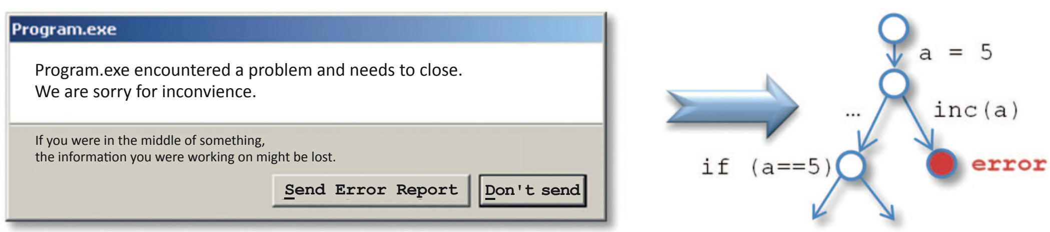
The approach described above, however, has limitations and cannot be applied in all cases. A major challenge is the **state space explosion problem** – a model checker is not able to verify the model in a reasonable time period. Various optimizations including both more efficient model representation as well as a faster model processing are then employed.

Another issue is the **undecidability of program model checking**. It means there are programs for which a model checker, regardless of its quality, cannot evaluate if they do or do not comply with the given specification. A solution here is limiting the constructs of input programs, e.g. it is not possible to use floating-point numbers, but just integers. The programs using the disallowed constructs cannot be automatically verified.

Results

Modern computers with large operational memory have opened the door for verifying real programs – the size of verifiable programs has grown significantly and although it is still not enough, we are already able to verify simpler programs. It is still necessary to look for better ways of representing programs (and relevant models) as well as more efficient methods. The other problem, the undecidability of model checking, also provides a lot of research possibilities. Here we are trying to extend the set of programs which may be verified so that the amount of limitations put on the verified program will be as low as possible.

On the basis of our research, we have developed our own model checker GMC (Gimple Model Checker), see http://d3s.mff.cuni.cz/~sery/gmc/, for verifying programs written in C/C++ languages. We also work on a tool for verification of source codes of active web pages used for example in internet banking. For more information visit: http://d3s.mff.cuni.cz/research/formal_methods/.



Creating a Friendly Web

Department of Software Engineering

http://www.ksi.mff.cuni.cz

Software engineering does not focus only on programming theory and practice of creation of large software systems.

With the beginning of the Internet and Web it has also dealt with how to construct web pages, how to browse them and how to combine their contents into higher units, services.

The latest methodology of developing software for web applications differs significantly from the classical methods of development made to fulfill customer's requirements. The first difference is that we do not actually know our potential customers, but we still want to win them over. This means the application idea itself must change as the needs of the market change. Teaching software engineering at the department also includes subjects from the areas of economics, management, and social or communication skills.

The Research Group:
Web semantization research group

www.ksi.mff.cuni.cz/semwex/

The Research:
Web information extraction, mining user preferences, semantic repository, experimental computer science

Don't you think it often takes ages to find something on the web? Haven't you found what you are looking for? Are you fed up with going through answers offered by an internet browser? Is it difficult for you to choose from thousands of internet shops?

Today, computers can offer a lot. Your disk might contain both a whole library and video rental shop, a computer will defeat the best of the best in chess, so why can you not simply get what you are interested in?

Web Semantization

This may sound incredible, but computers do not understand the web. They do not understand the meaning of what is written there.

They do not understand that the offer which just opened on your browser concerns the same mobile phone that is being sold somewhere else cheaper by 500 CZK.

Computers do not realize that it is a phone with a touch display, 3MPx camera without GPS navigation system but with the possibility of Wi-Fi connection.

To make a computer understand, it is necessary to help it a little. We have to explain the meaning (semantics) of the things being discussed on the web. We have to train a computer how to understand these things and it will then be able to search independently.

Mining User Preferences

Experts in mobile phones will recommend an ideal phone for you in a minute provided they are your friends and do not have side interests you can expect from a sales person. But what if you do not have such a friend? Or what if they do not have such grasp on your needs?

Believe me, a computer can help! Train a computer your preferences and it will recommend the most suitable phone for you or a film you might like. Today, the web is significantly social; linking web searches with a social network is hopefully one way to make the web friendlier.

Details

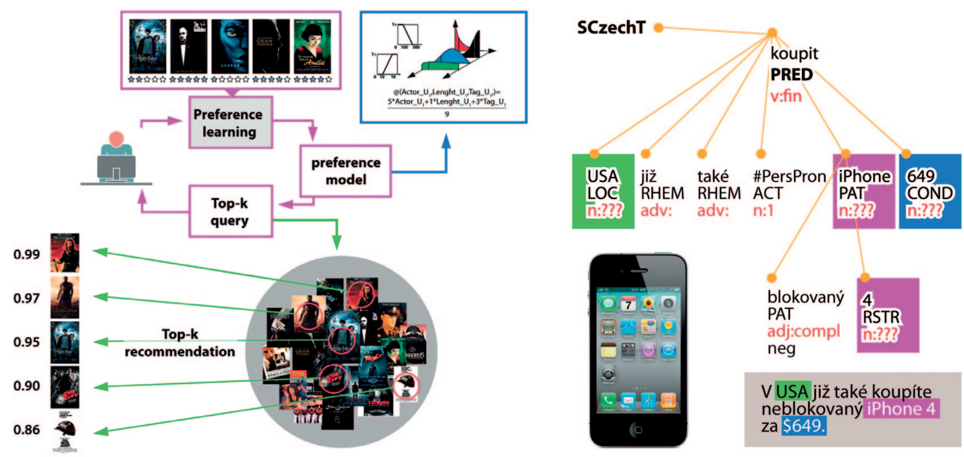
Both web semantization and mining user preferences are very complex disciplines. To reach a successful solution, however, you need to get deep into web technologies and use the most suitable methods and algorithms from the area of machine learning, data mining, statistics, artificial intelligence and natural language processing (see the right part of the Figure with analysis of the sentence “In the U.S. you can buy unlocked iPhone for $649 already” in Czech).

We have experience with the analysis of different web pages and we have developed new extraction algorithms. When the page structure is not informative enough, we start analyzing a text and we train, although so far to a limited extent, a computer to understand the contents.

Mining user preferences is an interactive process. The user evaluates a few offers, the system learns the user’s preference model from them, searches the entire available database and selects the options that are the most interesting for the user (see the left part of the Figure). We have tried several times to integrate a recommendation system straight into the internet shop users interface. The whole shop is thus adapted to the customers’ needs. Items are sorted out according to their interest and their most important parameters are highlighted. Using our system of mining user preferences increases sale significantly.

The original idea of a semantic web means that the creators of web pages will annotate their pages from the semantic point of view (add the meaning understandable for a computer). This requires both sufficiently trained creators and sufficient motivation. It turns out that this way is poorly feasible and the semantic web does not form even 1 % of the total web content.

We can see every day that a large number of people leave content on the web in the form of blogs and social network contributions. Our idea is to offer people sufficiently intuitive tools (with sufficient support of “smart” software) and transfer semantization into social networks. Motivation should stay the same as it is, e.g. tell your friends what I have experienced, found, … An experimental system for this vision is already in progress at the department and we are also creating our own social network. Ladies and gentlemen, the adventure is beginning, and we are setting off…



• XML and Web Engineering

Department of Software Engineering

http://www.ksi.mff.cuni.cz/

In addition to the theory and practice of programming, software engineering is focused on organizing and processing data using database methods.

A database may contain information about companies, texts, images, and other data from the Web or used for processing on the Web. There are special databases that contain data in XML format.

Research Group:
XML research group

www.ksi.mff.cuni.cz/xrg

Research topics:
Database, web data processing and visualization, modeling, integration and evolution of XML data.

Cooperation:
Fraunhofer ISST, DERI Galway, Vienna University of Technology, University of Rostock, University of Technology in Sydney, the companies Komix, Tovek and Galeos, the Anticorruption Endowment, the Parliament of the Czech Republic.

The global computer network known as the Internet has become a unique means of communication. Current applications such as Facebook, YouTube, Wikipedia and Google allow people to communicate through the Internet and retrieve information in a way that was completely unimaginable even fifteen years ago.

Despite the undisputed benefits, today's Internet has many practical problems which are being analyzed and solved by the worldwide scientific community.

Web Engineering Against Corruption

What do the fight against corruption and Web Engineering have in common? People who fight against corruption depend on accurate and current data from different sources. They need to properly filter and connect such data, for example to uncover a suspicious public contract. The Internet is a unique source of such kind of information.

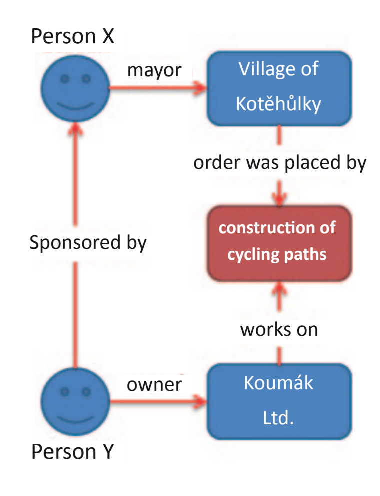
Freedom on the Internet makes filtering and linking of information the most difficult problem. You can try to search whether this year a state enterprise has announced any suspicious prospective public contracts where the contractor was selected on the basis of a single tender. Or try to determine whether there is an active politician in the city council who previously also owned a company that has now been granted a lucrative public contract by the city.

You will have to work hard to find and link the many sources that present information in many diverse and mutually almost incompatible forms. Moreover, there is a great danger arising from unreliable sources and incorrect interpretation of data.

Current results of research in the field of web engineering have the potential to simplify the job. In our group we develop these results and apply them in practice. We develop tools that recognize interesting sources of information on the Internet, obtain the necessary data from them, index them and connect them together.

In doing so we must deal with many problems, such as the diversity of data or its accuracy, duplication, and (un) trustworthiness.

The result is structured data which is used in two ways. The first allows one to find answers to the above questions. The second is the publication of data on the Web so that it can be used by others. We then use this when working on specific projects, such as the Anticorruption Endowment.

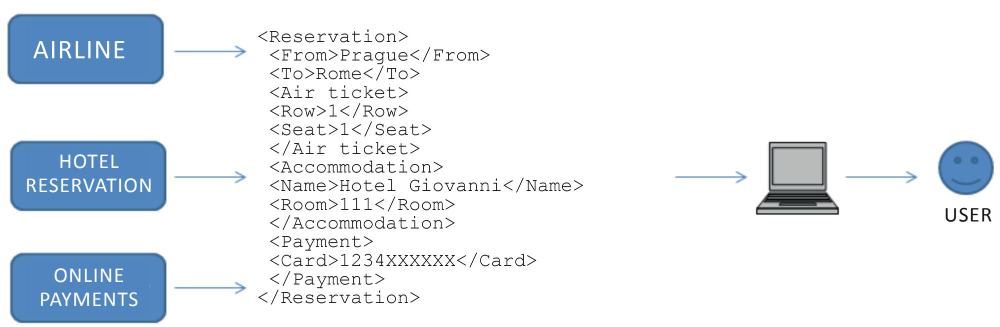


XML engineering against communication chaos

The internet is not only a means of communication between people but also between software systems. When you book an airline ticket on a travel server, you will start an avalanche of messages between systems, airlines, online payment gateways and reservations for hotels and cars.

