DISCLAIMER
Although this brochure was compiled with the utmost care, no rights can be derived from its contents.
Computing has evolved from its origins as a “mere” calculation tool to generating virtual realities. Currently, ICT facilitates, defines, and even shapes our lives as individuals, groups, organizations and society. Your bank account is a series of numbers stored in a database. You connect with your friends via virtual networks. Your gadgets communicate with one another even more than they do with you. You engage in conversations with artificially generated agents.

So making ICT systems more intelligent, dependable, secure and efficient will improve the quality of life of individuals, groups, organizations, and society. We create new possibilities with cyber technology and study the fundamental principles underlying computation and communication.

The Centre for Telematics and Information Technology (CTIT) at the University of Twente (UT) advances modern computer science through its thematic research and education programmes:

- Human-centred Interaction Technologies
  - How do humans interact with technology? How can technology support human needs? How can we generate virtual agents that display natural behaviour?

- Wireless and Sensor Systems
  - How can we build smarter environments? How can ICT systems interact with the physical world? How can “things” communicate more efficiently?

- Services Science
  - How do we design ICT systems to meet organizational requirements? How can we expand ICT services? How can we create them from existing services?

- Industrial Engineering and Operations Research
  - How can we design the distribution of Internet purchases? How can we optimize healthcare logistics? How can we understand and manage energy networks?

- Dependable and Secure Computing
  - How can we justify our trust in ICT systems? How can we verify their safety? How can we design reliable software? How can we protect against malicious attacks?

Prof. Dr. Jaco van de Pol
Leader CTIT Graduate School at Twente Graduate School
TWENTE GRADUATE SCHOOL

TWENTE GRADUATE SCHOOL OFFERS HIGH-QUALITY EDUCATIONAL PROGRAMMES BASED ON SUBJECTS CLOSELY RELATED TO THE WORK OF THE UNIVERSITY’S RESEARCH INSTITUTES AND TAUGHT AND SUPERVISED BY EXPERT RESEARCHERS FROM THESE SAME INSTITUTES. IT OFFERS AN INCREASING VARIETY OF INTEGRATED MASTER’S AND PHD PROGRAMMES FOR OUTSTANDING GRADUATE STUDENTS WHO ARE KEEN TO PURSUE A CAREER IN SCIENTIFIC RESEARCH.

CTIT
CENTRE FOR TELEMATICS AND INFORMATION TECHNOLOGY
The Centre for Telematics and Information Technology (CTIT) of the University of Twente is one the largest academic ICT research institutes in Europe.

CTIT ranks number 10 on the list of the biggest research and knowledge centres in the Netherlands.

ICT does not just enable us to do new things; ICT shapes how we do them. This constructive nature requires a research approach that combines perspectives from technology, business models and user needs. The 28 research groups cover a broad and multidisciplinary field ranging from primarily technology-oriented towards highly application-oriented approaches, and from ICT to business engineering and behavioural sciences. This combination provides CTIT with a unique blend of scientific disciplines that stimulates the exploration of multidisciplinary topics. CTIT has bundled its research into six Strategic Research Orientations, to create focus and sufficient critical mass around specific strategic topics:
1. Applied Science of Services for Information Society Technologies
2. Dependable Systems and Networks
3. Wireless & Sensor Systems
4. Natural Interaction in Computer-mediated Environments
5. Integrated Security and Privacy in a Networked World
6. Industrial Engineering and ICT

TGS PROGRAMMES
TGS programmes are set up in collaboration between the university’s faculties and research institutes. Next to the PhD research project leading to a dissertation, the broad selection of discipline related and elective courses enable students to specialize in a research area they are interested in while broadening their perspective on the societal context of technology and research. These aspects are integrated into the Twente Graduate School, which aims to give a kick-start to research talent.

