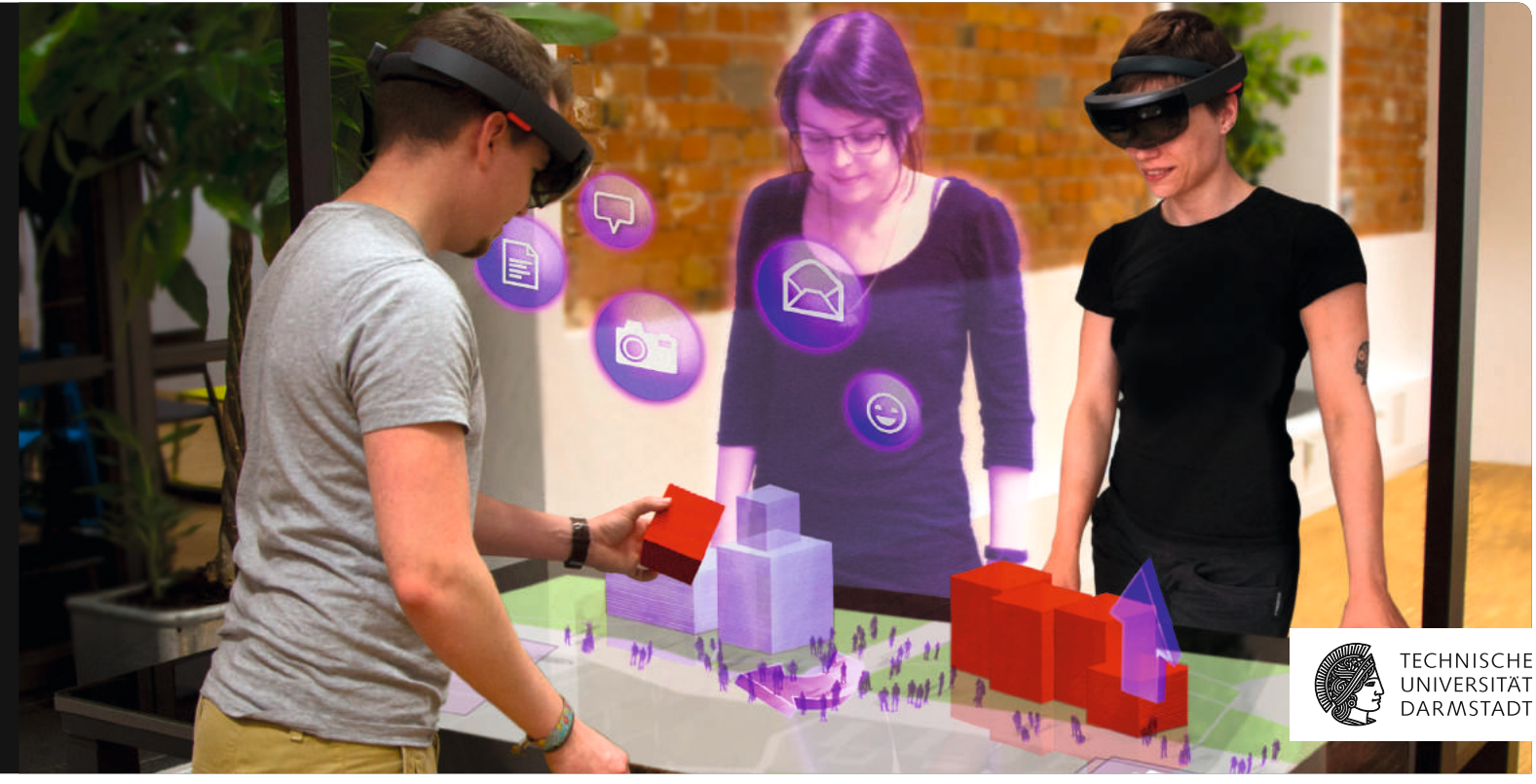

TECHNISCHE UNIVERSITÄT DARMSTADT

Telecooperation

Telecooperation Lab

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Photo (p.4): Jan-Christoph Hartung

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We celebrate!

Our last booklet in 2011 started with the very same statement, when Telecooperation research led by Prof. Dr. Max Mühlhäuser had existed for more than a quarter of a century, and his lab existed for a little over 10 years at Technische Universität Darmstadt. The present version of our booklet is edited at the occasion of the 60th birthday of Prof. Dr. Max Mühlhäuser. What a good reason for us researchers, who usually are focused on the future, to look back on our past, too. Hence, this booklet quickly reviews the past thirty-one years of Telecooperation research before we present what we're currently working on. So let's start with the beginning …

History

31 years ago, not long after finishing his PhD at the University of Karlsruhe under Professor Gerhard Krüger, young researcher Max Mühlhäuser accepted the offer to conceive and manage the first European research center of Digital Equipment Corporation (DEC), at the time the world's second largest computer manufacturer. His center should become a role model for industrial research and technology transfer centers co-located with academic research, and serve as a blueprint for similar centers in Europe, Australia, North America, and South Africa.

In 1989, Max Mühlhäuser moved back to academia, accepting a professorship position at the University of Kaiserslautern. His group grew, and his topics proliferated, now covering Telecooperation in the classical sense of IT-supported group cooperation over distance.

Professorship offers by Université de Montréal and University of Karlsruhe followed in 1992. Max Mühlhäuser accepted the latter one and started the Telecooperation Office (TecO) with support from his successors at DEC, Dr. Igor Varsek and Prof. Dr. Lutz Heuser. TecO would soon become the breeding place of Ubiquitous Computing research in Europe, with Professor Hans-Werner Gellersen starting as a PhD candidate there and taking the center to its full bloom after Professor Mühlhäuser's leave.