Communication is conducted in extensible markup language XML. The report provides information that is labeled using machine readable tags which are used by a different system for automatic extraction. This requires that the creators of the systems previously agreed to use a set of XML tags. Otherwise, the systems would not understand each other.

There are numerous problems connected with the creation of sets of XML tags. Sets are complex and must meet the requirements of many parties. Their work is demanding. Moreover, the communicating parties do not always agree on a common set. Then the different sets need to be mutually mapped. And last but not least, it is necessary to modify the set constantly as the requirements change (e.g. changing legislation). The creation and subsequent maintenance of sets of XML tags is difficult without sophisticated methods and tools. We develop such methods and tools and use them for specific projects. For example, we show how to efficiently create and manage XML tags for communication between health systems. In cooperation with the Fraunhofer Institute we are working on a set of XML tags for the German eGovernment.



• Service-oriented Architecture

Department of Software Engineering

http://www.ksi.mff.cuni.cz/

Software engineering is a set of activities based on engineering, computer science and management. Its aim is the design, development and maintenance of computer programs and more complex software systems used in any area of human activity.

Research group:
Service-oriented systems group

www.ksi.mff.cuni.cz/sosg/

Software Confederations
Service-oriented software systems based on knowledge of the given environment and problems preserving and promoting the specific know-how of their users.

Multi-criteria navigation
If you need to get from one place to another, time is one of the basic criteria. But it is not the only one. Others are price, reliability, etc.

Train communication
Modern railway vehicles and trains include a large number of cooperating devices. Networks designed for this environment are very specific and provide many interesting challenges.

The development of large software projects is not a trivial task, and many projects finished by failure. The causes of these failures are manifold. Some of them can be identified and corrected, others can be completely avoided. We explore the development of information systems (IS), the cause of their failure, and procedures giving a greater chance of successful completion of projects.

Motivation

A medium-sized company decides to buy a large software package that supports the scope of duties and paperwork the company deals with. The software package itself and its setup costs a lot of money, and additional costs and effort had to be expended to adapt the company to that software. After its deployment the expected success did not come; company performance even decreased slightly.

Causes

Similar stories are fairly common. How is this possible? Software packages are based after all on the best experience of large international companies, so why hasn't this medium-sized company increased productivity after using it?

The problem is that the environment and culture of large firms are significantly different from the environment and culture of small and medium-sized companies. Not only this – the behavior surrounding such firms differs significantly. A large multinational company more or less determines for itself with whom it will trade and under what conditions. Likewise, a multinational company tends to influence the standards and rules relating to its business.

In terms of the software structure and its use, what plays a crucial role is whether and how processes change in the organization whose activities the software should support.

Procedures that are stable can be optimized and automated, while the management of processes that change frequently, or even vary from case to case, must be controlled by people, not only by software.

Most software engineering textbooks and IS creation is based on the environment of large firms. The applicability of their recommendations in other environments is thus limited.

Our goal is to gather knowledge about the needs of small and medium firms, generalize them, and on this basis, and the basis of our own experience with this environment, to develop procedures leading to the creation of software conforming to these conditions.

Applications

The investigated architecture of IS can be used not only in the small and medium-sized enterprises (where it came from) but also in e-government, control systems, and other environments.

Some of its elements can also be used to create packaged software, or software development for large companies. The advantages can be seen especially in cooperative organizations and their IS, and in connecting existing systems and third-party systems to larger units.

Systems modeling
When creating automated information systems we want to exploit the advantages of modeling, even for the case where people are part of the system.

Efficient transformation of information
Effective formation of larger software units requires the effective transformation of group reports.

We are therefore searching for the means to transform these reports, which are of different formats including the most commonly used XML format.

Integration of heterogeneous data
When creating larger units it is sometimes necessary to link up applications at the data level, or to use data from different sources. This brings with it many challenges, such as how to store and process data which the original application logic did not expect, yet users need.

• Similarity Search

Department of Software Engineering

http://www.ksi.mff.cuni.cz/

Software engineering focuses on creating and maintaining computer programs that use data. The data may not only be tables, lists and texts, but also pictures and videos, i.e. multimedia data where searching is done on the basis of similarity.

The Research Group:
SIRET research group
Web: www.siret.cz

The Research Topics:
Indexing similarity, multimedia exploration systems, protein identification, and exploring chemical space

Cooperation:
RWTH Aachen University, University of Chile, Norwegian University of Science and Technology, Institute of Chemical Technology, Masaryk University, VŠB – Technical University in Ostrava.

Multimedia Searched According to "Raw" Contents

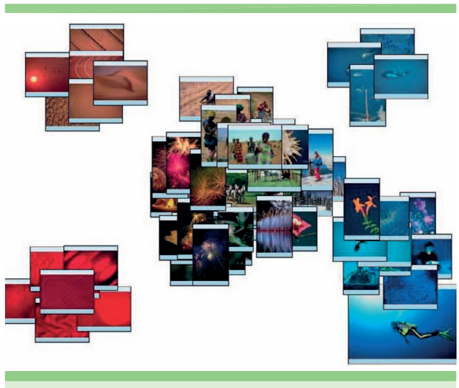
Today's world is going through a boom in multimedia content offered on the web or in independent archives. This has been caused by a massive use of digital gadgets for recording audio-visual reality. However, as much as multimedia data has become a common part of our lives, their searching is far from being solved.

Unless we want to make ourselves content with searching on the basis of texts "attached" to multimedia, we have to deal with the "raw" multimedia content itself. We may need to use this kind of searching much more often than we think.

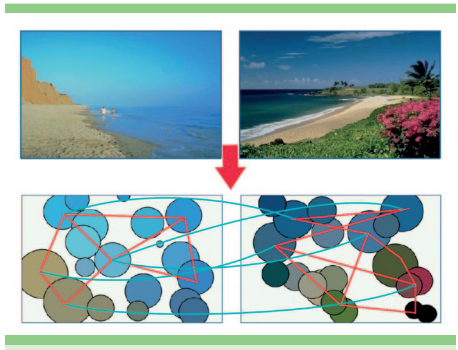
For instance, let us consider a huge database of CCTV video recordings in the streets or at airports consisting of billions of pictures a day. How do we identify a terrorist in such a spate of pictures? We do not have to enter the world of action movies to get another example; we can just go through our own digital archive of holiday pictures. We usually find tens if not hundreds or thousands of pictures in a number of files on the disc plus hundreds of hours of video recordings. How could we know them after ten years?

The ground of **content-based retrieval** in multimedia is **similarity search**. For this purpose it is necessary to specify a model of multimedia documents representation so that it would be possible to measure effectively their similarity. On the basis of similarity we can then build all the searching mechanism. The traditional way of searching is by **querying** – in the event of similarity search directly the selected interrogation multimedia (e.g. by a picture). This type of search is suitable if we "know what we are looking for"; see the example with a terrorist. However, in a number of applications we do not know what we are looking for and rather than targeted querying we would need to find out quickly what interesting contents the database contains; see the example with a home archive. Currently,

the multimedia exploration systems are the center of attention. Unlike querying, more complex issues of visualizing multimedia space are being solved, navigation within the space, interaction with the user – all in real time.



A fundamental criterion for implementing the similarity search is **its speed**. Even the best model is practically useless if it involves a time-consuming search. Therefore, there are database technologies being developed to make similarity search faster based on mathematical models assuming fulfilling certain properties used in the similarity function (e.g. **metric distance axioms**). The result is **similarity indexing structures**, which enable answering the query in much shorter time than would be required by a sequence search of the whole database.



When Looking for Similar Molecules

A similarity search does not consider only multimedia. It is also very highly valued in bioinformatics. At the end of the 90s the importance of proteins initiated a new branch of science, **proteomics**, which studies protein functions on the basis of their structure in space. It is well-known that molecules (proteins or RNA) with a similar structure also share a similar biological function. This knowledge may be used to foresee the functions of proteins. Let us imagine we have a new synthesized protein structure but we do not know its function. We can then compare the new structure with the structures of an already known function and identify the similar ones. We can then derive from the assumption that similar structures share similar functions the likely function of the new structure. Today, we know the structure and function of more than 50 thousand proteins. It is obvious that the task to identify similar structures may not be worked out without computing methods.

Another bioinformatics subject is **cheminformatics**, which deals with small molecules. As most medicine consists of small molecules, the research in cheminformatics is closely connected with medicine research. A new direction is searching and visualizing chemical space. Let us, for instance, imagine that we have two medicines (molecules) – each effective for another tissue. The task is to find a molecule that would be effective for both tissues at the same time. The solution may be reached by searching the chemical space where each point in the space represents one of all the conceivable molecules. The start and finish of the journey in the space are our two medicines while one of the molecules on the way could show the characters of both the resource and target molecules.

If we consider only molecules of the size of maximum 13 atoms and we take into account only five types of atoms, there are about 970 million of such molecules. Obviously, searching such a huge space is in great need of new computing methods.

Computer Graphics

Computer Graphics Group

http://cgg.mff.cuni.cz/index.en.php

Our research group focuses on the following topics:

1. Realistic Rendering:
Our goal is to render synthetic images that cannot be distinguished from photographs.

Applications can be found in film and television industry, advertising, architecture, industrial design or computer games.

1a. Predictive Rendering:
It is necessary to simulate reflection of light in a realistic way, for example for simulation of ergonomics in industrial design or architecture.

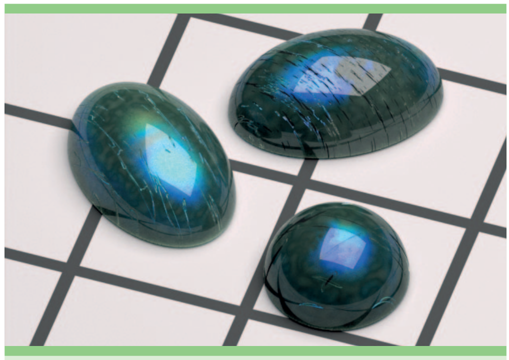
1b. Light Transport in 3D scene:
We develop new algorithms for realistic simulation of light transport in complex environments, where the state-of-the-art methods are too slow or fail to work.

1c. Simulation of natural phenomena
We investigate light propagation in the Earth's atmosphere, we simulate mechanics and optics of human hair, erosion of the Earth surface, and water flow.