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<tr>
<th>MANPOWER</th>
<th>475 RESEARCHERS</th>
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<tr>
<td>INTERNATIONAL EMPLOYEES</td>
<td>40%</td>
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<tr>
<td>TURNOVER</td>
<td>29 M. € (FOR THE YEAR 2012)</td>
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<tr>
<td>NUMBER OF SPIN-OFFS</td>
<td>OVER 80</td>
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<tr>
<td>SOME LIAISONS</td>
<td>PHILIPS, SIEMENS, SHELL, THALES, ING BANK, VODAFONE, MICROSOFT, NOKIA</td>
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## TWENTE GRADUATE SCHOOL PROGRAMMES WITHIN CTIT

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<th>TWENTE GRADUATE SCHOOL PROGRAMME</th>
<th>RELATED UT MASTER’S PROGRAMME</th>
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<td>DEPENDABLE AND SECURE COMPUTING</td>
<td>COMPUTER SCIENCE</td>
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<tr>
<td>HUMAN-CENTRED INTERACTION TECHNOLOGIES</td>
<td>COMPUTER SCIENCE, COMMUNICATION STUDIES, HUMAN MEDIA INTERACTION, PHILOSOPHY OF SCIENCE, TECHNOLOGY AND SOCIETY, PSYCHOLOGY</td>
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<td>INDUSTRIAL ENGINEERING AND OPERATIONS RESEARCH</td>
<td>APPLIED MATHEMATICS, INDUSTRIAL ENGINEERING AND MANAGEMENT</td>
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<td>LEARNING IN EDUCATIONAL AND TRAINING SETTINGS</td>
<td>EDUCATIONAL SCIENCE AND TECHNOLOGY, PSYCHOLOGY</td>
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<td>SERVICES SCIENCE</td>
<td>COMPUTER SCIENCE, BUSINESS INFORMATION TECHNOLOGY</td>
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<tr>
<td>WIRELESS AND SENSOR SYSTEMS</td>
<td>COMPUTER SCIENCE, ELECTRICAL ENGINEERING, TELEMATICS, EMBEDDED SYSTEMS</td>
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ICT systems are used as part of an ever-growing variety of applications and form a critical backbone of our societal infrastructure. Malfunctioning or sabotage of ICT systems cause financial expenses at best, cost lives at worst, or may even disrupt society.

An ICT system is called dependable if reliance can be placed justly on the services it delivers. This should be possible despite the occurrence of physical errors, communication problems, software errors, human operator mistakes, or attacks by malicious intruders. Dependability and security are to be interpreted in the broadest sense of the terms. Depending on the application domain, they include 7x24 availability, absolutely safe and timely behaviour, a guaranteed quality-of-service level, protection of the integrity of financial transactions, enforcement of digital rights and privacy of users.

Dependable ICT is a challenge, because applications tend to be geographically distributed, have increasingly complex and adaptive functionality, are connected via wired or wireless networks, and should be open for interaction with an unknown, sometimes malicious, environment.

In our Computer Science graduate programme, students will learn and develop traditional and novel methods and techniques for analysing and constructing dependable and secure systems. Traditional means are fault and intrusion detection, prevention, prediction, removal, and tolerance, so that systems keep working even despite faults, errors, or hackers. Emphasis will be put on computational methods, in the following areas:
- modelling, automated analysis and synthesis of dependable systems;
- algorithms and protocols to enforce dependability and security;
- design of dependable and secure software architectures.

Examples of research schools for deepening courses: Institute for Programming research and Algorithmics (IPA) and Advanced School for Computing and Imaging (ASCI).

ICT SYSTEMS ARE USED AS PART OF AN EVER-GROWING VARIETY OF APPLICATIONS AND FORM A CRITICAL BACKBONE OF OUR SOCIETAL INFRASTRUCTURE.
In our modern urbanised society, work, leisure and the environment become more and more intertwined. Electric cars are not only a means of transportation, but are also considered as batteries for storage of excess power - e.g. generated during the night - so that large power equipment can produce at a constant rate (grid storage). Micro power plants in houses will be actively controlled and steered by power companies, as a result of which the comfort of living can be balanced with the power requirements of the entire power grid. Households are increasingly making use of the internet to do their shopping, thereby changing the entire supply chain from localised to distributed chains, which in turn affects our mobility patterns. In an ageing society, communication devices and systems like e-Health will become more and more important in healthcare. At the same time, a patient’s choice for a hospital will be increasingly determined by online status information of waiting times, quality of care, etc. To respond to these challenges, we need an integrated perspective, based on a variety of disciplines. Such an integrated, systemic approach is exactly what lies at the heart of the Operations Research and Management Science disciplines. In this respect, a key role is played by current and future IT infrastructures development. The Industrial Engineering and Operations Research (IEOR) programme of the Twente Graduate School focuses on methods and models for the design of algorithms and information systems that support the self-organised urbanised networked systems.