In 1994, Professor Mühlhäuser received professorship offers from Institut Eurécom, France, and the University of Linz, Austria. The latter included the charter to develop turn-key ready solutions for an entire floor of an exciting new center linked to the world famous Ars Electronica electronic arts festival. The entire new group in Linz worked with great zeal in 1995, and over thirty TV stations from all around the world acknowledged the results at the opening.

After a visiting professorship stopover in California, he received further professorship offers from the Universities of Klagenfurt and Darmstadt. In 2000, his move to Darmstadt began. He started by taking over and reshaping the computing services "RBG" of the computer science department. By 2001, the restructuring of the Distributed Systems Lab, which he had taken over was finished, too – including the official name change to Telecooperation Lab. A prestigious offer came from TU Twente in 2006 including the offer to take over a large institute with several younger faculties and a large group of researchers.

More than six years ago, Max Mühlhäuser celebrated his "10/25 years anniversary": ten years at Technische Universität Darmstadt and a whopping quarter century of telecooperation research. For this occasion, a new group logo had been introduced, symbolizing the tight integration of humans, computers and "the Net".

From Past to Present

EARLY DAYS IN DARMSTADT

RECENT PHOTO

Today, our brochure connects the past and the present to our vision of the future. Max Mühlhäuser is heading the Telecooperation Lab at Technische Universität Darmstadt as an integral part of various collaborative efforts, including a doctoral school and two collaborative research centers. His group is conducting research in three fields of Smart Spaces: (1) **Cooperation**, i.e., networks and distributed systems, (2) **Human-Computer Interaction**, and (3) **Protection**, i.e., privacy, critical-infrastructure protection, and computational trust.

The rest of this booklet presents the research in these three fields, represented by the lab's so-called areas.

Welcome

Telecooperation Lab
The Telecooperation Lab (TK) represents a group of well over 30 people at Technische Universität Darmstadt, Department of Computer Science. Prof. Dr. Max Mühlhäuser is heading this group together with several senior researchers and group leaders.

Vision and Mission
We envision the future Internet to enable computer augmented smart spaces populated with smart objects; smart spaces vary largely in size, from a person's smart assistive 'halo' via meeting rooms, buildings, organizations, and cities, up to distributed venues and global knowledge spaces.
Our mission is the technological advancement of smart spaces, our vision the support and furthering of the humans populating them; this comprises improved ***cooperation*** among humans and smart spaces, enjoyable ***interaction***, and ***protection*** from malicious and hazardous threats.

Embedding
Our work is also influenced by the collaborative projects that we participate in, and by Prof. Mühlhäuser's roles, such as head of a doctoral school on privacy and trust for mobile users, deputy speaker of a collaborative research center on the future Internet, and more.

Department of Computer Science & TU Darmstadt
As early as 1957, the first programming lectures were held in Darmstadt. In 1972, the Department of Computer Science was founded as one of the first such departments in Germany. It is ranked among the top institutions of its kind in Germany. The department plays a decisive role in two of the six profile areas of the university: Cybersecurity, and Internet & Digitalization. The department is also closely interwoven with IT research in the region, including the two IT centric Fraunhofer institutes and the enterprises and institutes that constitute the so called Software Valley in southwest Germany, repeatedly flagged in comparative studies as (one of) the most powerful IT regions in Europe.

People

Professors

Prof. Dr. Max Mühlhäuser

Area Heads

Dr. Jörg Daubert

Dr. Niloofar Dezfuli

Dr. Sheikh Mahbub Habib

Dr. Stefan Radomski

Dr. Lin Wang

Further Postdocs

Dr. Florian Volk

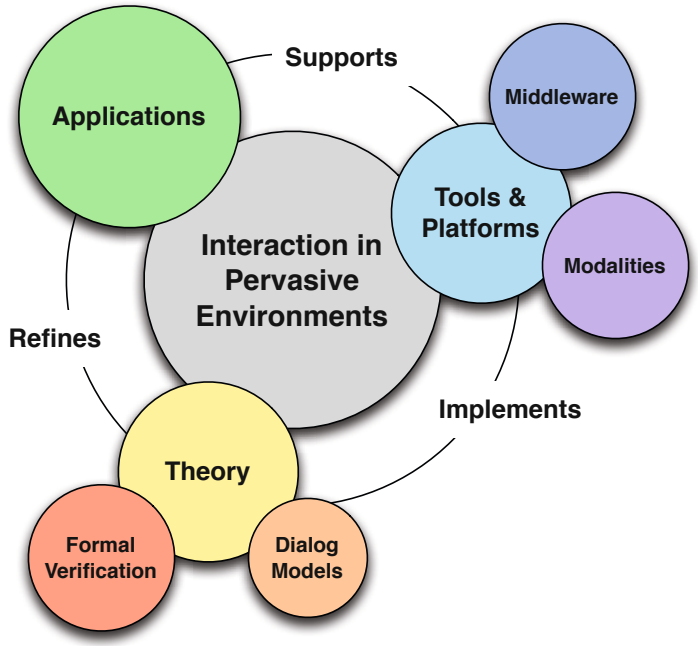
Dr. Andrea Tundis

Dr. Emmanouil Vasilomanolakis

Area: Reliable Interactive Things (RIT)

The area of Reliable Interactive Things (RIT) was recently restructured and is led by Dr.-Ing. Stefan Radomski. It researches dialog modeling techniques for multimodal, interactive systems with a focus on the verifiability of the resulting interfaces. To this effect, we develop, implement and evaluate various descriptions for interactive systems (e.g., rule-based approaches with reasoning or state-transition systems) and transpile them onto input languages of established technologies. The target platforms include anything from W3C recommendations for modality-specific markup to ANSI-C and even VHDL for resource constrained systems and integrated circuitry.