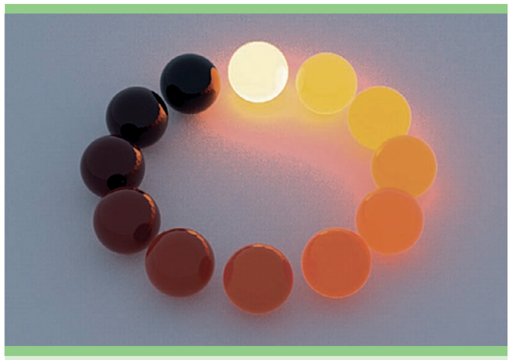
Computer Graphics
Charles University

Computer Graphics is a popular and rapidly developing discipline. Naturally MFF UK has a team of researchers that deal with various flavours of graphics. Our students can attend more than twenty lectures covering all the major parts of this discipline, enrol in seminars and participate in projects.

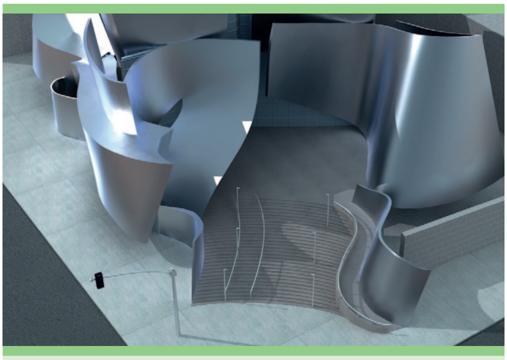
Computer graphics can be best illustrated by means of visualization. We present a few samples of our work.



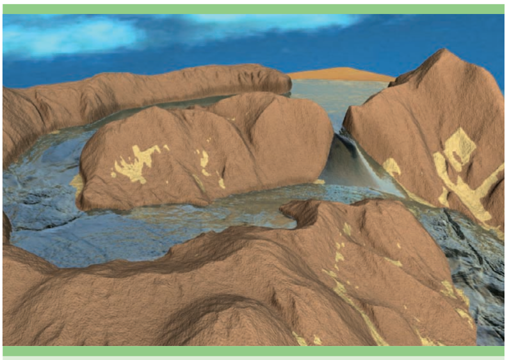
Realistic simulation of light reflection on the surface of labradorite



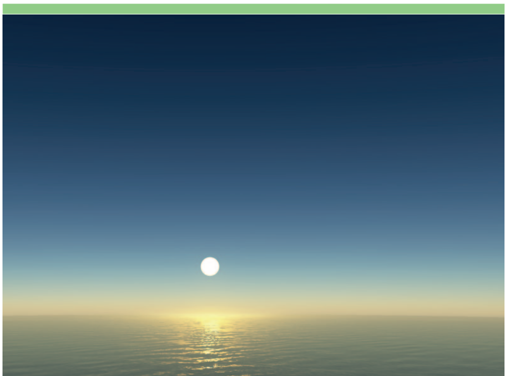
Realistic simulation of light emission from glowing objects



Simulation of light reflection on the surface of a building (Walt Disney Concert Hall, Los Angeles)



Simulation of terrain erosion and flowing water

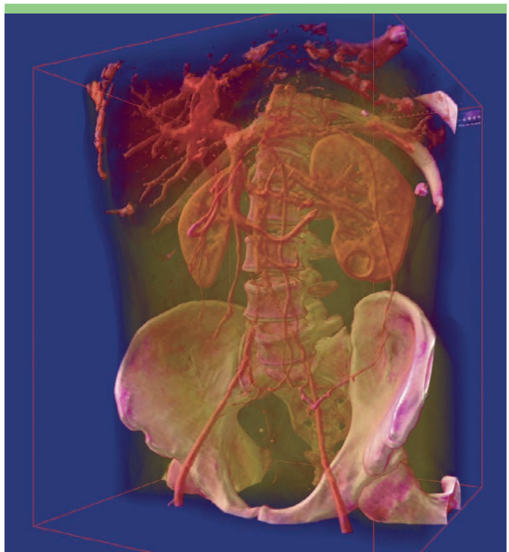


Simulation of sunrise, real-time graphics

2. Analysis and Visualization of Medical Data:
Medical devices, such as computer tomograph or magnetic resonance, are able to scan large amounts of data, which must be pre-processed and visually displayed for physicians so that they can read and interpret the vitally important information quickly and reliably.

3. Geometric Morphometrics:
Morphometrics is a discipline that investigates changes of shapes in anthropology, forensic disciplines and archaeology.

Geometrical parameters must be mathematically defined and they can then be investigated by means of elaborate statistical processes. The graphical aspect of 2D and 3D visualizations plays an important role in this investigation.



Visualization of a volumetric data set after segmentation

• Declarative Programming

Department of Theoretical Computer Science and Mathematical Logic

http://ktiml.mff.cuni.cz/

Basic Terms:

Entity is a real or virtual person, e.g. in computer games, a computer, an autonomous agent, an intelligent assistant, a robot or something else. It can be expressed by the word “existence”, but this word is used only by English language lovers. The word “entity” is shorter than the above-mentioned, and incomplete, list.

Agent is an entity capable of communicating. Every agent can exchange messages with any other agent. A group of agents is called a Multi-agent system.

Assistant is an agent capable of accepting and fulfilling commands; though not always successfully.

Specification of a program being developed is a function which assigns requested values to each entry.

Verification is a detailed proof that the particular program meets the specification.

An intelligent entity, e.g. an assistant, must have better capabilities than just observing detailed instructions when solving the saved task. If an agent is to prove its intelligent behaviour, it must be able to cope with situations in which not all conditions for using such instructions are met, or it has no instructions how to meet the target.

A simple command, such as “I will have a coffee,” given to a waiter or an intelligent robot requires that they think out thoroughly what to do if there is no water in the kettle, or if the machine is broken. They would not cope with these problems if they asked the headwaiter to help them. The headwaiter would simply consider them stupid and would think of dismissing them.

An assistant would definitely be considered competent and intelligent if they managed to meet more sophisticated requirements such as “*Make all arrangements for my trip to Paris where I am going to negotiate with **Electricité de France** next week.*” The assistant has to consider the time of the negotiation, the flight, accommodation in a hotel, and the head’s requirements for a rental car. Finally, they have to consider if it all follows the budget. The development of such programming languages is significant for artificial intelligence based on knowledge.

We have thus raised **the issue of intelligence of a living or virtual assistant, i.e. the complexity of a requirement that the assistant is able to solve**. There are two extremes:

• The requirement is a detailed algorithm which says **how** to meet the requirement. However detailed it is, such an algorithm can be good for nothing if the requirements for its use are not met.

• The requirement defines **what** must be done and the assistant has all the necessary knowledge also in the form of **what** must be done.

Languages used for programming tasks of the **how-type** are called **procedural**, e.g. C and Pascal. Languages aimed at tasks of the **what-type** are called **declarative** languages, e.g. Prolog and Haskell. The original thesis that intelligent entities must be able to understand and process descriptions of the what type makes it necessary to create appropriate declarative languages and relevant supportive means, which would make their use easier. The development of these languages is significant for **artificial intelligence** based on knowledge.

Both the declarative languages mentioned above – Prolog and Haskell – are available in a number of versions at MFF UK. As usual, each version has its obdurate defender.

The following simple program in Prolog contains the definition of the maximum of natural numbers. It is interesting because it includes only the definition and the subprogram element (M, L). Other matters are arranged by the Computer prover which forms the core of the Prolog implementation.

Study programs covering the problems specified in the list of basic terms belong to the sphere of theoretical computer science. Education and research in theoretical computer science is realized by the Department of Theoretical Computer Science and Mathematical Logic.

Alain Colmerauer
Created the logic programming language Prolog in 1972. He also created Q-systems, which was one of the earliest formalisms used for the development of the machine translation prototype TAUM-METEO.

```
prvek(X,[H{L]) :- prvek(X,L).
prvek(X,[H{L]) :- prvek(X,L).
maximum(M, L) :- prvek(M,L), not(prvek(Y,L), M<Y).
% Program Maximum Na dotaz:
% ? – maximum(M,[1,9,7,3,6])
% odpovídá M = 9
```

• Artificial Intelligence

Department of Theoretical Computer Science and Mathematical Logic

http://artemis.ms.mff.cuni.cz/
http://clp.mff.cuni.cz/
http://arg.mff.cuni.cz/
http://www.storyfactory.cz/
http://www.evropa2045.cz/

The discipline of Artificial Intelligence (AI) is studied within the field of study I1 – **Theoretical Computer Science** in compliance with the curriculum called "Non-procedural Programming and Artificial Intelligence." Students can attend a number of lectures, including a general introduction to AI and programming tools for AI, in particular logic and functional programming. The subjects of specialization comprise the following areas: artificial neural networks, machine learning and data mining, automated planning, theorem proving, constraint satisfaction, evolutionary algorithms and AI for computer games.

Within the course of their studies, students can participate in activities of the following **research teams**, which deal with various aspects of AI.

The Constraint Satisfaction and Optimization Research Group conducts research in planning and scheduling, mainly in the areas of production modelling and optimization.

The Smart Systems Research Group designs effective algorithms for machine learning and data mining tools.

Artificial intelligence is a young discipline dealing with the design of intelligent entities. Briefly speaking, researchers develop systems doing things that would require intelligence if done by men. Nowadays, AI covers a wide range of sub-disciplines exploring both general themes, such as automated planning or machine learning, and specific problems, such as automated car driving, story telling and medical diagnosis. Many other independent disciplines such as multi-agent systems, linguistics, robotics and special programming languages are closely related to artificial intelligence.

Planning involves searching for actions leading to a given goal state and it is one of the fundamental topics of artificial intelligence. We solve many problems such as path planning for multiple robots in a confined space, for example to pass through a crossroad as fast as possible, or how to make a production plan and to transform the plan to a feasible schedule of activities. We co-operated with the Entellexi company on the development of system MAK€ for production optimization. Nevertheless, applications of this system are going beyond production planning, for example to the area of project management.

Computer games need not be used only for fun and leisure but also in research and education. We participated in creating the simulation game Europa 2045, which helps its players to clarify the decision-making and control mechanisms of EU. The players have first-hand experience with the problems that integrated Europe has to face. More than 2000 students have played the game at secondary schools throughout the Czech Republic. In our own 3D virtual city, we investigate AI algorithms for the automated control of artificial agents. The outcomes can be used not only in computer games and simulation programs, but also as the controlling elements of rescue and exploratory robots.

They work on classification and pattern recognition, multimedia information processing and social networks analysis.

The Automated Reasoning Group studies theorem proving and its use in question answering using knowledge bases.

The Artificial Minds for Intelligent Systems group works on educational computer games and control techniques for virtual agents.