IEOR draws on specialized knowledge and (analytical) skills in the mathematical, physical, and social sciences, and combines such expertise with the principles and methods of engineering analysis and design. Unlike traditional disciplines in engineering, IEOR addresses the role of human decision makers and other stakeholders as key contributors to the inherent complexity of systems. IEOR specialists are problem solvers. They work on real-world problems, combine disciplines, and develop project and process-management expertise and communication skills. Industrial engineers may come from various undergraduate backgrounds in engineering and other quantitative fields.

Examples of research schools for deepening courses: Beta and Dutch Network on the Mathematics of Operations Research (LNMB).

**INDUSTRIAL ENGINEERING IS CONCERNED WITH THE DESIGN AND IMPROVEMENT OF OPERATIONAL AND STRATEGIC PROCESSES AND INTEGRATED SYSTEMS.**
The Twente Graduate programme WiSe (Wireless and Sensor Systems) addresses a new paradigm for bringing the flexibility of information technology to bear in every aspect of daily life. It foresees that people will be surrounded by embedded and flexibly (wirelessly) networked systems that provide easily accessible yet unobtrusive support for an open-ended range of activities, to enrich daily life and to increase the productivity at work. These systems contain a mixture of hardware and software: their scope may be as simple as a sensor, or as complex as a portable device, or even an entire building or city. Cooperation is a necessity in order to perform tasks with sufficient quality or efficiency, and to reach the required level of functionality and to support real-time interactions. The specific nature of these systems require them to be open, scalable, adaptable and dependable, while integrating heterogeneous devices ranging from tiny actuators to larger computers.

The programme targets students holding an Electrical Engineering or Computer Science Bachelor’s degree, who like to pursue a research career in Wireless and Sensor Systems. The WiSe programme is closely related to the Strategic Research Orientation (SRO) WiSe (Wireless and Sensor Systems) of the CTIT research institute. The research groups participating in WiSe have strong leading positions in both national and international multi-disciplinary research projects in this field. The WiSe programme is not just focussed on studying the fundamentals of wireless and sensor systems, but also the context of these sensor systems. To this end, WiSe is a multi-disciplinary and application-oriented programme, enabling students to come into contact with different (both technical and non-technical) disciplines and, by doing so, stimulating cooperation. Examples of application domains that are currently worked on by research groups in the SRO WiSe: entertainment, sustainability, logistics, industrial/public safety, mobility, agriculture, and medical.

Examples of research schools for deepening courses: School for Information and Knowledge Systems (SIKS) and Advanced School for Computing and Imaging (ASCI).
Services are essential and can become quite complex as more interrelated services appear and more actors get involved. This means that services must be approached from a scientific, a management and an engineering point of view.

Services Science is the study of complex service systems in which businesses create value through collaboration with suppliers, customers and other stakeholders using IT. The global connectedness in a service economy faces us with new levels of architectural complexity and new risks (e.g., security risks) as a result of the dependency on such systems, which need to be managed. An effective understanding of service systems requires that interactions between people, organizations, information systems, and technology are considered in the light of their ability to create business value in various and evolving contexts.

IT has the potential of enabling the creation of service systems and supporting the growth of the services sector. Most business services and processes are supported by IT services. The shift from products to services often implies an IT-enabled provision of e-services. High-speed networks and powerful computer systems have made these processes ubiquitous. From a methodological perspective, the emergence of the Service-Oriented Architecture has facilitated the roll-out of business processes to IT services, providing the benefits of effectiveness and flexibility.

The cornerstones of our Services Science programme are Management Science and Computer Science. The programme consists of a two-years Master’s phase and a three-years PhD phase. The Master’s phase offers two study schemes, one on the basis of a Master in Business Information Technology and the other on the basis of a Master in Computer Science. Both of them follow the rules of their respective Master’s programme, but have a distinct emphasis on ‘services science’. The PhD phase comprises courses that are meant for the student to gain more in-depth knowledge of services science, such as specialized courses offered by the university, and courses offered by the IPA, SIKS and BETA research schools. Furthermore, the programme includes an optional multidisciplinary case study, attendance of scientific events and, obviously, the PhD research.