Dr. Stefan Radomski
Area Head
Post-Doctoral Researcher



The area developed a series of multimodal interfaces and maintains an implementation of the W3C's State-Chart XML recommendation [1], as a proposed dialog manager for the W3C Multimodal Interfaces and Architecture recommendation. This state-chart interpreter implementation was extended to support a rich selection of different dialog management techniques, e.g., for rule-based reasoning and deduction via an embedded Prolog scripting environment or a Lua environment for embedded devices.

[1] https://github.com/tklab-tud/uscxml

dialog+

Dialog concepts for enabling a smart command & control interface via voice in a house environment. In combination with a semantic background information service for assisting the user during discussions. The goal for the user is that the system gives additional topic-related information, but does not disturb the user. The challenge here is to find out possibilities for the design of a smart assistant system at home in the future.

User Interfaces for Brain-Storming Meetings

How can appropriate means improve participation of the blind in workplace situations that require intense cooperation with the sighted? Here, we contributed in the areas of novel interaction devices and techniques, combined with research in the area of accessibility. This research was conducted in cooperation with Switzerland (ETH Zurich), Germany (TU Darmstadt), and Austria (TU Linz).

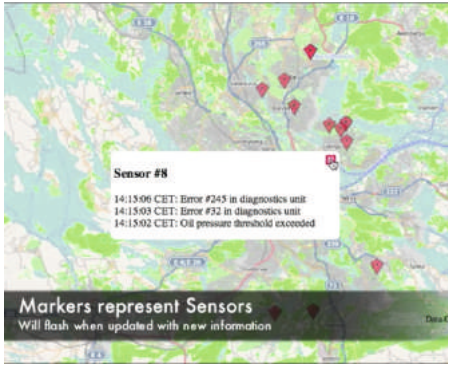
Smart Vortex

The goal of Smart Vortex was to provide a technological infrastructure for real time handling of massive product data streams. This EU project developed a comprehensive suite of interoperable tools, services, and methods for intelligent management and analysis of massive data streams, enabling better collaboration and decision making in large-scale collaborative projects concerning industrial innovation engineering.

Mundo Speech API

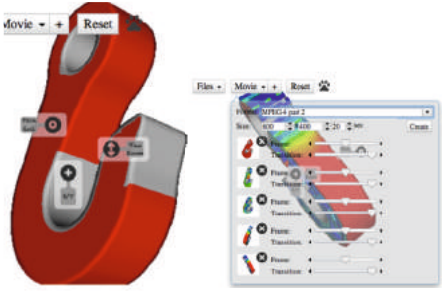
Development of a ubiquitous computing speech API to overcome the limitations of embedded devices and to support multiple audio input and output devices, and multiple text-to-speech engines and speech recognizers with different capabilities in a given environment.

Multi-Modal Map Display



A map display featuring situational awareness via spatial audio notifications and spoken messages. An HTML browser connects to the platform and is served with an XHTML page to display a map of the area. The platform pushes new notification onto the map and renders spatial audio to indicate the relative location.

Web-Based FEM Visualization



Visualization of a series of finite element method iterations in an XHTML browser. An object can be rotated freely and development over time can be explored. It allows exporting an animated movie of the series as a set of object pose key frames with interpolation in between.

State-Chart Debugger

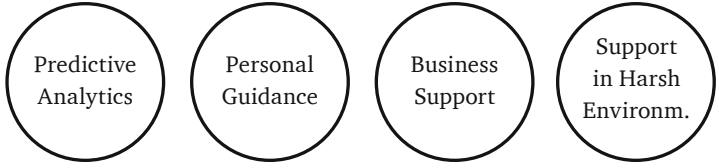
We developed a web-based debugger for the execution of SCXML documents. The debugging interface will allow registering breakpoints for different phases of the microstep(T) algorithm, which will cause the interpreter to suspend interpretation and allow for an inspection of the interpreter's state.

Area: Smart Proactive Assistance (SPA)

"Provision of smart proactive assistance (SPA) to humans or organizations by connecting ubiquitous technologies and advanced data analytics in everyday or emergency settings."

In 1991, the pioneer Weiser already had the vision of ubiquitous computing where pervasive technologies unobtrusively coexist with humans and support them in smart ways. Even a quarter of a century later, his vision does not come true. Indeed, a major step forward in pervasive technologies is done with modern mobile devices like smartphones, or IoT devices that can sense and change their and the user's environment. Those ubiquitous devices also offer access to information and services anywhere and anytime.

To achieve Weiser's vision, our research tackles the transformation of ubiquitous devices from reactive systems to unobtrusive proactive assistants acting on the user's behalf. Addressing the inherently interdisciplinary nature of such proactive systems, the SPA area is divided into four complementary focus areas:



Sebastian Kauschke
Doctoral Researcher

Christian Meurisch
Doctoral Researcher

Timo Nolle
Doctoral Researcher

Alexander Seeliger
Doctoral Researcher

- **Funding projects and cooperation partners**

Each focus area is supported by a government funded project or an industrial cooperation partner (see left side).

