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Institut für Informatik und
angewandte Mathematik
Universität Bern

www.iam.unibe.ch

IAM Annual Report 13/14

IAM Annual Report

Academic Year 2013/2014

September, 2014

Contents

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1.2 Personnel

Members

Dr. I. Aad; I. Alyafawi; C. Anastasiades; S. Arjoumand Bigdeli; P. Bertholet; Dr. E. Bourtsoulatze; Dr. P. Brambilla; Prof. Dr. T. Braun; G. Budweiser; Dr. U. Buchholtz; A. Caracciolo; Dr. P. Chandramouli; A. Chis; B. Choffat; D. Dhillon; Dr. D. Dimitrova; D. Donatsch; D. Esser; Prof. Dr. P. Favaro; A. Gomes; Prof. Dr. G. Jäger; Dr. A. Jamaković-Kapić; A. Kashev; I. Keller; I. Kokkinis; J. Kurs; Dr. R. Kuznets; Z. Li; Dr. M. Lungu; D. Mansour; M. Manzi; M. Marti; Dr. R. McKinley; L. Merino del Campo; N. Milojkovic; Prof. Dr. O. Nierstrasz; H. Osman; Dr. T. Papadhimitri; D. Perrone; Dr. D. Probst; F. Ranzi; Dr. F. Rousselle; T. Rosebrock; J. Saltarin; Dr. K. Sato; D. Schroth; Dr. A. Sellent; B. Spasojevic; A. Szabo; Prof. Dr. Th. Strahm; Prof. Dr. Th. Studer; J. Walker; J. Werner; Dr. Z. Zhao; Prof. Dr. M. Zwicker

Board of directors

Prof. Dr. Torsten Braun; Prof. Dr. Paolo Favaro; Prof. Dr. Gerhard Jäger; Prof. Dr. Oscar Nierstrasz; Prof. Dr. Matthias Zwicker

Managing director

Prof. Dr. Gerhard Jäger

Director of studies

Prof. Dr. Matthias Zwicker

Administration

Bettina Choffat; Dragana Esser; Iris Keller; Daniela Schroth.

Technical staff

Dr. Peppo Brambilla; Alexander Kashev.

2 Teaching Activities

2.1 Courses for Major and Minor in Computer Science

Autumn Semester 2013

- Bachelor 1st Semester

    Einführung in die Informatik (Die Dozenten der Informatik, 5 ECTS)

    Grundlagen der technischen Informatik (Th. Studer, 5 ECTS)

    Programmierung 1 (Th. Strahm, 5 ECTS)

- Bachelor 3rd Semester

    Diskrete Mathematik und Logik (G. Jäger, 5 ECTS)

    Computernetze (T. Braun, 5 ECTS)

    Einführung in Software Engineering (M. Lungu, O. Nierstrasz, 5 ECTS)

- Bachelor 5th Semester

    Mensch-Maschine-Schnittstelle (Th. Strahm, 5 ECTS)

    Computergrafik (M. Zwicker, 5 ECTS)

    Machine Learning (P. Favaro, 5 ECTS)

    Anleitung zu wissenschaftlichen Arbeiten (5 ECTS)

- Master Courses

    3D Geometry Processing (M. Zwicker, 5 ECTS)

    Advanced Networking and Future Internet (T. Braun, 5 ECTS)

    Computer Vision (P. Favaro, 5 ECTS)

    Dynamic Epistemic Logic (Th. Studer, 5 ECTS)

Modal Fixed Point Logics (G. Jäger, 5 ECTS)

Seminar: Algebra and Logic (G. Jäger, G. Metcalfe, 5 ECTS)

Seminar: Computer Graphics (M. Zwicker, 5 ECTS)

Seminar: Computer Vision (P. Favaro, 5 ECTS)

Seminar: Communication and Distributed Systems (T. Braun, 5 ECTS)

Seminar: Logic and Theoretical Computer Science (G. Jäger, 5 ECTS)

Seminar: Software Composition (M. Lungu, 5 ECTS)

- Service Courses

  Anwendungssoftware für Naturwissenschafter
  (Th. Studer, 3 ECTS)

  Basic Programming for Non-Informaticians. With Practicals. (P. Brambilla, 5 ECTS)

Spring Semester 2014

- Bachelor 2nd Semester

  Datenbanken (Th. Studer, 5 ECTS)

  Datenstrukturen und Algorithmen (P. Brambilla, 5 ECTS)

  Rechnerarchitektur (P. Favaro, 5 ECTS)

  Programmierung 2 (O. Nierstrasz, 5 ECTS)

- Bachelor 4th Semester

  Betriebssysteme (T. Braun, 5 ECTS)

  Berechenbarkeit und Komplexität (Th. Strahm, 5 ECTS)

  Automaten und formale Sprachen (U. Buchholtz, 5 ECTS)

  Praktikum Software Engineering (Th. Studer, 5 ECTS)

- Bachelor 6th Semester

  Anleitung zu wissenschaftlichen Arbeiten (5 ECTS)

- Master Courses

  Computability Theory (Th. Strahm, 5 ECTS)

  Convex Optimization (P. Favaro, 5 ECTS)

  Programming Languages (M. Lungu, O. Nierstrasz, 5 ECTS)

  Rendering Algorithms (M. Zwicker, 5 ECTS)

  Sensor Networks (T. Braun, 5 ECTS)

  Homotopy Type Theory (U. Buchholtz, 5 ECTS)

  Seminar: Computer Graphics (M. Zwicker, 5 ECTS)

  Seminar: Computer Vision (P. Favaro, 5 ECTS)

  Seminar: Software Composition (O. Nierstrasz, 5 ECTS)

  Seminar: Communication and Distributed Systems (T. Braun, 5 ECTS)

  Seminar: Algebra and Logic (G. Metcalfe, Th. Studer, 5 ECTS)

  Seminar: Logic and Theoretical Computer Science (Th. Strahm, Th. Studer, 5 ECTS)

- Service Courses

  Anwendungssoftware für Naturwissenschafter
  (Th. Strahm, 3 ECTS)

  Applied Biological Image Processing (B. Suter, T. Ochsenreiter, A. Sellent, 2 ECTS)

2.2 Colloquium in Computer Science

26/08/2013   Dr. Albert Banchs
             University Carlos III de Madrid
             *Energy Consumption Anatomy of 802.11 Devices and its
             Implication on Modeling and Design*

11/12/2013   Alessandro Foi
             Tampere University of Technology
             Anisotropically Foveated Patch Similarity in Nonlocal Image Denoising

09/05/2014   Prof. James Sterbenz
             University of Kansas
             Evaluation of Network Resilience and Survivability: Analysis, Simulation, Tools, and Experimentation

2.3   Students

- Major Subject Students: AS 2013: 205, SS 2014: 180

- Minor Subject Students: AS 2013: 107, SS 2014: 93

- Ph.D. Candidates: AS 2013: 36, SS 2014: 32

2.4   Degrees and Examinations

- PhD: 9

- Master: 11

- Bachelor: 16

- Completition of Minor Studies: 15 (90E: 2, 60E: 4, 30E: 6, 15E: 3 (645 ECTS))

- Semester Examinations AS 2013: 530 (2036 ECTS)

- Bachelor/Master Theses AS 2013: 15 (375 ECTS)

- Semester Examinations SS 2014: 429 (1547 ECTS)

- Bachelor/Master Theses SS 2014: 11 (190 ECTS)

2.5   Activities

- Project week "Faszination Informatik", Schweizer Jugend forscht, Bern, September 8-14, 2013

- Visitor Program, Gymnasium Bündner Kantonsschule, Bern, October 2, 2013

- Visitor Program, Gymnasium Kirchenfeld/Bern, October 24, 2013

- Contributing to the National Future Day for Girls and Boys, Bern, November 14, 2013

- Taster course for female students, Bern, March 27, 2014

- Visitor Program, Students from Computer Science Week IngCH, Bern, June 25, 2014

- Visitor Program, Gymnasium Thun-Schadau, Bern, July 1st, 2014

2.6 Awards

- IAM Alumni Prize 2013 for Dandolo Flumini's Ph.D. thesis "Weak Well Orders"

- IAM Alumni Prize 2013 for Marius Schwalbe's Master's thesis "Design and Development of an Endoscope Calibration Method and Unit for Laparoscopic Image Guidance Systems"

- IAM Alumni Prize 2013 for Aaron Karper's Bachelor's thesis "A Programming Language Oriented Approach to Computability"

3 Research Group on Communication and Distributed Systems

3.1 Personnel

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	Dr. Z. Zhao*	Tel.: +41 31 511 2639
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External Ph.D. Students:	A. Antonescu	email: antonescu@iam.unibe.ch
	M. Thoma	email: thoma@iam.unibe.ch
Guests:	D. Hawes Raluy	Polytechnical University of Barcelona, Spain, Erasmus student 01.09.2013-05.04.2014
	Prof. Dr. T. Trinh	Budapest University of Technology and Economics, Department of Telecommunications and Media Informatics, Hungary, Guest lecturer Autumn Semester 2013
	Dr. P. Hurni	Swisscom Guest lecturer Spring Semester 2014

* with financial support from a third party

3.2   Overview

The research group "Communication and Distributed Systems" has been investigating how multimedia applications and cloud computing services with high demands on the quality, reliability and energy efficiency can be supported by mobile communication systems and networks. Moreover, we are investigating localization mechanisms for wireless devices and new Future Internet paradigms such as Information-Centric Networking.