Examples of research schools for deepening courses: School for Information and Knowledge Systems (SIKS) and Advanced School for Computing and Imaging (ASCI), Institute for Programming research and Algorithmics (IPA) and Beta.

THE SHIFT FROM PRODUCTS TO SERVICES OFTEN IMPLIES AN ICT-ENABLED PROVISION OF E-SERVICES.
LEARNING IN EDUCATIONAL AND TRAINING SETTINGS

Student learning is the core process that is to be promoted in educational and training settings. In contemporary theories, learning is seen as a learner-centred process, characterized by awareness of the demand features of the situation (in which a situation is recognised as a learning task), sufficient motivation and volitional energy to become active, interpretation of the learning task in the light of previous knowledge, habits and available skills, execution of cognitive operations, varying from simple memorisation to so-called higher-order cognitive processes, application of metacognitive strategies and delivery of a relative end-product of learning, in the sense of a completed task or a problem solved. A key concept that integrates the more “constructivist” view of learning with rather “instructionalist” teaching and learning theories is the structuring or “scaffolding” of the learning process. The fact that individual differences of learners are likely to play a role in all these facets of learning, underlines the need for adaptability and flexibility in the application of all conditions that are directly or indirectly mobilised to support learning.

Research questions that are dealt with in this programme, concentrate on optimising learning in instructional settings, on creating effective conditions of schooling through professional development of teachers and improvement of school organisation and management, and on the technology and psychometric theory of the assessment of students’ learning outcomes.

Examples of research schools for deepening courses: Interuniversity Center for Educational Sciences (ICO), Interuniversity Graduate School of Psychometrics and Sociometrics (IOPS), Kurt Lewin Institute.

STUDENT LEARNING IS THE CORE PROCESS THAT IS TO BE PROMOTED IN EDUCATION AND TRAINING SETTINGS.
Human-Centred Interaction Technologies focuses on both the interaction of humans with the system and the interaction between humans through technology. The rapidly increasing availability and use of ICT in all aspects of the personal, organizational and societal life sphere during work, learning or leisure, call for a multidisciplinary and interdisciplinary approach of the subject, in which computer science and other engineering disciplines are linked with social sciences and the humanities. Human-Centred Interaction Technologies studies the technological, psychological, sociological and philosophical dimensions of human-media interaction.

The core research concerns the design of intelligent interactive systems that improve the quality of the user experience as part of a human-centred development process. Beside the technological perspective, this will involve an examination of the human in the loop. Therefore, other elements such as the assumptions underlying design and development (as they relate to e.g. ethical considerations), the acceptance and use as well as the impact and implications of the technology on the direct interaction of humans with the system, and the impact on a societal level are considered as well.

The technical and engineering programmes involved in this TGS programme are also focussed on building more and more involved computational models of users and user contexts for interpreting signals and processes that are considered as meaningful for humans and for artificial intelligent interactive systems in some particular practices. Considerable research efforts are spent on the attempt to interpret a user’s state of mind (e.g. by interpreting natural language text and speech, body language or brain signals) and to act upon this appropriately. To build such computational models, systems become increasingly dependent on the analysis of gigantic repositories of user interactions, such as user clicks logs, query logs, etc.

From a psychological and communicative perspective, the programme brings challenging questions to the fore about how meaning (embodied in the interface, content, actions, etc) is created, transferred and adapted in ICT-mediated environments. From a cognitive-ergonomic point of view, it is important to understand the neuro-cognitive possibilities and limitations of humans as they interact with their counterparts and with technology.

Examples of research schools for deepening courses:
School for Information and Knowledge Systems (SIKS) and HUMAINE summer school.

**THE PROGRAMME FOCUSES ON BOTH THE INTERACTION OF HUMANS WITH THE SYSTEM AND THE INTERACTION BETWEEN HUMANS THROUGH TECHNOLOGY.**
ADMISSION
REQUIREMENTS
AND ENROLMENT

THERE ARE TWO WAYS TO ENROL INTO A TGS PROGRAMME. YOU CAN START A MASTER’S DEGREE PROGRAMME AT THE UNIVERSITY OF TWENTE OR YOU CAN START A PHD PROGRAMME IF YOU HAVE ALREADY COMPLETED A MASTER’S PROGRAMME AT THE UNIVERSITY OF TWENTE OR ELSEWHERE.