To demonstrate our novel findings from the focus areas, we build integrated showcases (see next page), which are categorized into the four processing stages of a smart proactive assistant:

(1) ***sensing*** of data to deduct knowledge from ubiquitous devices (e.g., personal tracking, event log processing),

(2) ***modeling*** the context and environment by processing and aggregating information (e.g., user and context modeling, process modeling),

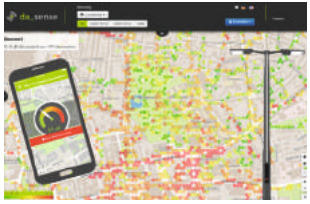
(3) ***prediction*** of the future (e.g., adaptive models, predictive models, Deep Learning), and

(4) intension specific ***intelligent actioning*** (e.g., personal or organizational assistance).

Sensing

KRAKEN.ME

Is a framework that realizes a multi-device user tracking suite to capture digital life, offering integrated tools for mobile, social and desktop tracking. It fuses data from both physical and virtual sensors.



SMART URBAN PLATFORM

This project realizes a sensor data fusion platform for smart cities, utilizing (i) fixed sensor infrastructures such as smart street lights, (ii) wireless sensor networks, and (iii) participatory sensing with smartphones.

Modeling

DISVIS 2.0

DIVIS focuses on realistic simulations of ad-hoc networks and mobility models in harsh environments (e.g., disaster situations). Our novel human-centered approach also considers cognitive processes.

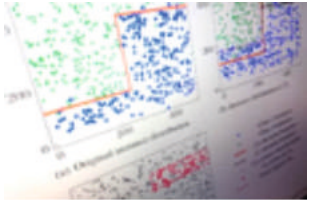
PROCESS MINING

Here, we focus on research to automatically mine insights in historic process data, providing future outlook and detecting malicious instances by using machine learning and data mining techniques.

Prediction

ANOMALY DETECTION

This project focuses on detecting anomalies in unknown business processes. It makes use of state-of-the-art Deep Learning methodology to accurately detect anomalous events in the execution of a process.



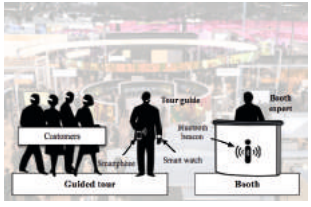
PATCHING FRAMEWORK

This project focuses on adapting an existing black-box classification model to new data by inferring and utilizing regions in the instance space where the existing model is error-prone.

Intelligent Actioning

INFRASTRUCTURE-LESS COOPERATION

This project focuses on investigating novel ways to enable intelligent support and cooperation between humans in infrastructure-less environments such as in disaster scenarios.



SMART ASSISTANTS

This collection of projects comprises the embodiments of our novel findings on smart assistants, which provide intelligent proactive support for humans (e.g., health guidance, or digital support).

DB Schenker "Predictive Analytics in a Railway Scenario"

Sensor technology has been integrated in railway systems for quite a while. Rail vehicles and the infrastructure are equipped with many sensors, on which security mechanisms like traffic control as well as control mechanisms on the trains are based.
The goal of this project is to leverage the recorded data and use it to predict relevant system failures in order to increase reliability and save costs.

Software Campus Project "PersonalAssistant"

software campus

In todays fast-paced environment, humans are faced with various problems such as information overload, stress, health and social issues.
The project "PersonalAssistant" aims to approach these issues through personal guidance or support within a user's daily and professional life. The Software Campus program is initiated by the Federal Ministry of Education and Research (BMBF).

Deep Reasoning about Unknown Processes (DRUP)

The goal of DRUP is to automate the analysis of unknown operational data to understand and optimize larger process structures. With the use of artificial intelligence, unknown structures can be understood to provide recommendations for process optimization.

Networked Infrastructureless Cooperation for Emergency Response (NICER)

NICER
Networked Infrastructureless Cooperation for Emergency Response

Crises, disasters and major catastrophic events are triggered by the forces of nature, human or technical failure or violence and terrorism. Technical infrastructures are damaged or destroyed.
We participate in NICER a collaborative project that explores how infrastructure-less information and communications technology can establish links between people in the event of a crisis, thus enabling them to work together to overcome the crisis.

Area: Smart Protection in Infrastructures and Networks (SPIN)

Our mission at SPIN is to enable secure, trustworthy and privacy aware interactions among connected actors and services. SPIN researchers are working on self-organized collaborative detection and response mechanisms that are trust and privacy aware as well as resilient to attacks and faults. Our smart solutions range from sophisticated and user-friendly trust management solutions to collaborative network intrusion detection systems, privacy-preserving IoT middleware, and resilient cyber-physical systems.

Researchers in the SPIN area are focus on the following topics:

- Computational Trust
- Communication Privacy
- Deep Learning for Cyber Security
- Collaborative Detection and Response
- Self-Organized Security for Cyber-Physical Systems
- Botnets
- Threat Analysis

Dr. Sheikh Mahbub Habib
Area Head
Post-Doctoral Researcher

Dr. Jörg Daubert
Area Head
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Dr. Emmanouil Vasilomanolakis
Post-Doctoral Researcher

Dr. Andrea Tundis
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Nikolaos Alexopoulos
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Carlos Garcia
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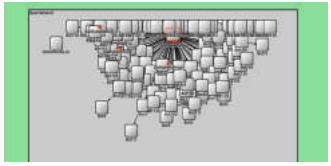
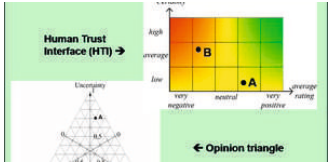
Tim Grube
Doctoral Researcher

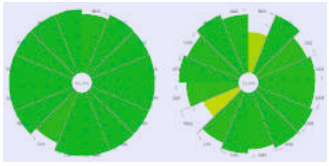
Rolf Egert
Doctoral Researcher



BOTNET SIMULATION FRAMEWORK (BSF)
Botnets are inherently stealthy, hard to analyze, even harder to stop and, thus, pose a significant threat to every ICT infrastructure. Our BSF models botnets in detail and yields monitoring strategies and takedown methods.