3.3   Research Projects

Mobile Cloud Networking

Mobile Cloud Networking (MCN) is a EU FP7 large-scale Integrating Project (IP) funded by the European Commission, and launched in November 2012 for a period of 36 months. In total 19 partners from industry and academia perform research on MCN.

The project is primarily motivated by an ongoing transformation that drives the convergence between the mobile communication and cloud computing industry, enabled by the Internet. These observations led to a number of objectives to be investigated, implemented and evaluated over the course of the project. The top-most objectives of the MCN project are to: a) extend the concept of cloud computing beyond data centres towards the mobile end-user, b) to design an 3GPP-compliant Mobile Cloud Networking architecture that exploits and supports cloud computing, c) to enable a novel business actor, the MCN provider, and d) to deliver and exploit the concept of an end-to-end MCN for novel applications and services. The key research and innovation issues that the MCN project is expected to tackle are the following: a) how to virtualise the Radio Access Networks (RAN), b) how to design a cross-domain Infrastructure-as-a-Service (IaaS) control plane, c) how to upgrade virtualisation and cloud computing middleware to support highly demanding, real-time network applications and services, d) how to design, deploy and operate mobile communication software components to attain and fully benefit from cloud computing attributes, e) how to ensure QoE with advanced content and service migration mechanisms for mobile cloud users and f) how to support multiple cross-domain aspects that must service a multitude of business actors and stakeholders.

The CDS group is involved in the following technical work packages (WP): WP3 on Mobile Cloud Infrastructural Foundations, WP4 on Mobile Network Cloud, and WP5 on Mobile Platform. Besides, the CDS group is leading

WP7 on Dissemination, Exploitation, Standardisation activities.

The scope of work within WP3 of the project is to offer a comprehensive testing framework for the LTE radio access network (RAN). In particular, the framework should allow the virtualisation of base stations (running a base station in the cloud) and the development of novel algorithms for the RAN such as load balancing which can exploit the advantages of virtualisation in order to improve mobility management and service delivery. In its current phase the task has delivered initial evaluations on the computational needs of LTE base stations and how running the network functions in the cloud can influence the execution time. Moreover, for the management of a virtualised RAN, an architectural model was designed, consisting of entities for communication with the end users as well as orchestration of the virtual, computational and networking resources. Implementation work on the architecture was initiated and testing is currently being done. In order to align with the general MCN architecture we were actively involved in activities within WP2.

The scope of WP4 is to develop a novel Mobile Core Cloud concept in support of the on-demand and dynamic deployment of mobile core networks in a cloud computing environment. In the second project year, the research activities of WP4 mainly cover two areas: shared memory and storage distribution; Mobility and Bandwidth as a service (MOBaaS).

In the context of MCN, where the goal is pushing most of the operator's network components into the cloud, a critical issue is the placement of the virtual components and the physical storage, taking into consideration user mobility. Moving virtualised network components close to the user reduces communication delays, thus improving the quality perceived by the user. Furthermore, it reduces the communication overhead on the network. Keeping the mobility information in a single centralized location (e.g. Mobility Management Entity) far from the user and the corresponding network components reduces the overall efficiency. On the other hand, splitting the storage into many locations close to the users raises data consistency issues. To solve this problem we rely on using shared memories for "local" communications, and on distributed shared storage (e.g. Ceph) for remote virtual instances. Ceph promises good robustness and consistency properties, relying on duplications of storage in random locations, and on direct communications between "peers". However, the random distribution of storage is to be made deterministic, depending on the user location. Controlling Ceph's storage in order to increase the overall network efficiency and user satisfaction is an issue we are currently investigating.

Mobility and Bandwidth as a service (MOBaaS) is a MCN service that generates prediction information to be used by any MCN defined services

in order to generate triggers needed for self-adaptation procedures, e.g., optimal run-time configuration, scale-out and scale-in of service instance components, or optimal network function placement. MOBaaS is defined to predict information regarding: (1) the movement of individual end-users (estimated location of an individual end-user in a future moment in time); (2) the traffic that these individual end-users will be generating at a certain location in a future moment in time; (3) bandwidth available in a certain location in a future moment in time. In order to make some predictions, MOBaaS needs certain inputs to learn the behaviors of end-users. Monitoring as a service (MaaS) will provide, in a periodic way, this information to MOBaaS, such that MOBaaS does not need to communicate with different MCN services. All the end-user relevant services will provide necessary information to MaaS, which will be aggregated and forwarded to MOBaaS. Since MOBaas is a supporting MCN service, it does not need a specific service manager (SM), instead a specific service orchestrator (SO) will be needed to initialize the virtual machine (VM) with a running prediction algorithm. In order to work in parallel with other MCN supporting services, such as MaaS, certain types of user data have to be used as inputs to the prediction algorithms. To achieve this, mobility trace data will be a used.

A key contribution of WP5 is to design and implement the follow-me cloud concept, which aims to provide cloud services and data to the mobile user as close as possible to minimize delays and improve performance. After the architecture design being successfully specified in the first year of the project, implementation of the first prototype has started. Significant contributions were made to the cloud orchestration framework, the Follow-Me Cloud concept development and the Information-Centric Networking integration into legacy and cloudified mobile networks. Such work has proven to be key in minimizing content access time and network load, while not creating relevant extra load on the cloud computing infrastructure. The work also contributed to other work packages in the project, namely to the performance evaluation carried out within Task "Real-time Performance of Infrastructure Resource Management Frameworks" and to end-to-end evaluations performed in Task "Experimentation and Evaluation".

As the project entered its second year, work on WP6 Integration has also started. In particular, definition of all interfaces and the interdependence of MCN services on each other is established. To allow for smooth integration and demonstration, common functional tests are defined, based on which performance evaluation and troubleshooting can be done.

Research staff: Andre Gomes, Zhongliang Zhao, Islam Alyafawi, Zan Li, Denis Lima do Rosario, Desislava Dimitrova, Imad Aad, Torsten Braun,

Almerima Jamakovic-Kapic

Swiss Academic Compute Cloud

The Swiss Academic Compute Cloud project (SwissACC) sustains the cloud-related activities of the AAA/SWITCH-e-Infrastructure for e-Science program and bridges the activities that are expected to become relevant for the upcoming SUK-Program 2013-2016 Wissenschaftliche Information: Zugang, Verarbeitung und Speicherung. The A^4-Mesh contribution to the SwissACC project includes a feasibility study on the A^4-Mesh integration into the Swiss Academic Compute Cloud to become a platform for storage and processing of the collected sensor data. Besides this main goal, the A^4-Mesh contribution implemented a solution provided by the feasibility study for a) storing experimentation data on a distributed computing and/or data storage infrastructure, such as Grid and/or Cloud and b) using SwissACC as a processing platform for the collected sensor data to be fed into the hydrology modelling and simulation system to make the environmental research process more efficient.

Integral Indoor 3D Guidance and Access-Control System

The central idea of the project in technical terms is to develop a software defined radio (SDR) system that is able to intercept GSM traffic from both base stations and mobile devices, independently of a subscriber, in order to enable localisation algorithms based on the time difference of arrival (TDOA). The main challenge in this aspect is to capture transmissions on the uplink (from mobile devices) and to be able to identify and localise the devices: Most, if not all software, available today deals with active participation of the phone in the communication to process the GSM signal and network operators take special measures to protect the identity of their users, which aggravates the problem.

In the first year of the project the focus was on gathering all specifications necessary for the development of the GSM sensor as well as dealing with device synchronisation (needed for time localisation) and GSM signal capturing (first done for the downlink). In the final, second year of the project we extended the first version of the GSM sensor from the first year to intercept also uplink GSM signals. The sensor was used to test the capturing of uplink GSM messages for localisation. Our experimentation showed that, in line with GSM standards, there are only few signalling procedures that carry uplink messages with unprotected user identity, i.e., messages that can be used by a passive system to position the device. During the testing process we also came across other interesting research challenges such as impact of user diversity and power distributions. In order to overcome these challenges we carefully determined evaluation scenarios that will allow us to test the accuracy of the system in terms of localisation error. Both, positioning algorithms using signal strength and propagation time were developed and evaluated. As main achievements of the project we identify: (i) a novel algorithm that allows highly precise evaluation of the time synchronisation between two devices, which was applied for GPS as an example; (ii) evaluation of the feasibility of GSM time localisation outdoors (successful) and indoors (challenging); (iii) the development of new positioning approach, namely, positioning through time-fingerprinting; and (iv) adapting proximity algorithms for power-based localisation that deliver few meters accuracy indoors.

We are using the USRP N110 and E110 equipment from Ettus Research as SDR platform. An embedded Linux system built with the Administration and Deployment Adhoc Mesh (ADAM) framework, developed at the University of Bern, has been ported to the N210 devices. On top of that the GNUradio software package was integrated and several other modules, borrowed from the Airprobe project, were incorporated into it for processing and interpretation of the GSM signals. The current version of the system is able to capture GSM signals on both uplink and downlink, attach high accuracy timestamps and interpret the messages, allowing us to derive valuable positioning information.