The Internet contains a great deal of useful information, which can hardly be found with the traditional search tools. Are you looking for a picture similar to that one you have just photographed? By means of **artificial neural networks**, pictures can be classified and grouped according to their content. Would you like to find words that sound similar in foreign-language texts without having to learn the particular language? Methods of machine learning and formal automata can help us. Our graduates use such methods in companies such as Google, PPF and others.

Virtual agents in the simulated 3D Story Factory environment

One of the proofs of intelligence is the ability of answering a given question. A number of systems therefore use a sophisticated database search techniques to find the answer. However what happens if there is no answer stored in the database? Strictly speaking, what follows if it is necessary to combine various pieces of information stored in the database? To solve this problem, we use **the technique of theorem proving** in the system SPASS-XDB. The question and the pieces of evidence from external information sources like Wikipedia are transformed into a logic formula, and search for the proof of the logic formula leads us to the desired answer. Now we can ask: “Which Swedish tennis player weighs less than Cindy Crawford?”

Evolution brought us where we are now. Why not use it to design intelligent systems? Evolutionary techniques such as genetic algorithms are used to solve various optimization problems. However the same approach can also be applied to design bodies of robots fulfilling a given task, e.g. simple motion from one place to another in liquid. This task can be realized by means of a formal model describing all possible robots, random generation of the initial population of robots and its further development by the technique “the more resilient specimen survives.” Will it result in a robot that is capable of swimming? Or, will the evolution lead us somewhere else?

What would artificial intelligence without **robots** be like? Our students participate successfully in international contests such as Eurobot and Field Robot Event to present the robots they constructed themselves. Their robots harvest crops, detect and destroy weeds and solve problems in artificial as well as real environments.

Linguistic Data for Language Technologies

Mathematical Linguistics

The engagement of mathematics and linguistics took place in in the Czech Republic back in 1958. But it was not until 1990 that the association was officially and permanently blessed by creating an independent institute and accrediting the doctoral and master study program of mathematical linguistics. It appears to be a long-term marriage that will last beyond generations.

Would you like your computers to translate from and into your native language better than most commercial systems do?

Would you like spell-checkers to correct even tricky mistakes?

Would you like your voice communication with machines to be more human-like and better informed?

Join us and study both aspects:
informatics and linguistics!

Personal computers have spread over generations and have become an indispensable part of our lives. Some users find them to be far more convenient typewriters, but almost all of them use computers to search for information. All such requirements are based on natural language; users' demands on automatic natural language processing systems are thus growing. Capability, memory capacity and the speed of modern computational technology are meeting such demands.

Advanced technologies also provide a basis for machine learning. Computers, just like human beings, learn according to the instructions given to them by a human being. Machine learning cannot therefore do without cooperation with people and their intellects.

So, what are linguists and computer scientists expected to do to meet these assignments?

Computer scientists (1) digitize language sources and texts of the particular language (i.e. they create language corpora), propose tools for processing the data and design a friendly user interface to approach the corpora.

Linguists (1) develop and propose systems to tag the corpora with appropriate linguistic data (i.e. they design annotation schemes). The team of linguists (linguist (2)) applies the annotation schemes to the corpus texts. The representative Czech corpus with extensive grammatical annotations was created from 1996 to 2001 in the Institute of Formal and Applied Linguistics (ÚFAL) at the Faculty of Mathematics and Physics of Charles University (MFF UK). It is known as the Prague Dependency Treebank and used worldwide.

On the basis of the processed data, computer scientists (2) design and implement automatic systems, which should ideally replace the linguist (2). Scientists create a textbook from the processed data from which the systems teach themselves. Since the textbook will never contain everything that one might meet in a language, the systems will never take the place of linguists entirely.

The iteration of computer scientist (1) – linguist (1) – linguist (2) – computer scientist (2) creates the basis for the machine translation systems, automatic indexing and summarizing, or for the systems of human-machine communication and their use in question answering, for example. The way to become an computer scientist (1) and (2) is easy: gain a degree in mathematical linguistics at MFF UK. If one wants to become a linguist (1) and (2), they can start getting ready at secondary school. For this purpose, there is an interactive exercise book available to the public.

The electronic exercise book, which comprises 12 thousand sentences to practice morphology and syntax, was semi-automatically built from the Prague Dependency Treebank. Using the program Charon, the user (teacher, student, parents) can choose a sentence with the requested language phenomena. Subsequently, they can parse the sentences, using the program Styx, and verify their results. In addition, the program Čapek makes it possible to practice morphological and syntactic parsing of the users' own sentences.

Because the preparation of annotated language data by professionals (linguists (2)) is an expensive activity, demanding in many aspects, the possibility to cooperate with non-professionals is being considered. Internet games are good examples of such a cooperation. The players of such games are primarily entertained, but the secondary product of their entertainment are annotations. For example, players' matching descriptions to pictures is extremely successful. In this way, most Internet pictures can be processed. Furthermore, the game PlayCoref has been implemented, in which players mark words referring to the same entity of the world in the text.

When typing on computers, users expect that the text editor is capable of finding and correcting mistakes made by the author. The spell-checker is of good quality in most text editors, but it fails to propose automatic corrections of higher quality. This is due to users' requirements and commercial aspects which determine usability of the modules. Grammar checkers are therefore much more demanding and do not achieve high quality yet.

In ÚFAL, a new grammar checker was developed that is capable of revealing mistakes in prepositional phrases (the case of the noun does not correspond to the case required by the preposition) even in more complex phrases. It also reveals mistakes in subject-predicate agreement even in sentences with multiple predicates. We might give many other examples, but grammar checkers of languages that are as morphologically rich as the Czech language will never be perfect.

In any language, there are many complications arising from ambiguity of language means on all language levels. Even in this particular area the data from the annotated corpus can be used to search for 'sensitive' contexts that are mistakenly marked as errors by a robust automatic parser. This holds to a great extent even for automatic derivation or summarizing. A number of language phenomena can only be processed on the basis of a wider context. Let us consider the following sentence: The Police arrived, evacuated almost a thousand people and exploded the bomb that had been laid there with a great care. One feels that the bomb was not laid safely but it was safely exploded by the police. But it is difficult to share this feeling with a computer. Similarly, the relative clause in the following sentences can be interpreted correctly only if we exclude one interpretation (in an interview with a famous politician) on the basis of the knowledge of behavior: In the morning, they delivered the bunch of roses for the bride I didn't like.

From the above-mentioned examples, it is obvious that computational and mathematical linguistics will face many problems to solve. Doctoral, master as well as bachelor theses deal with them significantly, and we believe that they will help to solve them in the future.

Machine Translation – Dream and Reality

Machine Translation

Machine translation (MT) is an attractive task on the border between informatics and linguistics. It is interesting both from the commercial and academic point of view. In the European Union alone, it could save a significant part of the billions of EUR spent annually on translating and interpreting. For academics, it means a forum for a number of disciplines.

Apart from the above-mentioned linguistics (see also page 100), translation is also a challenge for statisticians, computer scientists as well as pure software engineers. Today's practice may be summarized as follows: take texts in an amount equivalent to 27 meters of English books and their Czech translations. Find the corresponding pairs of sentences (there will be about 10 million of them) and parse each one. Translate a new sentence by looking for the bits you have already seen translated within the millions of the sentences. "Statisticians" and "linguists", formerly antagonists, are converging and the biggest potential today is seen in a combination of methods.

Let's not forget the overlap of MT with artificial intelligence: when translating, you can literally touch the products of the human mind and try to simulate them with a machine.

Exaggerated Expectations

With the first computers in the era of John von Neumann and Alan Turing, the expectations of fully automatic transfer of text from one language into another appeared. In 1954, according to an IBM press release, it was a matter of "three to five years". The discrepancy between these expectations and actual results then stopped the flow of funds into this area of research.

Today's vision is more cautious. We do not expect to achieve fully automatic translation of high quality without limiting the types of texts. However, despite its low quality, machine translation serves well even today in a number of situations, e.g. making websites in a language the script of which you cannot even read accessible, or for narrowly defined tasks (e.g. product manuals).

Phrase-Based Statistical Translation

The so-called phrase-based translation works with words as with indivisible units. The computer does not see any relation between the forms of the words "sleep" and "sleeps", "sleep" and "slept" or even between "sleep" and "snooze." Translating within this model is possible only thanks to the huge amount of sentences previously translated by people.

The computer pairs the sentences with their translations and finds which words in each clause approximately correspond to each other (see Figure 1). Out of the texts arranged in this way, a translation dictionary is automatically created. Unlike ordinary dictionaries, this one contains even ten-word sequences and the words are given in all forms in which they were detected. Once a sentence has been entered into the computer, the computer checks the various divisions of the sentence into "phrases" (we cannot speak about grammatical parts of a clause as the phrases totally ignore grammar). Each phrase is then translated with the help of the above-mentioned dictionary. Out of many translation possibilities of the phrases, the ones that collocate the best are selected (see Figure 3).

Deep Syntactic Translation

The translation based on parsing aims to provide grammatical output. It does not work with the raw form of a sentence but it gradually transforms it into its so-called surface and deep representations, a kind of sentence structure tree and the relations between the members.

The transformation into the other language is done in the deep representation, i.e. "tree to tree" translation (see Figure 2). The translation dictionary does not contain all word forms, the basic form is sufficient. The final declination and conjugation are done by a special component.

The system of deep translation consists of a number of modules of a very different character. For the initial parsing, statistical tools trained on dependency treebanks are used (see chapter on "Linguistics Data for Language Technologies"); the translation dictionary is created automatically from the translated texts. When translating tree to tree, there is also room to apply a wide range of stable linguistic rules characterizing the differences between the source and target languages.