CERTAINTRUST SDK
Computational Trust reasons about the expectation or probability about the behaviour of another entity. Our SDK allows computing this probability on the foundation of Bayesian logic. The SDK is available on our website for everyone to use.



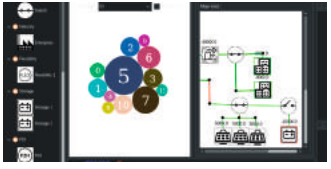
TRUST-AS-A-SERVICE FOR THE CLOUD ECOSYSTEM (TAAS4CLOUD)
TaaS4Cloud leverages computational trust methods, e.g., CertainTrust, Human Trust Interface, and Trust Visualization, to compare cloud services, in particular with respect to security requirements.

TUDA CYBER INCIDENT MONITOR (TRACING)
Creating awareness for the cyber attack situation is vital for security analysts. TraCINg integrates our collaborative honeypot initiative with other universities and institutes around the globe into one monitoring tool.

TWITTERIZE
Remaining anonymous while using social media can be a crucial requirement to exercise freedom of speech. Twitterize showcases how our anonymization techniques enable anonymous tweeting alongside normal tweeting.

HONEYPOT-TO-GO(HOSTAGE)
HosTaGe is the first smartphone app that empowers users via an easy to understand traffic light schema to assess the security of public Wifis and the presence of hackers while at the same time offering many advanced honeypot capabilities for experts.

INTRUSION DETECTION DATASET TOOLKIT (ID2T)
Developing, implementing and testing Intrusion Detection Systems (IDS) is difficult due to the lack of reliable and labelled test data. ID2T enables IDS experts to introduce a variety of labelled attacks into real-world data sets.



HOLEG SIMULATOR
Creating resilience is challenging in distributed systems such as the energy network. The HOLEG Simulator is a solution for modelling energy networks and identifying and evaluating resilient configurations based on the Holon analogy.

Privacy and Trust for Mobile Users
The Research Training Group "Privacy and Trust for Mobile Users" was launched in October 2015. The goals of the project are to empower users, protect their privacy, and improving trust among the stakeholders in our connected society. It is a highly interdisciplinary collaboration between computer science and the fields of law, economics, sociology, and usability research funded by the German Research Foundation (DFG)

Cryptography-based Security Solutions: Enabling Trust in New and Next Generation Computing Environments (CROSSING)
The collaborative research center CROSSING was launched in October 2014. The goal of this center is to provide cryptography-based security solutions enabling trust in new and next generation computing environments. In the context of CROSSING, we aim to advance computational trust methods for the benefit of cryptographic solutions. CROSSING is funded by the German Research Foundation (DFG).

Proactive Risk Management through Improved Cyber Situational Awareness (PROTECTIVE)
PROTECTIVE aims to provide security teams with a greater cyber capability through improved cyber situational awareness. We are investigating general aspects of trust-aware sharing of Threat Intelligence (TI) feeds within this project. The goal is to provide tools for multi-dimensional trust assessment of TI feeds to enable security analysts to judge the quality of TI feeds more reliably. PROTECTIVE is funded by the EU Commission under the H2020 program.

Center for Research in Security and Privacy (CRISP)

The former IT security centers EC SPRIDE and CASED have been united in order to bundle their strengths within the "Center for Research in Security and Privacy" (CRISP). Under the umbrella of CRISP, we participate in two research projects: (1) creating means to share control of private data among service consumers (that reveal private data to use seemingly "free" online services), and service providers (that monetize the private data collected from the users) with the help of PETs for adjusting the granularity control of data; (2) research in botnet control and defense mechanisms for IoT environments. CRISP is jointly funded by the BMBF and HMWK.

TAKEDOWN

The TAKEDOWN project aims to develop effective and efficient security solutions against organized crime and terrorist networks (OC/TN). Our goal is to develop an Open Information Hub that will include the interactive info graphs, data visualizations and video guides on OC/TN response and actions for national organizations and citizens. TAKEDOWN is funded by the EU Commission under the H2020 program.

PolyEnergyNet

PolyEnergyNet (PEN) is a project that deals with resilient energy networks that enhance combined resource types (electrical power, gas, heat) with Information and Communication Technology (ICT). Our research in this project is twofold: On the one hand, we develop anomaly-based detection algorithms for network disturbances. On the other hand, we address self-healing mechanisms that enable continued operation of combined IT and energy networks in the presence of disruptions. The latter research also addresses reliability challenges introduced by local producers of renewable energy. PEN is funded by the BMWi.

Area: Smart Urban Networks (SUN)

The Smart Urban Networks (SUN) group researches on networked systems and aims at developing algorithms and mechanisms for topology and protocol adaptation, task placement, and resource allocation, including transitions between subsequent optimal solutions. One core objective is to optimize the performance of networks and distributed systems for data-centric applications that rely on stream processing or real-time data analytics.

Urban Networks for Smart Cities are our most prominent target domain. As a response to virtually unmanageable growth and unprecedented challenges, more and more cities are transformed into 'digitally interwoven' ecosystems. As part of this transition, large scale data are continuously generated, e.g., from environment sensors and mobile devices, and must be processed under increasingly tight real-time constraints to render the much-desired intelligent behavior of the smart city ecosystem.