Research staff: Islam Alyafawi, Zan Li, Desislava Dimitrova, Torsten Braun

Enhanced Mobile Communication with Content-Centric Networks

Opportunistic networking defines communication in challenged networks, where connectivity and contact durations between devices are unpredictable and intermittent. Content-centric communication can support opportunistic networking. In this project, we focus our work on Content-Centric Networking (CCN) using IEEE 802.11 wireless networks. The main topics of this project are divided into three areas: memory management, energy efficient operation and content discovery/delivery.

We have implemented a communication scheme based on broadcast and unicast communication. Since connectivity between devices is unknown in opportunistic networks, discovery can only be performed via broadcast. If an answer is received, the content source can be addressed directly via unicast. Forwarding strategies switch back to broadcast if content sources disappear and are not reachable anymore via unicast. Evaluations have shown that adaptive unicast transmissions can significantly reduce the number of transmitted duplicates and decrease the required time for content retrieval. If multiple concurrent unicast flows are identified, a content source can switch back to broadcast.

To discover namespaces, we combined Regular Interest Discovery (RID) and Enumeration Request Discovery (ERD) discovery to increase discovery efficiency exploiting the advantages of both approaches. Content names in a content object cannot be changed without resigning the content. To support flexible location-based discovery, we have also designed and implemented an alias mapping approach that locally maps temporary names to unique static names. After an alias discovery, content retrieval is performed using the unique content name enabling the identification of identical content for duplicate suppression and caching.

If a requester never meets a suitable content source, Interests need to be forwarded. We investigated multi-hop forwarding based on overhearing and improved multi-hop forwarding by limiting Interest forwarding. We have also implemented algorithms to dynamically adapt Interest lifetimes based on current round trip times between requesters and content source. This enables faster retransmissions in case of collisions resulting in higher throughput. If connectivity to other nodes is intermittent, multi-hop forwarding does not work because CCN requires symmetric content retrieval, i.e., content is returned on the same path back to the requesters. Therefore, we implemented and evaluated agent-based content retrieval on Android smart phones and in hybrid emulation environments. Evaluations have shown that it is advantageous even in case of continuous connectivity but

different link capacities.

Caching can be extended to persistent storage on repositories. To avoid memory depletion, old content needs to be deleted. We designed and implemented an automatic storage replacement strategy for CCN repositories based on content popularity and age.

Research staff: Carlos Anastasiades, Tobias Schmid, Jürg Weber, Alexander Striffeler, Wafaa El Maudni El Alami, Arun Sittampalam, Lukas Diener, Rene Gadow, Lukas von Rotz, Nina Mujkanovic, Torsten Braun

Network Coding Based Multimedia Streaming in Content Centric Networks

Information Centric Networking architectures (ICN) have recently gained significant attention in the research community, as they promise to revolutionize the way data is exchanged in the Internet. They move from the traditional paradigm of Internet communication using IP addresses towards using names as addresses. This is motivated by the fact that when users browse the Internet, they care only about the data content and not where the content is stored. On the contrary, the IP model of communication focuses on where the data is located. Several problems are associated with the current IP network architecture like usability, performance, security and resilience to mobility. To cope with some of these limitations, content distribution networks (CDN) and peer-to-peer architectures have been proposed. These methods mainly deal with the scalability issue and attempt to exploit better the available network resources. CDN and P2P could be seen as a first step towards ICN. Network coding has been presented a decade ago as an efficient technique for heterogeneous both wired and wireless overlay networks to increase the throughput, decrease the delay, enhance resilience, remove the need for coordination between the network nodes etc. There are two major classes of network coding algorithms namely Linear Network Coding (LNC) and Random Linear Network Coding (RLNC). Both methods operate in finite fields. LNC decides about the coding operations centrally, although there are some decentralized designs, whereas RLNC randomly performs operations in finite fields and has only a small performance penalty compared to LNC when operations are in large finite fields. Network coding is interesting for multimedia

communication. The challenge with multimedia is that data is often scalable and data delivery should respect the tight decoding deadlines.

In this project, we envisage the design of novel network coding methods that will promote the use of ICN. We will build our techniques on the Content Centric Networking (CCNx) implementation, since it has many advantages like hierarchical prefixes and being open source. Some abstract ideas regarding the use of network coding in CCN have been very recently discussed. It mainly provides some examples motivating the appropriateness of network coding for the ICN framework, rather than specific solutions. In our perspective, specific problems should be resolved prior to employing such technologies. Specifically, open challenges are: what kind of prefixes should be used, security issues, where to cache information, how one can deal with multiple concurrent sessions accessing the network, could data correlation be exploited? The target of our project is twofold: (a) design network coding techniques that will improve the perceived quality of services and (b) propose an architecture for CCN appropriate for network coding enabled systems. We will focus on multimedia streaming applications, as it is the main source of data traffic in today's Internet. We will further target on the employment of our methods in social networks deployed when users want to share multimedia data. We believe that the ICN paradigm fits well into the framework of multimedia communication over social networks as users can take advantage of multiple interfaces to acquire the multimedia data faster and exploit efficiently the cached data as typically many users seek for the same multimedia data. We are convinced that the employment of network coding in CCN will accelerate the data delivery, improve multimedia quality, enable better the available resources, and revolutionize the caching strategies in CCN framework by considering data importance.

To validate the performance of our proposal, we will use NS-3 Direct Code Execution (DCE), which allows to run the CCNx implementation into a simulated network environment. Thus, we will be able to compare the performance of current version of CCNx with that of our proposed network coding enabled CCNx.

Research staff: Eirina Bourtsoulatze, Jonnahtan Saltarin, Torsten Braun

Wireless Networking for Moving Objects

The Future Internet will incorporate a large number of autonomous wireless objects moving with diverse patterns and speeds while communicating via several radio interfaces. Examples of such objects may include humans, cars or unmanned aerial vehicles, with every object acting as a networking device generating, relaying and/or absorbing data. The Future Internet will require global interoperability among objects/devices. To overcome current shortcomings, a number of research challenges have to be addressed in the area of networking, including protocol engineering, development of applications and services, as well as realistic use-cases. The COST Action IC0906 coordinated research efforts of national and international projects in the area of Wireless Networking for Moving Objects (WiNeMO).

In a joint research activity with University of Coimbra (Portugal) we have further developed mechanisms for energy saving in IEEE 802.11 wireless local area networks. In particular, we have identified the problem of congestion when multiple mobile stations are requesting buffered packets from an access point. A solution to address this problem has been developed, which consists of using time slots allocated to individual stations to request and receive the buffered packets. The initial solution has been developed during the Short-Term Scientific Mission of Torsten Braun at University of Coimbra.

Research staff: Torsten Braun, Carlos Anastasiades

Financial support: European Science Foundation, COST Action IC0906

Algorithms, Architectures and Platforms for Enhanced Living Environments (AAPELE)

Ambient Assisted Living (AAL) is an area of research based on Information and Communication Technologies (ICT), medical research, and sociological research. AAL is based on the notion that technology and science can provide improvements in the quality of life for people in their homes, and that it can reduce the financial burden on the budgets of European healthcare providers. The concept of Enhanced Living Environments (ELE) refers to the AAL area that is more related with the Information and Communication Technologies. To design, plan, deploy and operate, an

AAL system often comprehends the integration of several scientific areas. The Architectures, Algorithms and Platforms for Enhanced Living Environments (AAPELE) COST Action addresses the issues of defining software, hardware and service architectures and on studying and creating more efficient algorithms and protocols for AAL. Related CDS research activities include localization of wireless devices as well as activity detection of mobile users.

Research staff: Torsten Braun, Islam Alyafawi, Zan Li

Financial support: European Science Foundation, COST Action IC1303

Service-Centric Networking

Content-centric network (CCN) is a new and promising networking paradigm. CCN aims at moving from the host-to-host communication style to a new paradigm that focuses on content as the building block of the future Internet architecture. However, CCN does not consider the concept of services in its architecture. We believe that services, rather than content, should be the center of focus in future network architectures. This is due to the fact that content is just a subset of services and what applies to services can easily apply to content, but not the other way around.

Service-centric network (SCN) is a new networking paradigm where services are at the heart of its architecture. SCN is an object-oriented architecture where services and contents are considered as objects. Our research aims at building the SCN architecture based on CCN with extensions regarding service naming, name resolution, service routing, and service management.

We built the NextServe framework to support the publication, invocation, and orchestration of services over CCN. The naming scheme of NextServe allows services to be invoked by name. Also service results can be cached within the CCN network improving the response time significantly.

Authentication and trust in the service are another crucial topic in SCN. Legacy authentication methods can be applied to ICN without any major issues: the owner of a content signs using his private key, and publishes both content and signature, to be used by the receiver to verify that no alterations have been made on the way.

In SCN, the content is to be "serviced" by any service point that is not necessarily trusted, thus invalidating the signature of the original content.

We are investigating authentication techniques that can be used by a receiver to validate contents even after being changed by intermediate service points, without necessarily involving the owner of the original content.