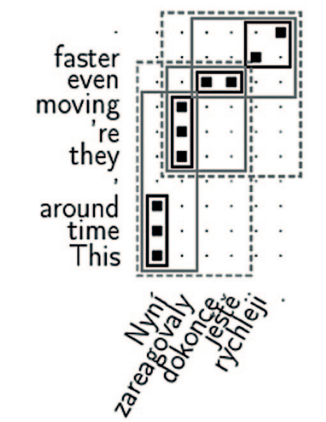


Fig. 1: Searching for translations of phrases

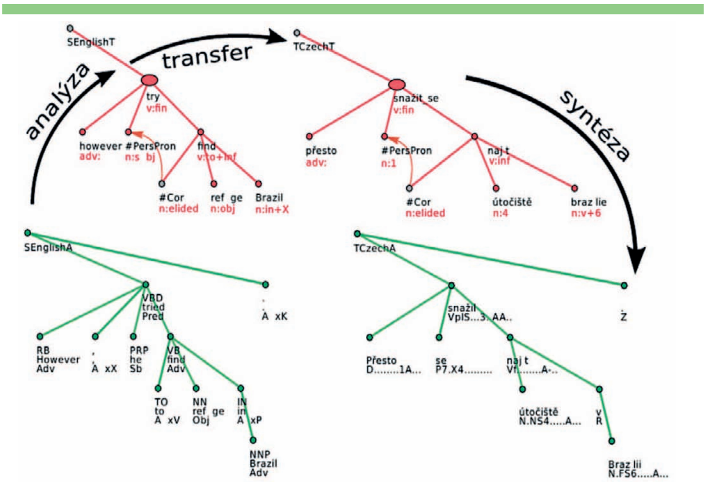


Fig. 2: Illustration of the deep translation method

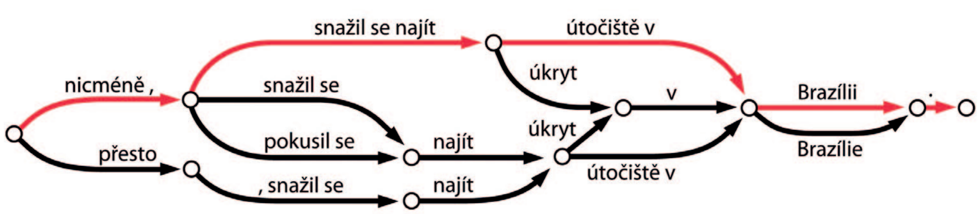


Fig. 3: Translation of the same sentence as in Fig. 2 by means of phrase-based translation

School of Mathematics

The School of Mathematics plays an important role in scientific and educational activities of the faculty. It deals with domestic and international grant projects with a rich publication output in prominent Czech and foreign mathematical journals. Scientific and professional work covers a broad spectrum of disciplines of modern mathematics:

Algebra, Cryptography, Mathematical Analysis, Geometry, Numerical Mathematics, Mathematical Modeling, Probability Theory, Mathematical Statistics, Econometrics, Financial and Insurance Mathematics, History of Mathematics and Didactics of Mathematics.

Members of the School are not only authors of scientific publications, mathematical textbooks for elementary schools, high schools and universities but also work on the editorial boards of Czech and foreign journals and participate in the preparation and organization of international conferences and workshops. They very often take a major part in the work of research teams in applied scientific areas outside mathematics such as biology, medicine, ecology, economics and technology.

The results of the School were awarded in 2010 when mathematics at the Faculty of Mathematics and Physics at Charles University in Prague was ranked as the only exact and natural science field in the Czech Republic in the *excellence* group in the prestigious *CHE Excellence Ranking*. The criteria according to which European university departments are assessed include the breadth of disciplines offered in masters and doctoral studies, mobility of students and teachers, the quality of libraries and information systems in addition to professional viewpoints. An integral part of the evaluation is assessing the living standard of students in terms of scholarships, tuition fees, accommodation in dormitories and availability of consultations.

Mathematical Analysis
Functional Analysis
Topology
Theory of Differential Equations
Calculus of Variations
Descriptive Set Theory
Geometric Measure Theory
Function Spaces
Real and Complex Analysis
Analysis of Differential Equations of Continuum Mechanics
Mathematical Modeling
Mathematical Structures
Continuum Mechanics
Modeling in Medicine
Riemannian Geometry
Numerical and Computational Mathematics
Hyperbolic Geometry
Logic
Matrix Calculus
Numerical Analysis
Industrial Mathematics
Algebra
Cryptology
Combinatorics
Geometry
Information Security
Teacher Training in Mathematics and Descriptive Geometry
Didactics of Mathematics and Descriptive Geometry
History of Mathematics
Probability Theory
Random Processes
Mathematical Statistics
Stochastic Geometry
Stochastic Analysis
Asymptotic Methods
Econometrics
Biomedical and Technical Applications
Simulation Methods
Portfolio Optimization
Modeling Economic Time Series
Risk Management
Financial and Insurance Mathematics
Valuation of Financial Assets
Life and Non-Life Insurance
Analysis of Financial Time Series

• School of Mathematics

Sokolovská 83, Praha 8-Karlín

Departments in the building:

Department of Algebra
Department of Mathematics Education
Department of Mathematical Analysis
Department of Numerical Mathematics
Department of Probability and Mathematical Statistics
Mathematical Institute of Charles University

Topics:

• Algebra, Logic, Cryptology

Matematical Structures

Mathematical structures is a summary of those fields of mathematics, which typically work with abstract quantities which have only partial support in intuitive thinking.

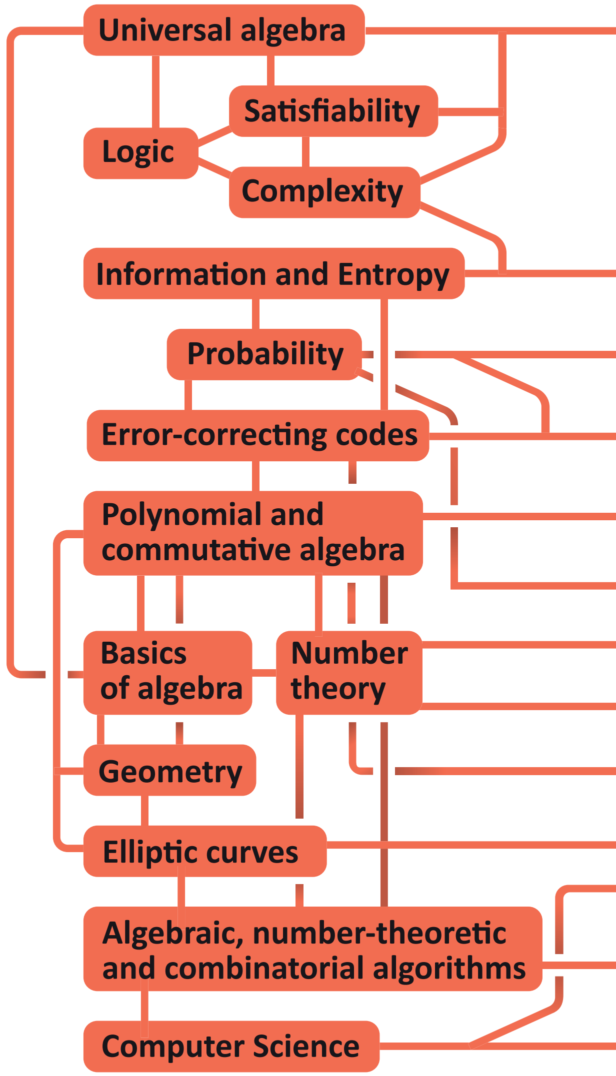
In the course of more than a century of development of modern mathematics, it has been shown that many natural problems – geometric, combinatoric and logical – can be converted into a language that has been developed through the generalization of simple numerical and geometrical relations.

Concepts such as a rings, commutative fields, and varieties proved themselves to be extremely useful in problems outside their original contexts. This ability to use abstract principles in a new context is typical for modern mathematics.

The source of this historical movement can already be found in ancient thought which clearly distinguished the general from the individual.

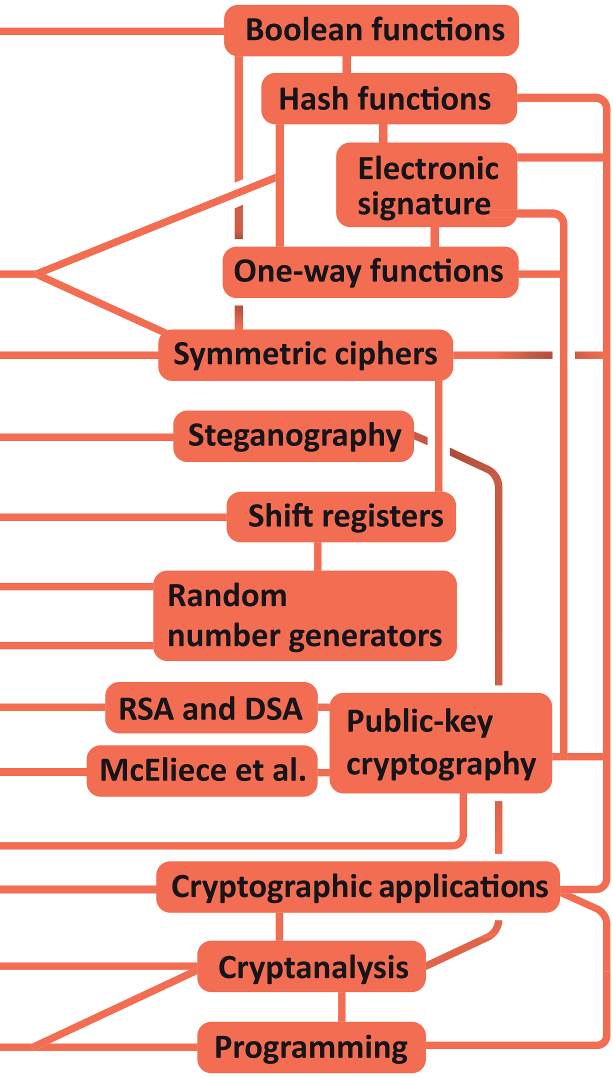
However, modern mathematical mind differs from that of the ancient world, in that it is systematically searching and finding hidden abstract structures in phenomena, which are seemingly simple and straightforward. For example, algebraic geometry can be understood as generalized counting with polynomials. A complicated theory is often surprisingly clarified with an abstract viewpoint.

The text continues in the chapter about the Mathematical Institute, page 122.



The diagram suggests how the mathematical disciplines which are important for cryptology are linked to each other, and how they are related to the main cryptologic systems, concepts and applications.

A similar diagram showing the relationships inside algebra and logic should rather take the form of concentric circles representing the process of abstraction and individualization.



The study branch **Mathematical Methods of Information Security** is administered and mostly taught by the Department of Algebra. Experts from private industry also participate in the teaching of subjects: programming, applied cryptography, cryptanalysis. The branch **Mathematical Structures** is taught by the Department of Algebra (algebra and logic), Department of Applied Mathematics (combinatorics), and the Institute of Mathematics (geometry).

Mathematical methods in information security

This is a young specialization whose aim is to provide, on one hand, a wide range of basic mathematical education, particularly with regard to algorithmic mathematics, and on the other hand give the practical knowledge which should help students to find work in their chosen field. Those who decide to pursue an academic career also have a wealth of interesting opportunities.

At the bachelor's level, compared with a specialization in General Mathematics, greater emphasis is put on standard programming skills and algorithmic knowledge, both in algebra and number theory. In addition, the students become acquainted with the principles of the most important cryptographic systems and their practical application. At the core, however, remain those subjects concerned with mathematical theory: at the bachelor's level these are number theory, the theory of finite objects and self-correcting codes, and the theory of algebraic curves (which have remarkable applications in cryptography).

At the master's level these core courses also include the study of quantum information, computational complexity, and some probability.

Subjects with a practical orientation include the structure of the flow of data over the Internet and their encryption, the major cryptographic standards and the legal protection of data.