ARE YOU CURRENTLY A BACHELOR’S STUDENT?

- You have already obtained your Bachelor’s degree
- Two-year programme with discipline related courses, 120 credits
- Opportunity to start an integrated MSc/PhD programme in the second year
- PhD research
- Deepening, broadening, academic skills and career development courses, 30 credits

*Some of our Master’s programmes are one-year programmes.

If you are currently a Bachelor’s student or if you have recently obtained your Bachelor’s degree, and if you are interested in pursuing a PhD through one of the integrated research programmes TGS offers, please have a look at our Master’s programmes.

To be admitted to a Twente Graduate School programme, you must have achieved excellent results in your Bachelor’s degree and have good research skills. Also, you must have gained admission to a relevant Master’s programme. The Twente Graduate School programme are particularly concentrated on research. Talented students can write their PhD proposal as part of their Master’s degree programme. For more information about the Master’s programmes, the admission requirements, and the tuition fee, please visit our website at: www.utwente.nl/master

ARE YOU CURRENTLY A MASTER’S STUDENT?

- You have already obtained your Master’s degree
- PhD research
- Deepening, broadening, academic skills and career development courses, 30 credits

If you have successfully attained a Master’s degree, you may enter a PhD programme at the Twente Graduate School. PhD candidates may either apply for a PhD position available at one of the research groups or try to obtain their funding themselves.

VACANCIES

Unlike in many other countries, most PhD students in the Netherlands are paid employees, often working directly for the university. Research projects are defined by the head of the research group, who subsequently recruits graduate students to carry out these projects. In case a PhD position is offered in the research field of your choice, you are kindly invited to apply to such a vacancy. Vacancies for PhD positions at the University of Twente, including those connected to the Twente Graduate School, are published on the vacancies website at: www.utwente.nl/vacancies
OWN FUNDING
You may also enter a Twente Graduate School programme as a PhD student with your own funding or with an international scholarship. In that case, research projects are initiated on the basis of proposals submitted by graduate students as part of their application procedure. A professor in a relevant field has to express interest in the candidate and the proposed line of research. Before a proposed research plan is taken into consideration, it must be clear that the candidate intends to submit an application for a secured funding scholarship. Please note that the University of Twente is not in a position to offer fellowships or similar funding for PhD students, other than the vacancies mentioned above.

ADDITIONAL INFORMATION
For more information about the Twente Graduate School, please visit the TGS website at: www.utwente.nl/tgs. For more information about the career development courses visit www.utwente.nl/ctd/en/phd
I elected to study at the University of Twente (UT) because I wanted to complete coursework in both Applied Physics and Computer Science. Eventually, it came down to a choice between Delft Technical University and UT and I decided to study in Enschede, in part because it was closer to my hometown. Having studied here for over a decade, I now know that there are many other good reasons to study here.

I am in the TGS programme Dependable and Secure Computing; I conduct research at the interface of two topics: formal methods and parallel programming. The Formal Methods and Tools research group develops methods and tools for formal verification of systems. This means that, based on the specification of a model, all possible states of a problem are calculated, and the result is then used to prove certain properties. An example of such a property is there is never a forbidden condition or that a response follows within a certain period of time if a button is pushed. In my research, I devise methods to compute all possible states faster by using computers with many processors. There are techniques to make calculations (algorithms) suitable for parallel execution and I apply these to operations on binary decision diagrams. A binary decision diagram is a way to store information which is efficient with respect to memory usage.

So far, I have fulfilled a part of my 30 education credits by attending summer schools, with a number of courses at the National Institute for Programming Research and Algorithms (IPA). I also participated in the TGS introduction days and I followed Research Management, one of the courses offered by TGS. Of the things I learned during this course, one of the most important was that, in science, it is crucial to know what other researchers are doing and to know where your research fits into the rest of the field. Personally, I find that the added value of TGS lies in its useful courses on offer.

I am still not sure what my next step will be after completing my PhD. A postdoctoral position in bioinformation could definitely be interesting; but for now, I just need to focus on obtaining my PhD.

NAME: Tom Van Dijk

TWENTE GRADUATE SCHOOL PROGRAMME: DEPENDABLE AND SECURE COMPUTING