Research staff: Dima Mansour, Torsten Braun, Imad Aad

Adaptive Network Coding for Video Communications

During the Hasler funded project "Adaptive Network Coding for Video Communications", our research has focused on: (a) the design of methods that make the optimal coding and scheduling decisions for adaptive video streaming systems and (b) the design of an interactive free-viewpoint video streaming scheme that uses Prioritized Randomized Network Coding (PRNC).

Specifically, we dealt with the problem of jointly determining the optimal Priority Random Linear Coding (PRLC) and the scheduling decisions when the receivers can obtain layered data directly from multiple servers. The layered data is protected by means of PRLC in order to respect the unequal levels of data importance. Differently from the state-of-the-art Random Linear Coding (RLC) approaches where data blocks are transmitted sequentially, the data from multiple data blocks is jointly considered. Markov Decision Processes (MDP) are used to formulate the problem. Large performance gains are observed over methods treating the data blocks sequentially. Reinforcement learning approaches such as Q-learning are studied in order to cope with MDPs' overwhelming computational complexity that renders them inappropriate for practical settings. The presented Q-learning and MDP solutions are examined in an illustrative example for scalable video transmission.

Moreover, we investigated the design of an optimized delivery strategy based on PRNC for free viewpoint streaming over overlay networks. We consider that the images are captured by an array of cameras that acquire a scene of interest from different perspectives and that any intermediate viewpoint not included in the camera array can be virtually synthesized by the decoder, at a quality that depends on the distance between the virtual view and the camera views available at decoder. Since in overlay networks the bandwidth is limited, the delivery of all the views is not possible. We first introduce the layered Quality of Experience (QoE) concept and then

we organize the cameras (views) in layered subsets. These subsets are then delivered to clients through a PRNC streaming scheme, which deals with the network and clients heterogeneity and effectively exploits the resources of the overlay network.

Research staff: Nikolaos Thomos

Financial support: Hasler Foundation

Enterprise Integration of WSNs and IoT-devices

The aim of the project is to investigate new methodologies to enable interoperability between wireless sensor networks (in general various heterogeneous Internet of Thing devices (IoT) devices) and enterprise IT systems. The project assumes that the lower layers of a typical IoT/WSN protocol stack is mature and concentrates on application layer protocols, service-based integration of devices and (semantic) data content abstraction. We implemented a novel semantic overlay for IoT protocols, based on a semantic service description language (Linked USDL). It supports modeling IoT/WSN specific details, including technical interface descriptions, data representation (input/output) as well as different communication patterns. For enterprise IT systems that do not support a specific application layer protocol the semantic descriptions enable algorithmic solutions for automatic conversion between technical interfaces and automatic creation of further technical interfaces. The semantic representation of services and things support seamless integration of various heterogeneous devices and abstracts the things monitored by a WSN away from the actual sensing devices. Furthermore, we investigate to use of emerging enterprise-level protocols and the impact of scaling towards the needs of IoT-devices.
Evaluation results show that the performance of the platform is very promising and the overhead imposed by the semantic overlay is reasonable compared to alternatives such as WSDL. OData, as one example of an enterprise-level protocol has been studied and its feasibility on an IoT-device level has been demonstrated. Furthermore, an empirical study on the challenges and opportunities of semantics in IoT has been conducted.

Research staff: Matthias Thoma, Torsten Braun

Financial support: SAP (Switzerland) Inc.

Scaling of Distributed Applications in Cloud Computing Environments

Cloud computing enables provisioning and distribution of highly scalable services in a reliable, on-demand and sustainable manner. Our project's aim is to model and test different virtual machine (VM) scaling policies based on both Service Level Agreements (SLAs) and application-level monitoring information. We assume that the management system will control enterprise distributed applications, which are able to scale horizontally by increasing the number of VMs allocated to running the application's services. We employ SLAs for describing the performance invariants of the distributed application and then we use the SLAs as input to the management system for scaling the number of application's VMs under varying workload conditions. We consider different SLA scaling policies, both reactive and predictive. Reactive scaling simply responds to changes in the SLA compliance level (e.g. ratio of the current value of a application metric and its maximum allowed value) by changing the number of VMs allocated to a service until the SLA ratio returns to a safe value (e.g. between 0.6 and 0.9). We also developed a SLA scaling mechanism using results from queueing theory, by controlling the number of allocated VMs based on the relation between the concurrent number of requests executed by the service and the average execution time obtained at that concurrency level. We are currently extending these mechanisms to incorporate a prediction component. We are investigating the usage of both regression and non-linear mechanisms for forecasting the values of near-future workload. The project also explores modelling of distributed applications by characterising application performance under different workload patterns. We built a statistical model of the distributed application's performance by profiling the execution times of atomic operations and inter-service network round-trip times. These statistical models are then used for constructing a simulation model of the target application in CloudSim cloud simulator. We have extended CloudSim to support simulation of multiple cloud tenants (isolated applications with different SLA contracts), accurate time-shared CPU scheduling of concurrent tasks and multiple SLA-based VM scaling managers.

We have evaluated the accuracy of workload modelling in CloudSim by comparing the execution results in both a real distributed small-scale testbed and then by replicating the same workload in our extended simulator. The outcomes of evaluating the reactive and predictive scaling mechanisms are encouraging and seem to validate using them as reliable means of scaling cloud systems.

Research staff: Alexandru-Florian Antonescu, Torsten Braun

Financial support: SAP (Switzerland) Inc.

Testbed for Mobile and Internet Communications

Our research group maintains its own comprehensive and heterogeneous network testbeds for various purposes. A wired testbed is used to build networks of experimental routers and end systems to be able to evaluate the behavior of new networking protocols and architectures in realistic environments. The testbed also forms a productive network of Linux PCs and provides the storage capacity and CPU power for many of our research group's projects. An educational laboratory network for students' training is also connected and has been used for teaching in the Bachelor program. Our research group also takes part in PlanetLab (http://planet-lab.org) and GpENI (https://wiki.ittc.ku.edu/gpeni/). PlanetLab is an open platform for developing, deploying, and accessing planetary-scale services. For this purpose we are hosting three PlanetLab nodes in our testbed network. GpENI is a distributed set of sites, interconnected at layer 2 (or layer 2 tunnels) to enable experimentation at layers 3 and higher. For this purpose we are hosting three GpENI nodes, two GpENI routers and one GpENI controller node in our testbed network. Moreover, we have installed three Cisco routers. Each of them is terminating a L2TP connections to provide a major European GpENI concentrator point. We are connected to the University of Kansas, the ETH Zürich and the University of Zürich.

Moreover, we deployed two powerful servers for offering virtual machines/networks in a fast and user-friendly way, one running Xen (http://xenserver.org/) and the other running OpenStack (http://www.openstack.org/). Virtualization alleviates the overhead of buying, setting up and managing virtual machines/networks, offering the users/researchers efficient and easy ways of running their experiments while reducing the financial costs and saving time, on a network that is not a simulation one.

Our research group also runs wireless testbeds. The research group owns a number of sensor nodes: Embedded Sensor Board (ESB), Modular Sensor Board (MSB), tmote SKY nodes, BTnodes, TelosB nodes, and micaZ nodes. Some of these nodes are operated as part of the Wisebed infrastrucuture. Another testbed consisting of multiple wireless mesh nodes (17 x PCEngines WRAP, 10 x Meraki Mini, 6 x PCEngines ALIX) has been deployed throughout the building and work environment of the research

group. In this testbed, multi-channel communication, multi-path routing and the management framework ADAM have been evaluated. The testbed is currently used by several Ph.D. theses and student projects.

Research staff: All members of the CDS research group

3.4   Ph.D. Theses

- Zhongliang Zhao "Context-aware Adaptive Opportunistic Routing in Mobile Ad-hoc and Sensor Networks", June 26, 2014

- Denis Lima do Rosario "Cross-Layer Optimizations for Multimedia Distribution over Wireless Multimedia Sensor Networks and Flying Ad-Hoc Networks with Quality-of-Experience Support", joint-supervision PhD Degree of Federal University of Para, Belem, Brazil, and University of Bern, July 16, 2014

3.5   Master's Thesis

- Wafaa El Maudni El Alami: An Agent-based Content-centric Networking Application for Data Retrieval, September 2013

3.6   Bachelor's Theses

- Simon Alexander Hirsbrunner: Indoor Localisation In Wi-Fi Networks Using An Improved Centroid Approach, July 2014

- Arian Uruqi: Content Discovery and Retrieval Application for Mobile Content-centric Networks, March 2014

- Adrian Hänni: Ipad / Iphone App as a Front-End for Prototype of a Highly Adaptive and Mobile Communication Network Using Unmanned Aerial Vehicles (UAVs), February 2014

- Marcel Stolz: OviS Wizard. A User-Friendly Mesh Network Deployment App for iOS, December 2013

- Daniel Moser: Human Mobilty Models for Indoors, August 2013

3.7 Awards

- Best Paper Award, 7th IFIP Wireless and Mobile Networking Conference for Zan Li, Desislava Dimitrova, David Hawes and Torsten Braun for the paper entitled "TDOA for Narrow-band Signal with Low Sampling Rate and Imperfect Synchronization", May 2014

- Best Paper Award, ARMS-CC-2014 Workshop for Florian Antonescu and Torsten Braun for the the paper entitled "Simulation of Multi-Tenant Scalable Cloud-Distributed Enterprise Information Systems", July 2014

- Support for young researchers grant (Nachwuchsförderung) by the University of Bern for Islam Alyafawi, for the ICC14 conference, Sydney, Australia. June 2014.