These courses are taught by experts who are actively involved in research in these areas. Visit us at:
http://www.karlin.mff.cuni.cz/katedry/ka/ka.htm

• Mathematics and Descriptive Geometry Teacher Education

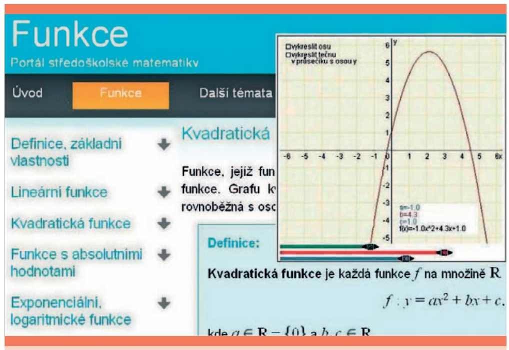
Department of Mathematics Education

The Department of Mathematics Education guarantees the study programme education in mathematics and descriptive geometry for high-school teachers and in mathematics for middle school teachers. The Department also cooperates with other faculties of Charles University to provide education for students of mathematics in combination with other subjects.

Members of the department specialize in a number of disciplines of mathematics and in didactics of mathematics. They also deal with modernization and innovation of teaching and create inspiring mathematical problems which combine mathematics with real life. In addition, they study the development of pupils' and students' reasoning and their approach to acquiring mathematical skills and knowledge, e.g. financial literacy.

Members of the Department place emphasis on the use of information technology, as well as computer and educational programmes. Students are led to study natural sciences and technology. Members of the Department also work on the editorial boards of Czech journals, as well as foreign popular and professional journals.

The Department organizes professional and educational events for tal-

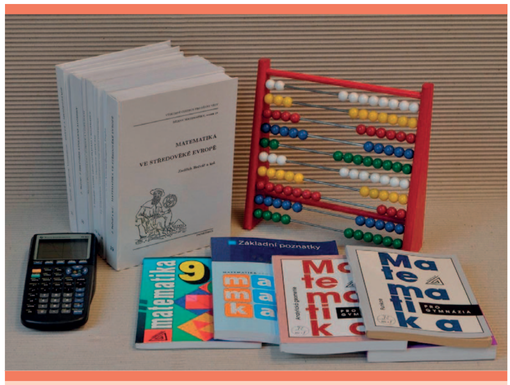


Education and Textbooks

One of the activities of the Department is the creation of high-quality textbooks and teaching materials for school mathematics. Members of the Department are authors of textbooks, workbooks and collections of problems for all types of schools – from elementary schools to universities. They also participate in creating websites and exemplary didactic tests. Thus, the department influences the level of mathematics education in the Czech Republic.

History of Mathematics

Intensive research is done in the history of mathematics. Attention is paid mainly to the



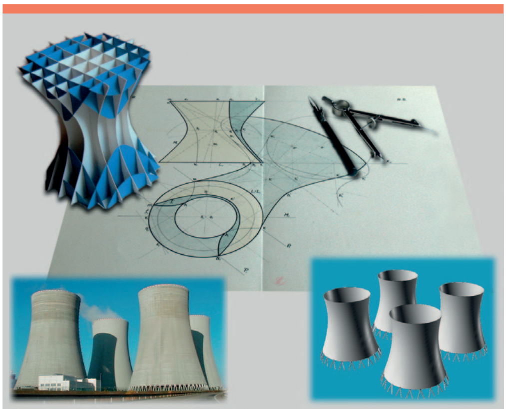
development of particular disciplines, to mathematics of certain historical periods and to the survey of the development of mathematics. Results are regularly published in the edition History of Mathematics, in national as well as international journals and collections.

Education seminars and the international conference History of Mathematics are organized for mathematicians, teachers and doctoral students.

Doctoral study

Graduates from master study programmes can continue in the doctoral study program General Issues of Mathematics and Computer Science, which focuses on elementary mathematics, mathematics education and history of mathematics. Topics of dissertations are connected with the research areas developed by the Department and other co-operating institutions.

Individual approach to students, wide range of topics, training to gain knowledge, skills and working habits ensure success in their studies.



Geometry necessarily accompanies us on the way from a classic drawing and computer visualization to its technical use.

ented students, for doctoral students and teachers from educational practice. It is also involved in lifelong learning and in teaching at University of the Third Age. The Department participates in arranging students' contests and further professional work and activities.

The DME is one of two institutes in the Czech Republic which offer the study programme of descriptive geometry. It can be studied only in combination with mathematics.

The so called MDg programme is aimed at students who are deeply interested in a wide range of geometric disciplines such as descriptive, differential, projection, algebraic, computational, Euclidean and non-Euclidean geometries. The study starts from simple drawing and operating a number of geometric programs to computational geometry and geometric modelling. Emphasis is placed on the relations of geometry with art, architecture and technical practice. The programme is enriched with optional lectures and seminars.

Bachelor's and Diploma theses of our students gain awards in national as well as international contests, such as Students' Scientific and Professional Activity.

Some students teach geometry at universities and higher secondary schools during their studies. Graduates find employment at departments of mathematics at technical faculties and faculties of education at Czech and foreign universities.

More information can be found on the webpage **http://www.karlin.mff.cuni.cz/katedry/kdm/**

• Mathematical Analysis and its Applications

Department of Mathematical Analysis

Mathematical analysis is one of the very important mathematical disciplines. The beginnings of classical analysis date back to the 17th century. It is connected with Isaac Newton and Gottfried Wilhelm Leibniz, who are considered to be the founders of the differential and integral calculus.

Classical – real and complex – mathematical analysis follows Newton's and Leibniz's terms, especially in the theory of real functions, including the modern theory of derivatives, integrals and the theory of exceptional sets on the real axis.

Modern analysis does not deal only with differentiation and integration. Neither does it work only on spaces consisting of numbers. Its methods are applicable on a wide range of complex abstract spaces. You can find more information about some of the many disciplines of mathematical analysis in another part of this page.

There you will also learn that mathematical analysis is a very theoretical and demanding discipline yet widely applicable. Mathematical analysis can be studied in the follow-up master study program at MFF UK, or in the doctoral study program at the Department of Mathematical Analysis after graduating

Mathematical models are often used when studying animate and inanimate nature; physical, biological, economic and social processes. Their relations, expressed in mathematical language, take on the form of complex equations in which the unknowns are not particular numbers but functions and more complex objects. The methods of mathematical analysis play a significant role in formulating and solving such equations.

The solution of equations cannot often be calculated directly. Subsequently, it becomes important whether a solution exists, or how many solutions there are and what their properties are. In addition, the properties of time-dependent solutions for large values of the time variable are of great interest to mathematicians. Even values of chaotic solutions prove to approach rather non-chaotic sets, or so-called attractors of the equation. An example of an attractor is shown in the picture.

Methods of this research lie on the border of two disciplines of mathematical analysis: differential equations and functional analysis. In the sphere of differential equations, it is the problems of existence, uniqueness and the properties of their solutions that are of major interest, while functional analysis studies infinite-dimensional spaces in which the solutions can be found. The approach of functional analysis enables us to deal with complex objects (such as functions) as if they were 'points' of a particular space of infinite dimension. Geometric imagination is certainly important here, although some objects, especially in infinite-dimensional spaces, can hardly be imagined.

Even a four-dimensional cube is quite a difficult object to imagine (see the picture).

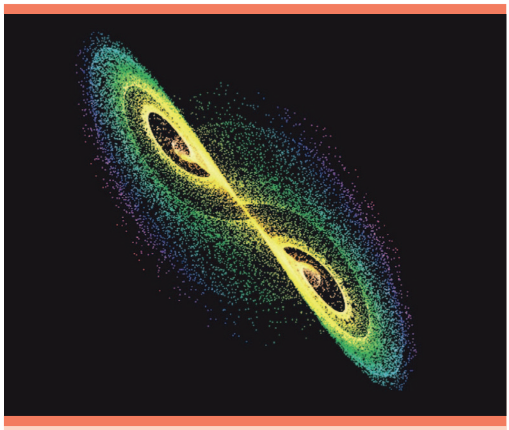
The more abstract branch of functional analysis explores infinite-dimensional spaces together with their structure from various perspectives. In functional analysis various approaches are combined, which is peculiar to mathematics in general, for example, with probability theory or the theory of groups, or the combination of classical analysis with so-called topology that investigates some genuinely geometric aspects of abstract spaces. It is often necessary to know some properties of the investigated function before it can be found. These problems are explored by the subdiscipline of functional analysis called the theory of function spaces. The desired functions' properties can then be expressed in the form of a list of all spaces to which the function belongs.

Among other disciplines explored at the Department of Mathematical Analysis are geometric measure theory and the calculus of variations, by methods of which we try to find solutions to minimize the energy of a given system. Deformation of a body made of an elastic material is one example. Within the research, optimal conditions are sought to ensure that the material does not tear apart and it can be subsequently deformed back to its original state.

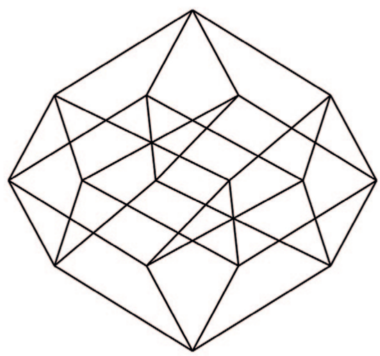
Another discipline that the department focuses on is descriptive set theory. In this field, the complexity of the definitions of mathematical objects (sets, functions, relations) is studied. One of the most important methods is represented by infinite games, in which two hypothetical players alternately choose their moves according to predetermined mathematical rules. Satisfying some properties of the complex mathematical objects is surprisingly dependent on whether or not the first player has a winning strategy.

from the *General Mathematics* bachelor study program.

More information can be found on the webpage:
http://www.karlin.mff.cuni.cz/katedry/kma/



An attractor of a so-called dynamic system – a time dependent system of differential equations



A planar projection of a four-dimensional cube

• Numerical and Computational Mathematics

Department of Numerical Mathematics

Numerical and computational mathematics can be characterized as a part of mathematics which deals with processing mathematical models by means of computer technology.

Numerical mathematics thus represents a transition from purely theoretical mathematics to results useful in practice. From this point of view, it is an important discipline of mathematics.

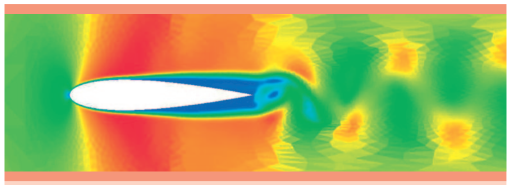
One can find numerical mathematics used in all spheres of human activity, mainly in technology and natural sciences, but also in economics, insurance, medicine and so forth.

Students can choose to study numerical and computational mathematics after the second year when they have acquired general knowledge of all mathematical disciplines. During the summer break students can cooperate on small projects offered and paid for by the Department.