The research topics of SUN include:

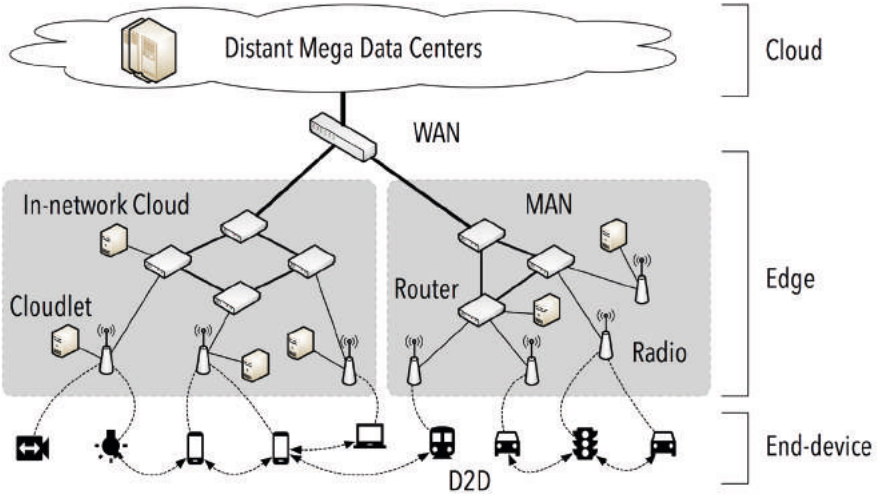
- Edge Computing and In-Network Processing
- Distributed Systems and Algorithms
- Software-Defined Networks
- Cloud Computing and Data Centers
- Green Networking and Computing

Dr. Lin Wang
Area Head
Post-Doctoral Researcher

Michael Stein
Doctoral Researcher

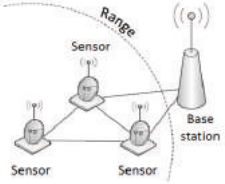
Jens Heuschkel
Doctoral Researcher

Julien Gedeon
Doctoral Researcher



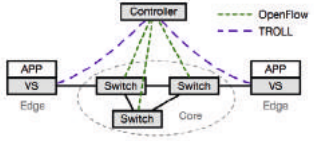
The SUN area is researching on edge computing and proposes a new framework called SmartEdge. A critical resource mismatch has been observed in the IoT context where large volumes of data that are constantly generated by massive amounts of devices need to be processed while those devices themselves are resource constrained. By involving the power of cloud computing, cloud-based solutions resolve this mismatch, but bring about new concerns over latency, traffic, and privacy. To handle this situation, edge computing was recently proposed by introducing an intermediate tier equipped with computing resources at the network edge. The main goal of SmartEdge is to advance this research direction by identifying major scientific challenges in edge computing and providing a unified platform and solutions to address them. These challenges include edge runtime environment, edge control system, edge resource management, as well as distributed data analytics. Accordingly, theoretical foundations, efficient algorithms and mechanisms, as well as reference system architectures, will be produced to guide the design, development, and operation of a modern edge computing system for IoT.

Local Algorithms for Dynamic Topology Adaptation



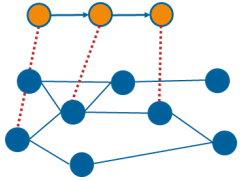
We develop local algorithms for dynamic topology adaptation in wireless sensor networks, where the initial network topology is determined based on the transmission range of the device and a set of topological constrains has to be satisfied during the adaptation process. In particular, we propose topology adaptation algorithms based on motif signatures and validate their effectiveness with real-world scenarios such as P2P video streaming.

Software-defined Protocol Adaptation at the Network Edge



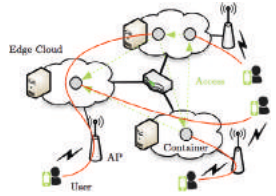
We provide an integrated solution for software-defined control over both the network core and the edge. The edge network device is equipped with a novel architecture named VirtualStack (VS), which enables network protocol virtualization and features dynamic transitions between protocols at line rate. The edge device communicates with the controller via a new control protocol called TROLL, being complementary to OpenFlow.

Service Discovery and Operator Placement for In-network Processing



We investigate the possibility of upgrading ubiquitous edge devices such as wireless routers to integrate them into the In-Network Processing paradigm and use them as brokers for distributed service discovery. In addition, we search for efficient heuristics and hybrid approaches to place application operators on a variety of opportunistic devices to enable In-Network Processing while delivering good quality of service to users.

Online Resource Management for Edge Computing



We develop online resource allocation algorithms with theoretically guaranteed performance for the coordination of distributed edge clouds, where we assume no a-priori knowledge on resource price or user mobility. Besides, we investigate the service placement problem in edge computing for social virtual reality applications, where user interactions are characterized and service colocations are penalized according to resource contention.

MAKI - Multi-Mechanisms Adapation for the Future Internet
This DFG Collaborative Research Center aims to create an innovative promise to make the communication systems of the future more adaptive to changes, particularly during ongoing operations. The SUN group is involved in two subprojects of MAKI: (A01) Systematic development of distributed and self-organizing adaptation mechanisms for communication topologies. (B02) Multi-mechanisms adaptation of distributed systems with discrete optimization, as well as the distribution, synchronization, and execution of transition decisions on devices.