3.8 Further Activities

Memberships

Torsten Braun

- Chair of ERCIM working group on eMobility

- Erweitertes Leitungsgremium Fachgruppe "Kommunikation und Verteilte Systeme"', Gesellschaft für Informatik

- SWITCH Stiftungsrat

- SWITCH Stiftungsratsausschuss

- Vice President of SWITCH foundation

- Kuratorium Fritz-Kutter-Fonds

- Expert for Diploma Exams at Fachhochschule Bern

- Expert for Matura Exams at Gymnasium Kirchenfeld, Bern

- Management committee member of COST Action IC 0906 Wireless Networking for Moving Objects (WiNeMO)

- Management committee member of COST Action IC 1303 Algorithms, Architectures and Platforms for Enhanced Living Environments (AAPELE)

- External Advisory Board Member of Space Internetworking Center (SPICE) at Democritus University of Thrace, Greece

- Board Member (Gesellschafter) of VGU Private Virtual Global University, Berlin, Germany

Editorial Boards

Torsten Braun

- Editorial Board Member of Informatik Spektrum, Springer

- Editorial Board Member of Journal of Internet Engineering (Editor in Chief)

- Editorial Board Member of Telecommunication Systems, Springer

Conference Chairs

Torsten Braun

- Wired/Wireless Internet Communications 2014, Steering committee, Paris, France,May 26-28, 2014

- International Symposium on Quality of Service 2014, Steering committee, Hongkong, May 27-28, 2014

- 7th IFIP Wireless and Mobile Networking, Vilamoura, Keynote Chair, Portugal, May 20-22, 2014

- European Conference on Networks and Communications, Workshop Chair, Mobile Cloud Infrastructures and Services, Bologna, Italy, June 23-26, 2014

Conference Program Committees

Torsten Braun

- ICCCN International Workshop on Sensor Networks, Nassau, Bahmas, July 30 - August 2, 2013

- ACM SIGCOMM 2013 Workshop on Future Human-Centric Multimedia Networking, Hongkong, China, August 16, 2013

- International Conference on Next Generation Wired/Wireless Advanced Networking, St Petersburg, Russia, August 27-29, 2013

- IEEE Vehicular Technology Conference, VTC 2013 Fall, Las Vegas, USA, September 2-5, 2013

- IEEE International Conference on Network and Service Management 2013, Zürich, Switzerland, October 14-18, 2013

- IEEE Local Computer Networks, Sydney, Australia, October 21-24, 2013

- IEEE Globecom Workshop Wireless Networking and Control for Unmanned Autonomous Vehicles, Atlanta, USA, December 9, 2013

- IEEE Globecom 2013, Atlanta, USA, December 9-13, 2013

- 6th International Workshop on Multiple Access Communications, Vilnius, Lithuania, 16-17 December 2013

- Ninth International Conference on Wireless Communication and Sensor Networks (WCSN-2013), Allahabad, India, December 16-19, 2013

- IEEE Symposium on Network Cloud Computing and Applications, Rome, February 5-7, 2014

- Communication Technologies for Vehicles, Offenburg, Germany, May 6-7, 2014

- IEEE International Symposium on Quality of Service, Hongkong, China, May 26-27, 2014

- Wired/Wireless Internet Communications, Paris, France, May 26-28, 2014

- IFIP Networking Conference, Trondheim, Norway, June 2-4, 2014

- IEEE International Conference on Communications, Sydney, June 10-14, 2014

- EUCNC Workshop Mobile Cloud Infrastructures and Services (MCIS), Bologna, Italy, June 23, 2014

Desislava Dimitrova

- 6th International Workshop on Multiple Access Communications, Vilnius, Lithuania, December 16-17, 2013

- AIMS 2014 - PhD Workshop, Brno, Czech Republic, June 30 - July 3, 2014

Ph.D. Jury Memberships

Torsten Braun

- Thomas Bohnert, University of Coimbra (Portugal), October 24, 2013

- Laurynas Riliskis, Lulea University of Technology (Sweden), February 10, 2014

Imad Aad

- Antonio Sapuppo, Aalborg University (Denmark), September 10, 2013

Project and Person Reviewing Activities

Torsten Braun

- Project Reviewer for 7th Framework Programme of the European Community for research, technological development and demonstration activities

- Swiss National Science Foundation

- Academy of Finland

- Research Council of Norway

- TU Hamburg Harburg, Germany

- University of Bremen, Germany

- University of Potsdam, Germany

- Karlsruhe institute of Technology, Germany

- IMDEA Networks Institute, Spain

- Flemish Agency for Innovation by Science and Technology (IWT), Belgium

Journal Article Reviewing Activities

Torsten Braun

- Journal of Communications and Networks
- Journal of Zhejiang University Science C (Computer & Electronics)

Desislava Dimitrova

- IEEE Wireless Communications Magazine
- Elsevier Computer Communications
- Elsevier Computer Networks
- Elsevier Performance Evaluation
- International Journal of Distributed Sensor Networks
- Springer Wireless Networks

Almerima Jamakovic-Kapic

- Oxford Journal of Complex Networks
- Elsevier Computer Networks

Eirina Bourtsoulatze

- ACM/IEEE Transactions on Networking
- IEEE Communications Letters

Imad Aad

- Elsevier Computer Networks Journal
- IEEE Transactions on Wireless Communications
- Telecommunication Systems Journal

Zhongliang Zhao

- IEEE Journal of Transactions on Mobile Computing
- Elsevier Journal of Ad Hoc Networks

Carlos Anastasiades

- IEEE Network Magazine

Invited Talks and Tutorials

Torsten Braun

- Telematiknetze, Kaderkurs Telematik, Bundesamt für Bevölkerungsschutz, Schwarzenburg, Switzerland, September 3, 2103

- Content-Centric Networking in Opportunistic Networks, 8th Technical and MC Meeting, COST Action IC 0906, Ohrid, Macedonia, September 24-25, 2013

- Software-Defined Service-centric Networking, SWITCH SDN Workshop, Zürich, Switzerland, October 30, 2013

- Information-Centric and Software-Defined Networking, ICT LEIT in H2020 Info Day and International Brokerage Event, Koc University, Istanbul, Turkey, December 6, 2013

- Passive Localization of Wireless Devices, Workshop on Network Data Storage, Access, and Analysis, Zürich, Switzerland, March 31, 2014

- Localization using Distributed Radio Sensors based on Software-Defined Radios, University of Coimbra - CISUC, Coimbra, Portugal, April 22, 2014

- Routing Protocols for and Deployment of Flying Ad-hoc NETworks, Keynote, 6th International Workshop on Communication Technologies for Vehicles, Offenburg, Germany, May 7, 2014

- Content-Centric Networking in Opportunistic and Delay-Tolerant Networks, Final Event of Space Internetworking Center 2014, Xanthi, Greece, June 10, 2014

- Internet of Things, iCIS Summer Workshop, Coimbra, Portugal, June 24, 2014

- Future Internet, iCIS Summer Workshop, Coimbra, Portugal, June 24, 2014

Organized Events

- Doctoral Workshop on Distributed Systems, for Ph.D. students from Universities of Bern, Neuchâtel and University of Applied Sciences Fribourg, Kandersteg, Switzerland, June 3-5, 2014

3.9 Publications

Publications submitted in the academic year 2013/2014 and appearing in the following academic year are not listed.

Book Chapters

- Anastasiades, Carlos; Braun, Torsten; Siris, Vasilios (2014). *"Information-Centric Networking in Mobile and Opportunistic Networks"*. In: Wireless Networking for Moving Objects. Springer Lecture Notes in Computer Science, Vol. 8611. ISBN: 978-3-319-10833-9

- Jamakovic, Almerima; Bohnert, Thomas Michael; Karagiannis, Georgios (2013). *"Mobile Cloud Networking: Mobile Network, Compute, and Storage as One Service On-Demand"*. In : Galis, Alex; Gavras, Anastasius (eds.) The Future Internet. Lecture Notes in Computer Science: Vol. 7858 (pp. 356-358). Springer Berlin Heidelberg. DOI: 10.1007/978-3-642-38082-2_33.