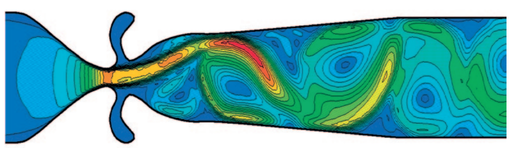
In these projects students get to know practical aspects of numerical mathematics and they can thus gain the first opportunity to participate in scientific activities. In addition, students can con-

Computer Simulations in Fluid Mechanics

Computational fluid dynamics is an important application of numerical and computational mathematics. Its aim is to simulate complex processes in fluids (liquids and gases). In addition, it is a replacement for expensive experiments in the development of new airplanes, turbines and other technological units. Another interesting topic is the interaction of fluids and structures with applications on the vibration of aircraft wings, but also blood flow in heart vessels and voice creation in human vocal cords.



Visualization of the distribution of the Mach number (the ratio between the gas velocity and the speed of sound) given by the numerical solution of the flow of viscous gas around an aircraft profile.



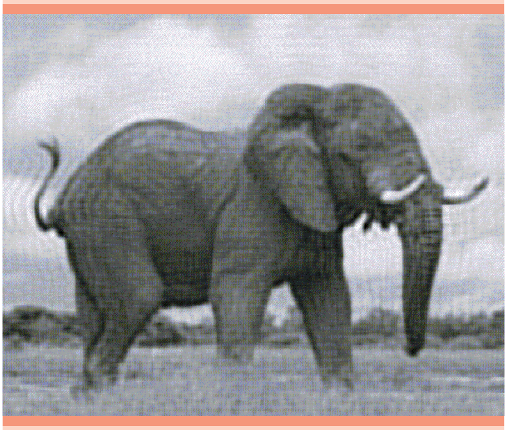
Velocity distribution of air passing through human vocal folds.

Image processing and reconstruction

Image processing and reconstruction represents a modern and rapidly developing area of mathematics with applications in astronomy, radiology, medicine (CT, MRI) and so forth.

Data are typically damaged by errors in measurement, losses by transfer and compression. The aim of numerical methods designed for the solution of such problems, is to obtain the most accurate reconstruction of visual information possible while suppressing errors at the same time.

Photograph damaged by random errors (e.g. lens movement or defect of the camera).



Reconstruction of the photograph by means of a hybrid Krylov Method.

tinue developing these projects within their bachelor or diploma thesis. The curricula of numerical and computational mathematics can suit students with various challenging interests. They provide students with self-fulfillment in mathematics applied in various areas of natural sciences, technology, humanities, creative computer work, high-level software creation, work with computer networks, computer modelling, simulations and control of complex structures and processes.

And last but not least, it can satisfy students interested in so-called ‘pure’ abstract mathematics when creating the theory of computational processes, in which profound knowledge of a variety of mathematical disciplines can be applied.

Graduates in numerical mathematics find employment in any area where computer technology is used. Specifically, it is industry and economy, education (mainly tertiary), and basic and applied research.

As well as all graduates in other disciplines of mathematics, they can work in public administration, justice, banking and so forth. The best students can continue in doctoral studies at various institutions in the Czech Republic or abroad (France, Germany, Great Britain, the USA).

More information about the studies can be found under:
http://www.karlin.mff.cuni.cz/katedry/knm/

• Probability Theory, Mathematical Statistics

Probability Theory

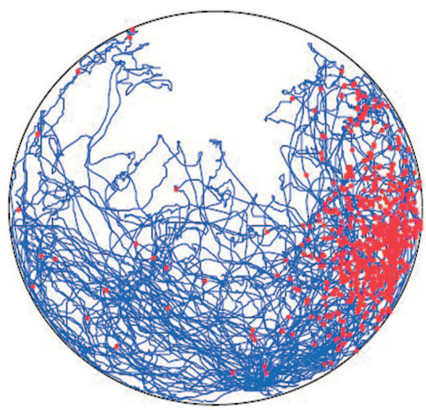
The theory of probability is a special discipline of mathematics which studies regularities of random events. Disciplines and terms based on probability are often marked by the attribute random or stochastic. A random process is a model of a random event taking place in time or in space. Such models are widely used in physics, economics, insurance, biomedicine and other fields of science and technics.

The study of probability and random processes makes students capable of applying the theory first hand. The topic of the thesis can be either theoretic or aimed at computer simulations and applications. Applicants for doctoral studies enter scientific training. They are offered educational exchanges at prominent universities abroad. Graduates can find fulfillment in the academic or scientific sphere or even out of it.

The theory of probability can be studied in a master or a doctoral study program at the Department of Probability and Mathematical Statistics after graduation from the bachelor study program General Mathematics.

We have selected two topics from the theory of probability. Stochastic differential equations are typically used when modeling dynamics of processes in which random impacts and continuous time must be considered. Mainly qualitative properties of the possible solutions are explored to prove to what extent the selected model is reasonable. In particular cases, a solution is sought by means of simulations. These methods are widely used mainly in natural sciences, mathematical engineering and in some areas of social sciences, economics and financial mathematics.

Stochastic geometry offers three-dimensional models of random sets, e.g. point processes, systems of particles, fibers and surfaces, random mosaics, which is used for describing



Spatio-temporal modeling of neural impulses (together with the Institute of Physiology AS CR) real structures in materials research, biology, medicine, geology and other sciences. The combination of probability theory, integral geometry, mathematical morphology and spatial statistics brings us tools for exact mathematical studies but also the basics for computational processing of 2D and 3D images and statistical description of variability. Another stage of research is dynamics in time.

PIDEA is an example of research projects in mathematical statistics. It is a European project aimed at accelerated fatigue tests of components of dashboard computers for airbuses. Attention is paid mainly to graphics cards of dashboard computers, which are cores of modern aircraft. Because these devices are extremely reliable and they are examined and maintained regularly, it is impossible to gain enough data on defects to assess and analyze its reliability.

To gain data, modules are subject to fatigue tests under far higher temperature, vibration and humidity than usual in ordinary operations. The tests are designed to reveal weaknesses of the components and verify if the components or the dashboard computer as a whole meet requirements set by the regulators of air traffic.

Workers and doctoral students of the Department of Probability and Mathematical Statistics were responsible for an effective plan of an experiment, which resulted in great financial savings, and for a statistical evaluation of the data. The methodology being developed appears to be suitable for fatigue tests of other devices and materials. The result of the project consists in both recommendations leading to higher reliability and theoretic solution of mathematical problems, which appear within the fatigue tests.

Mathematical Statistics

Mathematical statistics arises from the modern theory of probability. It deals mainly with real-world models taking random impacts into consideration. Its methods are used more and more for evaluating information based on only partial knowledge.

The studies provide deep practical as well as theoretical knowledge adequate not only for practice but also for further doctoral studies and academic career. Students learn about the essentials of statistical reasoning and methods used in practice including operating statistical software systems.

Graduates can find employment in any sphere where mass data are processed, i.e. where data from industry, biology, medicine, sociology, opinion polls, public administration, insurance and banking are analyzed. Very interesting and creative fulfillment is offered by universities and other academic and research institutions.

Mathematical statistics can be studied in a master or a doctoral study program at the Department of Probability and Mathematical Statistics after graduation from the bachelor study program General Mathematics.

More information about the studies can be found under:
http://www.karlin.mff.cuni.cz/~kpms/

• Econometrics, Financial and Insurance Mathematics

Econometrics

Econometrics uses tools of mathematics and mathematical statistics to model complex economic phenomena of random character. It deals with analyzing and verifying such models, predicting trends of development and with optimal decision-making within economic systems under incomplete or missing information.

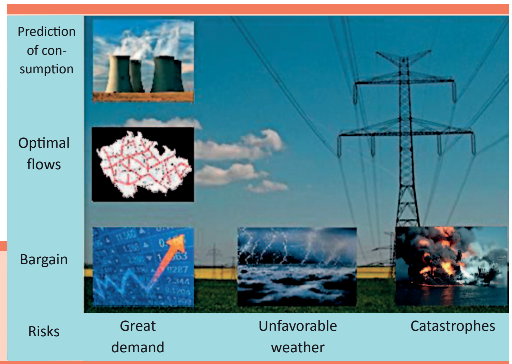
Students of econometrics can focus on financial mathematics, on special parts of mathematical statistics used in industry, management and market research. They can continue extending their knowledge of economics, computer science and abstract mathematics.

They can find employment in all spheres requiring profound knowledge of mathematics, mathematical statistics and economics, especially in the financial sector and public as well as private management.

Econometrics can be studied in the master and doctoral study programs at the Department of Probability and Mathematical Statistics. The master study program follows the bachelor study program General Mathematics.

Research activities in econometrics at the Department of Probability and Mathematical Statistics include: solving problems of stochastic optimization; testing the structure, stability and robustness of stochastic programs; searching for methods of portfolio optimization, risk management and their computational realizations; generating scenarios of future development; stress tests; research of utility functions and modeling financial and economic time series. For instance, current problems of the European Monetary Union (EMU) in the area of credit risks pricing for incomplete and non-homogenous data have been solved at the department.

Students of econometrics can meet practical problems in lectures or when working out their diploma thesis projects. In seminars, students deal with new results of theory. In addition, they are also led to work in teams and to work out projects in association with their proposers, usually professionals from economic practice, and with respect to their requirements.



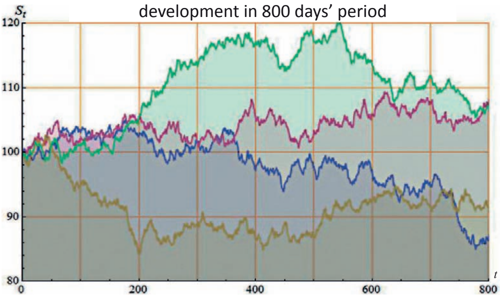
Examples of real problems solved by students of econometrics in a project seminar.

The number of unsolved problems in financial and actuarial mathematics, as well as in other mathematical fields is increasing. Financial and actuarial products become more and more complicated due to rapidly growing competition and globalization. The turnovers of financial transactions reach enormous amounts (a graduate from MFF is a director of an algorithmic-trading company with the turnover accounting for millions of billions CZK).

Graduation in financial and insurance mathematics is the necessary condition for getting the position of Actuary accredited in the EU (Appointed Actuary). Appointed actuaries have a special position in companies engaged in insurance activities. They are responsible for reporting the financial statements of insurance companies to the Czech National Bank.

The research is primarily aimed at modelling financial phenomena at banks, insurance companies, pension funds, and other financial institutions. This includes problems of solvency and analyses of financial time series. Currently, particular attention is being paid to modelling credit risks. In this respect, the characteristics such as value at risk or measures of the extreme-expected-loss type are studied. Often the methodology of simulation methods is used, see the simplified picture below.