Software Campus Project “DynamicINP”
In this BMBF-funded project, we study two important aspects of In-Network rocessing: first, the placement of application components in the network based on a hybrid approach to balance the solution quality and execution time and, second, the selection of communication patterns for highly dynamic edge environments and their impact on the placement. We look at these problems in an urban network context and validate our findings through real-world scenarios.

EIT Digital Activity “CC4BA”
Embedded in the action line “Future Networking Solutions”, this EIT Digital initiative tackles the problem of a vendor-neutral certification and testing center for Software Defined Networking (SDN) and Network Function Virtualization (NFV). With an European consortium of partners from industry and research, a market study and service portfolio were created. In addition, this project developed solutions for multi-domain orchestration of SDN/NFV services.

Area: Tangible Interaction (TI)

Since many years, all of our interactions with the digital world are channeled through either mice and keyboards or touching on a rigid glassy visual facade. While successful and well-established, these input devices do not incorporate the highly developed manipulation skills, practices and dexterity of their users in the physical world. Also, the feedback channel, i.e., monitors or touchscreens separate us from the the digital world rather than integrating into the physical world that we live in.

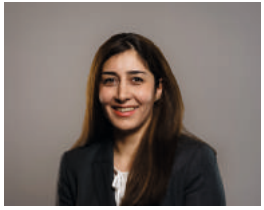
Our vision is to develop innovative computer interfaces that span the digital and physical (tangible) worlds and, thus, giving rise to qualitatively new experiences. Our research focuses on leveraging the physical world and tangible objects (including the human body) surrounding us to make user interfaces more natural, expressive and engaging. This is not only limited to individual but also to collaborative scenarios where multiple people work together in either collocated or remote settings.

Digital Fabrication

Augmented Human & Reality

Hybrid Workspaces

Remote Collaboration



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Towards this goal, we design, implement, and study novel interfaces, devices and interaction techniques in four areas:

(1) **Hybrid workspace:** We investigate how digital and physical documents are used in conjunction. We study how tabletops can support such hybrid use and design interaction techniques that integrate both digital and physical practices of working with documents.

(2) **Augmented humans & reality:** In this area, we are interested in turning the physical world, tangible object, and the human body to interfaces so that users can naturally interact with the digital world.

(3) **Digital fabrication:** This strand of research focuses on making passive 3D fabricated objects interactive by embedding and 3D-printing sensory components within the objects themselves.

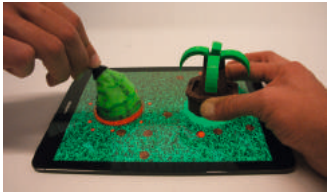
(4) **Remote collaboration:** This area focuses on narrowing the experience gap between being present and participating remotely in meeting or personal assistance scenarios by developing immersive interfaces and interaction techniques that go beyond being there.

- **Funding projects and cooperation partners**

Proximity-based Interaction

Proximity-based Interaction extends the input space of prior on-body user interfaces by focusing on the degree of freedom offered by the elbow joint, i.e., flexion by moving the hand toward and extension by moving the hand away from the body. We propose to use this proximity dimension as an additional input modality for one-handed mobile interaction.

Flexibles



Flexibles add expressive deformation input to interaction with on-screen tangibles. Based on different types of deformation mapping, Flexibles can capture pressing, squeezing, and bending input with multiple levels of intensities on capacitive touch-screens. A Flexible is printed in a single pass on a consumer-level 3D printer without requiring further assembly.

PeriTop

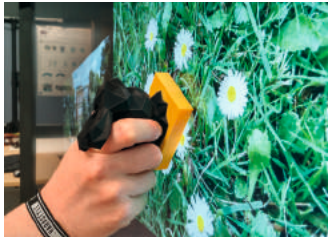
PeriTop explores the possibilities of augmenting a LCD-based tabletop with top projected peripheral displays to enable seamless integration of digital and physical content. It expands techniques known from purely physical environments, like stacking, to hybrid environments and extends them with additional digital support.

Liquido

Liquido is a method to make 3D-printed objects interactive by embedding liquids. Based on two liquid sensing patterns, objects capture tilting and motion interactions. Liquido reduces the assembly effort after printing, is low-cost, and is easy-to-apply on a standard dual-extrusion 3D printer using commercially available printing materials.

Holochess
Holochess is a novel concept combining Augmented Reality and 3D-printed interactive tangibles for players at two different locations. It allows playing a traditional chess game by using real figures on the local player side and virtually augmented figures of the remote opponent. The local figures are printed using conductive materials to be recognized on a touch enabled surface.

Permulin
Permulin provides a partly shared, and private output and simultaneous input. It is based on a set of novel interaction concepts that support fluid transitions between individual and group activities, coordination of group activities, and concurrent, distraction-free in-place manipulation.



BYO*
BYO* presents two concepts to enrich interaction on and among devices through 3D-printed conductive customized tangibles to 1) bring your own information, and to 2) bring your own tools. It allows users to easily share digital contents across various touch-enabled devices and to manipulate them with individually designed tools without additional hardware required.

Teaching

The majority of our courses are part of the teaching cluster Net Centric Computing (NCS), but we also contribute to the Cybersecurity cluster Trusted Systems (TS) and the cluster Human Computer Systems.

As part of the mandatory Bachelor's curriculum, we teach the course Computer Networks and Distributed Systems (CNuVS, in German). This lecture introduces students to the basics of the Internet architecture and protocols, important distributed algorithms used on the Internet, and some techniques for planning and assessing large networks. A more in-depth treatment of Internet protocols and algorithms is taught occasionally under the heading TK0: Internet.