Reviewed Journal Papers

- Bilogrevic, I; Jadliwala, M.; Joneja, V.; Kalkan, K.; Hubaux, J.; Aad, Imad Rafic (2014). *"Privacy-Preserving Optimal Meeting Location Determination on Mobile Devices"*. In: IEEE Transactions on Information Forensics and Security, 9(7), pp. 1141-1156. 01.07.2014. DOI: 10.1109/TIFS.2014.2318435

- Lima do Rosario, Denis; Zhao, Zhongliang; Braun, Torsten; Cerqueira, Eduardo (2014). *"A Cross-Layer QoE-Based Approach for Event-Based Multi-Tier Wireless Multimedia Sensor Networks"*. In: International Journal of Adaptive, Resilient and Autonomic Systems (IJARAS), 5(1), 1-18. IGI. DOI: 10.4018/ijaras.2014010101

- Bernardo, Vitor; Pascoal Curado, Marilia; Braun, Torsten (2014). *"An IEEE 802.11 energy efficient mechanism for continuous media applications"*. In: Sustainable Computing: Informatics and Systems, 4(2), 106 - 117. Elsevier. 13.04.2014. DOI: 10.1016/j.suscom.2014.04.001

- Bourtsoulatze, Eirina; Thomos, Nikolaos; Frossard, P. (2014). *"Decoding Delay Minimization in Inter-Session Network Coding"*. In: IEEE Transactions on Communications, 62(6), pp. 1944-1957. IEEE. 18.06.2014. DOI: 10.1109/TCOMM.2014.2318701

- Bourtsoulatze, Eirina; Thomos, Nikolaos; Frossard, P. (2014). *"Distributed Rate Allocation in Inter-Session Network Coding"*. In: IEEE Transactions on Multimedia, PP(99), p. 1. 03.06.2014. DOI: 10.1109/TMM.2014.2328320

- Aguiar, Elisangela; Riker, Andr; Cerqueira, Eduardo; Abelm, Antnio; Mu, Mu; Braun, Torsten; Pascoal Curado, Marilia; Zeadally, Sherali (2014). *"A real-time video quality estimator for emerging wireless multimedia systems"*. In: Wireless Networks, pp. 1-18. Springer. 06.03.2014. DOI: 10.1007/s11276-014-0709-y

- Faical, Bruno S.; Costa, Fausto G.; Pessin, Gustavo; Ueyama, J; Freitas, Heitor; Colombo, Alexandre; Fini, Pedro H.; Villas, Leandro; Osrio, Fernando S.; Vargas, Patricia A.; Braun, Torsten (2014). *"The use of unmanned aerial vehicles and wireless sensor networks for spraying pesticides"*. In: Journal of Systems Architecture, 60(4), 393 - 404. Elsevier. 29.01.2014. DOI: 10.1016/j.sysarc.2014.01.004

- Filho, Geraldo P R; Ueyama, J; Villas, Leandro A; Pinto, Alex R; Gonalves, Vincius P; Pessin, Gustavo; Pazzi, Richard W; Braun, Torsten (2014). *"NodePM: A Remote Monitoring Alert System for Energy Consumption Using Probabilistic Techniques"*. In: SENSORS, 14(1), pp. 848-867. 06.01.2014. DOI: 10.3390/s140100848

- Lima do Rosario, Denis; Zhao, Zhongliang; Santos, Aldri; Braun, Torsten; Cerqueira, Eduardo (2014). *"A Beaconless Opportunistic Routing Based on a Cross-Layer Approach for Efficient Video Dissemination in Mobile Multimedia IoT Applications"*. In: Computer communications, 45, pp. 21-31. Elsevier. DOI: 10.1016/j.comcom.2014.04.002

- Riera, Jordi Ferrer; Tzanakaki, Anna; Antonescu, Alexandru-Florian; Anastasopoulos, Markos; Garca-Espn, Joan A.; Escalona, Eduard; Peng, Shuping; Landi, Giada; Bernini, Giacomo; Belter, Bartosz; Parniewicz, Damian; Hesselbach, Xavier; Figuerola, Sergi; Simeonidou, Dimitra (2014). *"Virtual Infrastructures as a Service enabling Converged Optical Networks and Data Centres"*. In: Optical Switching and Networking. ISSN 1573-4277. Elsevier. DOI: 10.1016/j.osn.2014.05.017

- Thomos, Nikolaos; Pulikkoonattu, Rethnakaran; Frossard, Pascal (2013). *"Growth Codes: Intermediate Performance Analysis and Application to Video"*. In: IEEE Transactions on Communications, 61(11), pp. 4710-4721. 28.11.2013. DOI: 10.1109/TCOMM.2013.092813.120865

- Pessin, Gustavo; Osrio, Fernando S.; Souza, Jefferson R.; Ueyama, J; Costa, Fausto G.; Wolf, Denis F.; Dimitrova, Desislava; Braun, Torsten; Vargas, Patricia A. (2013). *"Investigation on the evolution of an indoor robotic localization system based on wireless networks"*. In: Applied Artificial Intelligence, 27(8), pp. 743-758. 16.09.2013. DOI: 10.1080/08839514.2013.823328

- Goleva, Rossitza; Atamian, Dimitar; Mirtchev, Seferin; Dimitrova, Desislava; Grigorova, Lyubina (2013). *"3G network traffic sources measurement and analysis"*. In: Transactions on Emerging Telecommunications Technologies. 04.09.2013. DOI: 10.1002/ett.2703

- Laurila, Juha K.; Gatica-Perez, Daniel; Aad, Imad; Blom, Jan; Bornet, Olivier; Do, Trinh Minh Tri; Dousse, Olivier; Eberle, Julien; Miettinen, Markus (2013). *"From big smartphone data to worldwide research: The Mobile Data Challenge"*. In: Pervasive and Mobile Computing, 9(6), 752 - 771. Elsevier. 21.08.2014. DOI: 10.1016/j.pmcj.2013.07.014

Reviewed Conference Papers

- Antonescu, Alexandru-Florian; Braun, Torsten (2014). *"SLA-Driven Simulation of Multi-Tenant Scalable Cloud-Distributed Enterprise Information Systems"*. In: Workshop on Adaptive Resource Management and Scheduling for Cloud Computing (ARMS-CC 2014), held in conjunction with PODC 2014. Paris, France. 15.07.2014.

- Dimitrova, Desislava Cvetanova; Alyafawi, Islam Fayez Abd; Ferreira, Lucio Studer.; Gomes, Andre; Nikaein, N.; Georgiev, A.; Pizzinat, A. (2014). *"Challenges ahead of RAN virtualization in LTE"*. In: MCIS workshop, collocated with EuCNC 2014. Bologna, Italy. 23.06.2014.

- Ferreira, Lucio Studer; Pichon, Dominique; Hatefi, Atoosa; Gomes, Andre; Dimitrova, Desislava Cvetanova; Braun, Torsten; Karagiannis, Georgios; Karimzadeh, Morteza; Branco, Monica; Correia, Luis M. (2014). *"An Architecture to offer Cloud-Based Radio Access Network as a Service"*. In: European Conference on Networks and Communications 2014 (EuCNC 2014). Bologna, Italy. 23-26.06.2014.

- Karagiannis, Georgios; Jamakovic, Almerima; Briggs, K.; Karimzadeh, Morteza; Parada, Corici, M.J.; Taleb, T.; Edmonds, A.; Bohnert ,T.M. (2014). *"Mobility and Bandwidth Prediction in Virtualized LTE Systems: Architecture and Challenges"*. In: European Conference on Networks and Communications 2014 (EuCNC 2014). Bologna, Italy. 23-26.06.2014.

- Lima do Rosario, Denis; Zhao, Zhongliang; Braun, Torsten; Cerqueira, Eduardo; Santos, Aldri; Alyafawi, Islam Fayez Abd (2014). *"Opportunistic Routing for Multi-flow Video Dissemination over Flying Ad-Hoc Networks"*. In: 15th IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM 2014). Sydney, Australia. 16-19.06.2014. ISBN: 978-1-4799-4786-7

- Alyafawi, Islam Fayez Abd; Dimitrova, Desislava Cvetanova; Braun, Torsten (2014). *"Real-Time Passive Capturing of the GSM Radio"*. In: IEEE ICC 2014 - Signal Processing for Communications Symposium. Sydney, Australia. 10-14.06.2014. ISBN: 978-1-4799-2003-7

- Anastasiades, Carlos; Braun, Torsten; El Maudni El Alami, Wafaa (2014). *"Agent-based Content Retrieval for Opportunistic Content-Centric Networks"*. In: Proc. of the 12th International Conference on Wired & Wireless Internet Communications (WWIC 2014). Paris, France, 26-28.05.2014. Lecture Notes in Computer Science. ISSN 0302-9743, Volume 8458. Springer.

- Mansour, Dima; Braun, Torsten; Anastasiades, Carlos (2014). *"NextServe Framework: Supporting Services Over Content-Centric Networking"*. In: Proc. of the 12th International Conference on Wired & Wireless Internet Communications (WWIC 2014). Paris, France.

26-28.05.2014. Lecture Notes in Computer Science. ISSN 0302-9743, Volume 8458. Springer.