Four possible trajectories of an asset price development in 800 days' period



Financial and Insurance Mathematics

Financial and insurance mathematics is one of the most growing fields in applied mathematics. A common feature of both disciplines lies in uncertainty. The underlying tools for studying related random phenomena are probability, statistics, stochastic calculus, all based on a deep knowledge of mathematics.

The MSc degree in Finance and Insurance Mathematics requires completion of credits in the field of study which includes calculus, statistics, stochastic processes, optimization, banking and finance, life and general insurance, insurance law, accounting, mathematical and computational methods for finance & insurance, financial management and risk theory. The graduates possess the knowledge needed for modelling and managing of risks in banks, insurance companies, social security, financial consulting and in supervising those institutions. The topics of their theses are often related to the projects of the European Union.

Beyond the usual mathematical and financial courses, the professional Bc study programme in Financial Mathematics comprises also some courses on actuarial mathematics. After graduation from the Bc study programme General Mathematics, students can enroll at the Department of Probability and Mathematical Statistics and continue in the follow-up master and doctoral study programme Financial and Actuarial Mathematics.

More information about the studies can be found under:
http://www.karlin.mff.cuni.cz/~kpms/

Mathematical Modeling in Physics and Engineering

Mathematical Institute of Charles University

Mathematical modeling in physics and engineering is a unique challenging interdisciplinary study which combines mathematical analysis, numerical mathematics and physics.

Students of this specialization are in close contact with students of analogous specialization within the program of 'Physics', see page 68. We believe that modeling of complex problems requires not only deep knowledge in the specialized field but also broad awareness of the general methods and the latest results available in all of the above specializations.

We mainly use this approach to study problems of continuum mechanics. Despite the considerable breadth of problems being studied we maintain excellence in teaching in all areas. We try to give students lectures which are presented by the specialists in particular fields, and we want students to know mathematics and physics on the highest level.

We strive to ensure that our graduates were able to bridge communication barriers between engineers, theoretical mathematicians, physicists, and programmers, and thus contribute to solving problems beyond the scope of one field. Thanks to these capabilities our graduates can easily work in applied

Continuum Mechanics

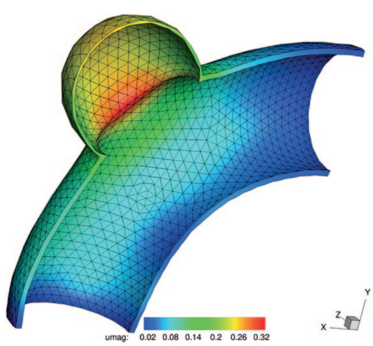
A lot of 'traditional' materials (e.g. body fluid) as well as materials produced by modern technologies have interesting properties on a macroscopic level. Fluid, for example, can 'spontaneously climb' up a rotating rod immersed in fluid (look for the Weisenberg phenomenon on the Internet), it may itself become 'hard' if it faces a fast deformation (keywords are shear-thickening, or liquid armor). It is useful to apply classical physics and the notion of 'continuous medium', or continuum mechanics, to describe such phenomena. It comes out that it is very difficult to design a good model which would be simple and, at the same time, good enough / capable to exactly describe the particular phenomenon. Numerous models, used in continuum mechanics, are younger than quantum mechanics and general theory of relativity. Consequently, classical physics has still its importance! We use mathematical modeling for identification of particular models and for studying their mathematical properties.

Modeling in Medicine

One of the typical sources of great problems, which is solvable if you have good knowledge of mathematics and physics, is modeling in medicine, for example, blood flow modeling. Mechanical blood behavior cannot be described with the help of classical models of materials. Moreover, it is necessary to observe a series of biochemical reactions which are important when we want to see and describe, for example, blood clotting. To this must be added an accurate description of blood vessels which consist of many anisotropic layers and are deformed due to blood flow. All this must be combined together to gain a model which can be used for studying properties of the artificial heart replacement. Naturally, blood modeling does not represent the final stage of mathematical modeling. We also study shape memory materials (alloys), propagation of cracks in solids, multicomponent materials, and multiphase flows. In all these cases we also deal with mathematical analysis and we solve numerically corresponding partial differential equations.

Jindřich Nečas Center for mathematical modeling

We are charter members of the Nečas Academic Center and we still participate in its current activities. The center is a joint project of several Czech institutions. Besides Faculty of Mathematics and Physics, the members are, for example, Department of Evolutional Differential Equations of Mathematical Institute, Academy of Sciences (AV ČR), or Department of Computational Methods of Institute of Computer Science, AV ČR. The center has capacity to invite renowned scholars from abroad to give series of lectures or participate in research. It also acts as a partner of similar institutions abroad.



Flow in an elastic tube with a bulge. Solving Navier-Stokes equations for the flow with an elastic problem for the deformation of the wall.

mathematics, physics and engineering, both in academic and in commercial sectors, both at home and abroad.

During your studies you will learn to ask questions about the nature of natural phenomena, you will learn to suggest mathematical models of these phenomena and the way of analyzing them and using them for computer simulations.

An important part of the study is learning how to distinguish characteristics which are or are not important for the description of a certain phenomenon

Once the basic level of applying necessary tools is mastered, you can specialize in choosing the topic of your master degree thesis which is usually somehow connected with continuum mechanics. However, you do not have to study only continuum mechanics and its applications in geophysics and medicine. You can devote yourself to mathematical analysis or numerical solution of problems from other areas. In addition, you will be able to participate in projects of institutions involved in 'Jindřich Nečas Center for mathematical modeling'.

It is natural that students leave for stays abroad. Our long-term partners are, among others, Ruprecht-Karls-Universität Heidelberg (joint doctoral study program), University of Oxford, or Texas A&M University.

Our students are charter members of Charles University in Prague SIAM (Society for Industrial and Applied Mathematics) student chapter. Its mission is to enable students to establish contacts with similar groups in the world and develop not only scientific activity but also organizational abilities.

http://www.karlin.mff.cuni.cz/katedry/mu/index.php

Mathematical Structures – Geometrical Part

Mathematical Institute of Charles University

Historically mathematics evolved primarily as a necessary language for describing physical phenomena. This influence is most evident in geometry (covariant derivatives, which in physics go by the name of gauge fields, are used for a unified description of elementary particle interactions; Riemann geometry provided the necessary language for Einstein's theory of gravity).

The influence of modern theoretical physics on current mathematics in recent decades has increased dramatically and led to the formation of many new areas of mathematics, which are typically interdisciplinary.

New branches of mathematics (supersymmetric theories, non-commutative geometry, quantum group theory, mathematical theory of quantum computers, and mathematics needed for quantum field theory and string theory) were created under the influence of theoretical physics.

This new development is reflected in the conception of the field of mathematical structures. In its geometrical, and to a large extent algebraic, part it is much closer to theoretical physics and provides all graduates a broad-based education useful for a wide variety of fields.

The turning point in understanding the geometry of the natural world was the discovery of non-Euclidean geometry in the early 19th century. This solved the thousand-year-old problem known as Euclid's fifth axiom, which in the Euclidean plane states that given a straight line and a point not on that line, there is only one parallel line that goes through that point.

N. Lobachevski described a so-called hyperbolic geometry where the fifth axiom does not hold, therefore it is possible (while maintaining all other axioms) to have many such parallel lines. Hyperbolic geometry was discovered practically at the same time by C.F. Gauss and J. Bolyai. This opened the gateway to a rich world of many different non-Euclidean geometries.

A crucial role in the description and classification of these new geometries was played by the Erlangen program formulated by German mathematician F. Klein and later developed by Klein, Riemann, Poincaré, and others. Poincaré's circular model of the hyperbolic plane is shown on the following page.

In addition to hyperbolic geometry, spherical geometry was also described. Since antiquity it was known that the surface of the Earth is curved, but it was not clear what shape it was. Columbus died believing that the Earth was pear-shaped. Even when the first ship returned after circumnavigating the globe, it was not excluded that the Earth had the shape of a tyre.

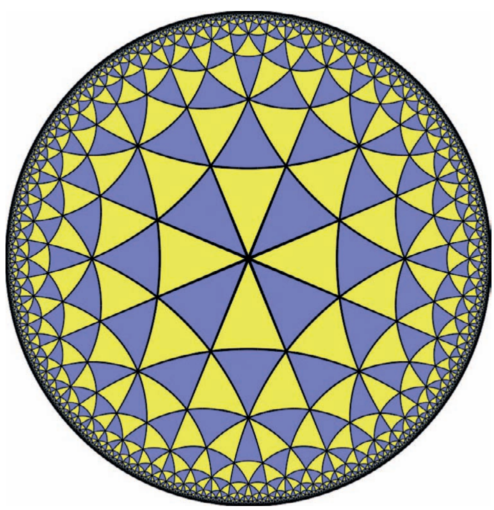
In 1904 Henri Poincaré found a way to characterize a two-dimensional sphere (or its deformation), and also formulated the hypothesis that such a characterization is also true in higher dimensions. This is particularly interesting in dimension 3, because today it is not clear what shape the universe is in which we live. Einstein's theory of relativity says that space is curved, but does not say exactly what it looks like.

In 2000 top contemporary mathematicians formulated 7 major unsolved mathematical problems and the Clay Mathematics Institute announced a reward of one million dollars for solving each of them. One of the problems is Poincaré's conjecture in dimension 3. In 2003, Grigori Perelman proved the truth of Poincaré's conjecture (and refused to accept the reward for solving it).

The picture shows Poincaré's circular model of hyperbolic geometry. The boundary circle represents the points "at infinity"; lines in this geometry are formed by arcs of circles (perpendicular to the boundary circle), or line segments that pass through the center of the circle. All triangles have the same hyperbolic size. It is also one of the infinitely many possible regular tilings of the hyperbolic plane. Its symmetry has an interesting algebraic structure. Similar themes often occurred in M. C. Escher's works of art.

The hyperbolic plane, unlike the Euclidean, has a negative constant curvature, owing to which it does not "fit" into the Euclidean plane. Its three-dimensional analogy, i.e. hyperbolic space, appears in Einstein's general theory of relativity and basically shows the curvature of light rays around massive objects.

Lines that meet at the boundary circle are parallel. We easily see that for a given straight line and a point not on that line there are exactly two such parallel lines going through that point.



The study of mathematical structures therefore requires a well-developed capacity for abstract thinking and the acceptance of new concepts. The Faculty of Mathematics and Physics of Charles University carries out top world-level research in all fields studied within mathematical structures, i.e. algebra, geometry, combinatorics, and logic.

The main goal of this field is to prepare students well for such research. Of course, not every graduate will eventually find work in the academic sphere, which after all is not sought after by everyone. Others will find that their preparation in working with abstract concepts and the ability to connect general principles with specific examples make them far more attractive on the labor market than it might seem. Our website: **http://www.karlin.mff.cuni.cz/katedry/mu/index.php**

Contents

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