The regular 'TK-cycle' starts with the lecture
TK1: Distributed Systems and Algorithms; half of this course is dedicated to distributed programming paradigms and techniques, the other one to the basic distributed algorithms one should know when building distributed systems. *TK1: Distributed Systems* offers both a software engineering and a distributed algorithms perspective on this fundamental field of computer science. Two out of four hours per week are devoted to exercises.

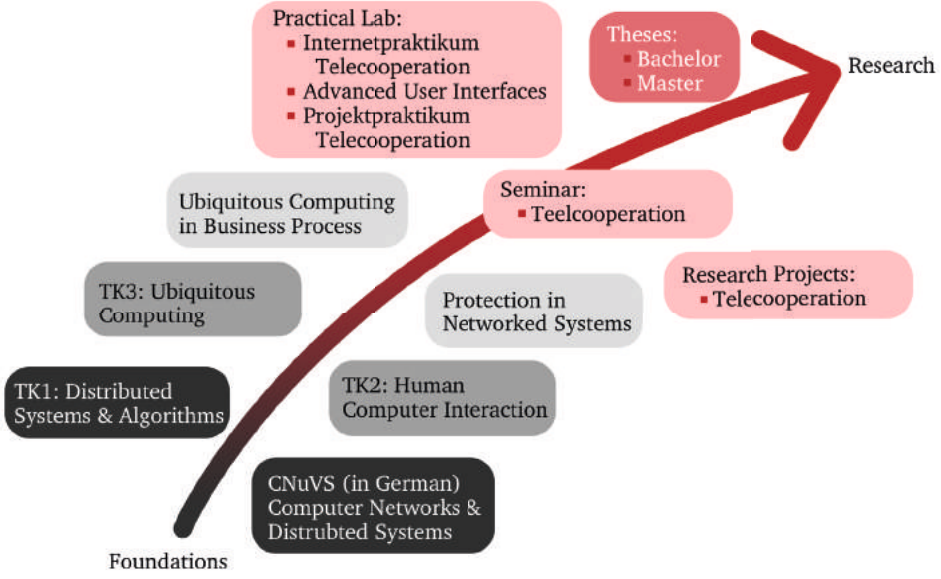
TK2: Human Computer Interaction is a recommended introduction for every computer scientist willing to learn how to build computers and software for humans, not just for tech nerds.

TK3: Ubiquitous Computing is a preferred course for students who are interested in our research and in working or doing a thesis with us. It provides a comprehensive introduction to topical approaches and links them to research fields featured in this booklet: cooperation, interaction, and protection. Exercises constitute half of this four hour per week course.

Ubiquitous Computing in Business Processes provides an enterprise software perspective on our main research field. Practical examples, taken from real use cases, illustrate the approaches taught.

Various courses are offered on an irregular basis, in addition to the above-mentioned **TK0**. The list includes
Web Engineering, **Voice User Interface Design,** and networking topics such as **Edge Computing**.

A considerable number of offerings provide hands-on experience in our field. Our practical labs are much in demand, as are our seminars; dozens of Bachelor and Master theses carried out every year show that students find our topics and our research quite attractive.



Further Expertise and Former Projects

Over the years, Telecooperation Lab has acquired broad expertise in each of its three research fields. Some of this expertise and a few of the related past projects will be briefly mentioned below.

1. INTERACTION

Our expertise in interaction concepts and technologies covers a considerable spectrum that falls in seven categories:

a. support for *computer-mediated collaborative* work, both synchronous (co-located and distributed meetings) and asynchronous (time-decoupled)
b. interaction concepts for the *"smartphone of the future"*, including rollable and foldable displays, pico projectors, and wearable displays (AR/VR headsets), and palm-based and other on-body interaction
c. *model based interaction engineering:* support for separating core software from interaction and for automatically adapting the latter to various (combinations) of modalities, such as audio, display, second-screen, gesture etc.; a language and concept for efficient avatar programming
d. *paper-inspired interaction*, either based on computed-augmented pens and paper, or on "piles of" ultra-thin paper-like displays
e. A showstopper exhibit that allows visitors to virtually conduct the Vienna Philharmonics at the House of Music (together with Prof. Borchers, RWTH)
f. Novel approaches to mobile and large-event centered social video sharing
g. Novel interaction concepts for highly efficient nonlinear video editing and for video browsing

2. COMMUNICATION

Earlier and recent work in networks and distributed systems and solutions ranges from low Internet layers to application layers roughly as follows:

a. IP Network: novel concepts for layer 3 congestion *control* with minimal overhead
b. Overlay networks: numerous contributions to P2P solutions, e.g., for *emergency response* and efficient video streaming.
c. IoT / Cyberphysical Systems: the renowned software platform Mundocore (motto: stretching from tiny sensors to large servers) with its unified event-socket-stream programming paradigm and its various services for context awareness, location, indoor navigation, orchestration etc.
d. Internet-of-Services: novel research contributions to IoS open service markets and business *process matchmaking*
e. Technology enhanced knowledge work / learning: e.g., the renowned *Digital Lecture Hall* with presenter and collaboration support for large audiences

3. PROTECTION

Activities in addition to those described for the SPIN area include:

f. Sophisticated approaches to location / mission privacy and *secure multiparty communication* – particularly suited for authorities (firefighters etc.)
g. Usable Security, e.g., by means of machine learning assisted optimization and *sanitization of access control* in large organizations
h. *Privacy protecting smart meter protocols*
i. *Security and Resilience in Smart Energy and Polyenergy Networks*

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