- Li, Zan; Dimitrova, Desislava Cvetanova; Hawes Raluy, David; Braun, Torsten (2014). *"TDOA for Narrow-band Signal with Low Sampling Rate and Imperfect Synchronization"*. In: 7th IFIP Wireless and Mobile Networking Conference (WMNC 2014). Vilamoura, Algarve, Portugal. 20-22.05.2014. ISBN: 978-1-4799-3060-9

- Zhao, Zhongliang; Braun, Torsten; Rosrio, Denis; Cerqueira, Eduardo (2014). *"CAOR: Context-aware Adaptive Opportunistic Routing in Mobile Ad-hoc Networks"*. In: 7th IFIP Wireless and Mobile Networking Conference (WMNC 2014). Vilamoura, Algarve, Portugal. 20.-22.05.2014. ISBN: 978-1-4799-3060-9

- Antonescu, Alexandru-Florian; Braun, Torsten (2014). *"Improving Management of Distributed Services Using Correlations and Predictions in SLA-Driven Cloud Computing Systems"*. In: IEEE/IFIP Network Operations and Management Symposium (NOMS 2014). Krakow, Poland. 5-9.05.2014. DOI: 10.1109/NOMS.2014.6838320

- Karagiannis, Georgios; Jamakovic, Almerima; Edmonds, Andy; Parada, Carlos; Metsch, Thijs; Pichon, Dominique; Corici, Marius; Ruffino, Simone; Gomes, Andre; Secondo Crosta, Paolo; Bohnert, Thomas Michael (2014). *"Mobile Cloud Networking: Virtualisation of Cellular Networks"*. In: Proceedings of 21st International Conference on Telecommunications (ICT 2014). Lisbon, Portugal. 05.-07.05.2014. DOI: 10.1109/ICT.2014.6845149

- Furquim, Gustavo; Neto, Filipe; Pessin, Gustavo; Ueyama, Jo; de Albuquerque, Joao P.; Clara, Maria; Mendiondo, Eduardo M.; de Souza, Vladimir C.B.; de Souza, Paulo; Dimitrova, Desislava Cvetanova; Braun, Torsten (2014). *"Combining Wireless Sensor Networks and Machine Learning for Flash Flood Nowcasting"*. In: 28th International Conference on Advanced Information Networking and Applications Workshops (WAINA). Victoria, BC, Canada. 13-16.05.2014. DOI: 10.1109/WAINA.2014.21

- Thoma, Matthias; Braun, Torsten; Magerkurth, Carsten; Antonescu, Alexandru-Florian (2014). *"Managing Things and Services with Semantics: A Survey"*. In: IEEE/IFIP Network Operations and Management Symposium (NOMS 2014). Krakow, Poland. 5-9.05.2014. DOI: 10.1109/NOMS.2014.6838366

- Anastasiades, Carlos; Schmid, Tobias; Weber, Jürg; Braun, Torsten (2014). *"Opportunistic Content-Centric Data Transmission During Short Network Contacts"*. In: IEEE Wireless Communications and Networking Conference (WCNC 2014). Istanbul, Turkey. 6-9.04.2014. ISBN: 978-1-4799-3083-8

- Zhao, Zhongliang; Lima do Rosario, Denis; Braun, Torsten; Cerqueira, Eduardo (2014). *"Context-aware Opportunistic Routing in Mobile Ad-hoc Networks Incorporating Node Mobility"*. In: IEEE Wireless Communications and Networking Conference (WCNC 2014). Istanbul, Turkey. 6-9.04.2014. ISBN: 978-1-4799-3083-8

- Thoma, Matthias; Braun, Torsten; Magerkurth, Carsten (2014). *"Enterprise Integration of Smart Objects using Semantic Service Descriptions"*. In: IEEE Wireless Communication and Networking Conference (WCNC 2014). Istanbul, Turkey. 6-9.04.2014. ISBN: 978-1-4799-3083-8

- Thoma, Matthias; Kakantousis, Theofilos; Braun, Torsten (2014). *"REST-based sensor networks with OData"*. In: 11th IEEE/IFIP Annual Conference on Wireless On-demand Network Systems and Services (WONS). Obergurgl, Austria. 2-4.04.2014. DOI: 10.1109/WONS.2014.6814719

- Antonescu, Alexandru-Florian; Oprescu, Ana-Maria; Demchenko, Yuri; de Laat, Cees; Braun, Torsten (2013).*"Dynamic Optimization of SLA-Based Services Scaling Rules"*. In: 5th IEEE International Conference on Cloud Computing Technology and Science (CloudCom). Bristol, UK. 2-5.12.2013. IEEE. DOI: 10.1109/CloudCom.2013.44

- Oprescu, Ana-Maria; Antonescu, Alexandru-Florian; Demchenko, Yuri; Laat, Cees de (2013).*"ICOMF: Towards a Multi-cloud Ecosystem for Dynamic Resource Composition and Scaling"*. In : 5th IEEE International Conference on Cloud Computing Technology and Science (CloudCom). Bristol, UK. 2-5.12.2013. IEEE. DOI: 10.1109/CloudCom.2013.14

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4 Computer Vision Group

4.1 Personnel

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4.2 Overview

Prof. Dr. P. Favaro joined the IAM and established the Computer Vision group in June 2012. The Computer Vision group conducts research on the broad areas of image processing, machine vision, pattern recognition, and imaging and sensor design by employing models, algorithms and analysis tools from optimization theory, probability theory, and applied mathematics. Our general aim is to extract high-level information from images by using digital processing. Such high-level information can be in the form of geometric or photometric quantities about objects in the scene, or semantic attributes such as their category, their function, etc. In order to achieve this aim, we use a systematic approach based on three pillars: modeling, inference and experimental validation. The first step in digital processing requires modeling sensors and distortions of their measured signals such as optical aberrations (defocus and motion blur), noise, spatial loss of resolution and quantization. Moreover, a careful analysis of models allows us to design novel imaging architectures that can more efficiently and accurately capture visual data. For instance, light field cameras (recently become a commercial product) allow for single-snapshot digital refocus-

ing (i.e., the ability to change the focus plane of an image after capture via digital processing) by incorporating a microlens array in conventional cameras. Models also allow us to infer their parameters or a distribution of their parameters by assuming some stochastic description of the data. Parameter estimation can then performed via optimization techniques, which require a careful selection of suitable algorithms and understanding of their behavior. Finally, both sensor and data models are validated experimentally by using both synthetic and real data. Currently, our efforts have been devoted to problems in: inverse imaging (deblurring, blind deconvolution, super resolution), 3D estimation (multi view stereo, photometric stereo, coded aperture photography), motion estimation (structure from motion, tracking), and, more recently, in object categorization.

4.3   Research Projects

Image Deblurring

In photography motion blur is an unpleasant artifact generated by camera shake and object motion during the exposure time. In some cases it is possible to avoid the problem by using the so called "lucky image" method, that consists in taking many images and select the one with the best quality. If it is not possible to take many images of the same event, then the "lucky image" method can not be used. It might also happen that all the images are blurred. In this project we consider the case where a single blurry image is available and one wants to recover a corresponding sharp image. Since no information on the motion of the camera or of the objects is given, this problem is also called *blind deconvolution*.

To estimate a sharp image one has to estimate some kind of information on the motion that generated the blurry image. This information can be represented mathematically as a function, called Point Spread Function (PSF), that represent each pixel of the blurry image as a convex combination of pixels of the sharp image. Because estimating the blur function and the sharp image has more unknowns than the dimension of the input image, the problem is particularly challenging and a regularization prior is required.

A prior widely used in many image processing problems is the *total variation* prior. This prior is based on the assumption that the gradients of natural images are sparse. Many algorithms successfully deploy *total variation* for estimating the PSF and the sharp image. Nonetheless, recent theoretical results show that *total variation* should fail. We provide both analysis

and experiments to resolve this paradoxical conundrum, and reveal the principle behind the success of total variation deblurring. We introduce a blind deconvolution algorithm that, in spite of its extreme simplicity, it is very robust and achieves a performance comparable to the state of the art.

Research staff: Daniele Perrone, Paolo Favaro

Uncalibrated Near-Light Photometric Stereo

This project investigates the problem of 3D reconstruction of a scene from 2D images. In particular, we focus on photometric stereo which is a technique that computes the 3D geometry from at least three images taken from the same viewpoint and under different illumination conditions.

A common assumption used in photometric stereo is to consider distant point light sources. This assumption is valid if the dimensions of the scene are much smaller compared to the distance of the lights from it. Then the illumination can be considered spatially invariant, yielding thus an easier mathematical problem formulation. Relaxing the distant light assumption would increase the use of photometric stereo in applications, such as endoscopy and the reconstruction of large indoor objects. Unfortunately, close-light calibration is not a trivial task. Thus, an uncalibrated near-light photometric stereo method would further increase its use in practice.

Recently we dropped the distant light approximation of the photometric stereo problem and considered the illuminants to be placed near the scene. We did this first for the calibrated case, and proposed a least-squares solution for the depth map estimation of the scene from at least eight input images. Then we introduced a more robust iterative solution for estimating the normals and reflectance. We also proposed a solution for the more challenging case of the uncalibrated near-light photometric stereo method where no prior information about light position and intensities is needed. We achieved this by first analyzing the reconstruction ambiguities and then by introducing an iterative technique to solve for the normals, reflectance and lights. Finally, we demonstrated the practical use and accuracy of our algorithm with real world experiments and compared with the state-of-art in uncalibrated distant light photometric stereo.

Research staff: Thoma Papadhimitri, Paolo Favaro

Shape Learning

People can see. This means they recognise objects and infer their pose and orientation. It is also possible for us humans to decipher the 3D structure of the objects we see, and establish correspondences between different instances of the same category. For example, we can find the ears of cats in multiple images even if we see those particular cats for the first time.

Without prior knowledge these task are not possible. People therefore must have a very good model of the visual world. It is believed that the model is learned from the enormous amount of visual input people receive during their lives. Also evolution favored brains to have a good wiring that enables efficient learning, or have a good model to begin with. This is the reason why unsupervised learning is key to understand vision.

In our project we developed algorithms that find correspondences between object parts in an unsupervised manner. We investigated scenarios where the class labels are given or absent. We not only cluster local parts together, as in other works in the literature, but collection of parts. This provides more articulation, so we can localise parts of the objects in these clusters.

Most state of the art detection algorithms use only the appearance of the object, and discard the 3D information. The methods that use it (3D deformable parts models) provide more details about the detected objects, like a pose estimate. They learn a mixture model of appearance from multiple view-points, but not a single 3D representation. We developed a volumetric description of objects based on HOG features. The advantage of our method is it simplicity. We can train our model by optimising a convex function, which is much easier than training a mixture model. The amount of supervision is also reduced, as only the object orientation is needed.

Research staff: Attila Szabó, Paolo Favaro

Financial support: Swiss National Foundation, grant nr. 149227

Light Field Blind Deconvolution

Light field/plenoptic imaging is an emerging technique that vastly surpasses conventional imaging in terms of the scene information gathering ability. While a conventional camera captures a projection of rays from a 3D scene onto a 2D plane, a light field camera aims to capture the intensity and direction of all incoming rays. Plenoptic cameras are inherently

endowed with capabilities of digitally varying focus, resolution, and depth of field. These cameras can be constructed by placing a microlens array between the camera lens and the sensors. In recent years, plenoptic cameras have been successfully marketed for industrial inspection-related applications as well as for consumer photography.

As these commercial cameras are portable, camera shake is sometimes unavoidable and may result in blurry light fields. Similarly, due to the finite exposure of the sensor, pictures of moving objects might also appear blurry. We address for the first time the issue of motion blur in light field images captured from plenoptic cameras. We propose a solution to the estimation of a sharp light field given a blurry one, when the motion blur point spread function is unknown, i.e., the so-called blind deconvolution problem.

A straightforward approach of applying current blind deconvolution approaches on a view of a blurry light field image would be highly inadequate because the spatial resolution in a view severely decimated. Due to the complexity of the imaging model, as an initial attempt, we investigate the case of uniform (shift-invariant) blur of Lambertian objects. i.e., we consider that objects are sufficiently far away from the camera to be approximately invariant to depth changes and their reflectance does not vary with the viewing direction. We introduce a highly parallelizable model for light field motion blur that is computationally and memory-wise efficient. We then adapt a regularized blind deconvolution approach for the light field deblurring problem.

Research staff: Paramanand Chandramouli, Paolo Favaro

Coherent Estimation of Depth Maps and Sharp Images from Coded Aperture Video

Aim of this project is to coherently estimate depth maps and sharp all-in-focus images from a monocular video sequence acquired with a coded aperture. Image based depth estimation is a basic ingredient of robot navigation and driver assistant systems but has become more and more popular also in computer graphics. One way to obtain depth information of a scene is to introduce a coded binary pattern into the aperture of a camera. Knowing the effect the pattern has on the defocus blur of a conventional camera, one single image is sufficient to estimate a depth map of a scene. Additionally an all-in-focus image that is free of defocus blur can be reconstructed. Applying this procedure to a sequence of images

shows small errors in the estimations as distracting flickering artifacts. In our project we aim to estimate depth and all-in-focus images coherently from a coded aperture video. To achieve this coherence, we need information on the motion of objects in the scene, i.e. we have to perform motion estimation on coded aperture video. The image formation of coded aperture video allows to model motion, especially at occlusion borders, more robustly than motion estimation on traditional videos. Exploiting the opportunity to estimate correspondences robustly over a sequence of image, depth and all-in-focus images can be estimated coherently. With the help of the methods developed in this project we plan to obtain a single camera set-up that can estimate depth and all-in-focus images from a moving scene without any further equipment than a small pattern introduced in the camera and a computer to estimate the desired information.

Research staff: Anita Sellent, Paolo Favaro

Financial support: Deutsche Forschungsgemeinschaft (DFG)

4.4   Ph.D. Thesis

- Thoma Papadhimitri, "New Perspectives on Uncalibrated Photometric Stereo", June 2014.

4.5   Master's Thesis

- Remo Diethelm, "Accurate Scale Thresholding via Logarithmic Total Variation Prior", August 2014.

4.6   Further Activities

Invited Talks

Paolo Favaro

- Invited Talk at Dagstuhl, Germany: Uncalibrated Photometric Stereo

- Invited Talk at Workshop on Recent Trends in Computer Vision, Maryland – USA: Uncalibrated Photometric Stereo

- Invited Talk at Czech Technical University: Total Variation Blind Deconvolution

- Invited Talk at University of Oxford: Total Variation Blind Deconvolution

- Invited Talk at University College London: Total Variation Blind Deconvolution

Anita Sellent

- Invited Talk at EPFL: Coded Aperture Depth Estimation October 2013.

Conference Program Committees

Paolo Favaro

- ECCV 2014, Zurich, Switzerland – Tutorial Chair

- CVPR 2014, Portland, USA – Program Committee

Reviewing Activities

Paolo Favaro

- British Machine Vision Conference (BMVC)

- Conference on Computer Vision and Pattern Recognition (CVPR)

- European Conference on Computer Vision (ECCV)

- Conference on Energy Minimization Methods in Computer Vision and Pattern Recognition (EMMCVPR)

- International Conference on Computer Vision (ICCV)

- Conference on Neural Information Processing Systems (NIPS)

- SIAM Journal on Imaging Sciences

- Signal Processing

- International Journal on Computer Vision (IJCV)

- IEEE Transactions on Image Processing (TIP)

- UK National Research Council (EPSRC)

Anita Sellent

- IEEE Transactions on Circuits and Systems for Video Technology

- Winterschool of Computer Graphics

Daniele Perrone

- IEEE Transactions on Image Processing

4.7   Publications

Journal Publications

- T. Papadhimitri and P. Favaro, "A Closed-Form, Consistent and Robust Solution to Uncalibrated Photometric Stereo via Local Diffuse Reflectance Maxima", International Journal of Computer Vision, 2014.

- A. Sellent and P. Favaro, "Optimized Aperture Shapes for Depth Estimation", Pattern Recognition Letters, 2014.

Refereed Conference Proceedings

- A. Sellent and P. Favaro, "Optimising Aperture Shapes for Depth Estimation", Workshop on Vision, Modeling and Visualization (VMV), 2013.

- A. Sellent and P. Favaro, "Which Side of the Focal Plane are You on?", IEEE Conference on Computational Photography (ICCP), 2014.

- A. Oberdorster, P. Favaro and H. P. A. Lensch, "Anamorphic pixels for multi-channel superresolution", IEEE Conference on Computational Photography (ICCP), 2014.

- D. Perrone and P. Favaro, "Total Variation Blind Deconvolution: The Devil is in the Details", IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2014.

- T. Papadhimitri and P. Favaro, "Uncalibrated Near-Light Photometric Stereo", British Machine Vision Conference (BMVC), to appear in September 2014.

- T. Gaspar, P. Favaro and P. Oliveira, "Synchronization of Two Independently Moving Cameras Without Feature Correspondences", European Conference on Computer Vision (ECCV), to appear in September 2014.

5 Logic and Theory Group

5.1 Personnel

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	(until 31.10.2013)

Guests: Prof. Dr. T. Nemoto   Japan Advanced Institute of
Science and Technology,
School of Information Science
Japan
September - October 2013 and
March - April 2014

* with financial support from a third party

5.2 Overview

The LTG research group (logic and theory group) focuses on theoretical computer science and mathematical logic, especially proof theory, computational logics and theory of computation. We have been dealing for many years with formal methods, analysis of deductions, general computations and, in particular, applications of mathematical logic to computer science. During the previous year the main subject areas have been the following:

Computational Logic: Logical formalisms are perfectly suited to the specification of complex systems, the representation of knowledge and information, the description of processes (e.g. in distributed multi-agent systems) and for providing formal proofs of important system properties such as, for example, correctness and fairness. The research group has long been interested in the deductive, procedural and dynamic aspects of the corresponding formalisms and in the design of modern deductive systems. New approaches are being developed for information update purposes. In addition, the way in which simple, logical formalisms can be extended to become genuine multi-user systems taking into account the dynamic aspects of ontologies in the data mining context and in connection with the semantic web is being investigated.

Proof Theory: This research topic focuses on the development and analysis of formal systems of first and second order arithmetic, set theory and

of what are known as logical frameworks (type and set theoretical, explicit, constructive, extensional, intentional). Our interests range from feasible subsystems of arithmetic to highly impredicative set and type theories and deals with the interplay between constructive, recursive and operational approaches. In addition, abstract computations and computable knowledge are being investigated.

5.3   Research Projects

Algebraic and Logical Aspects of Knowledge Processing

The main focus of this research project is on three foundational pillars of classical, constructive and feasible axiomatic systems. We will study these frameworks by using a variety of proof-theoretic techniques and by emphasizing their computational properties. The main formal frameworks considered are: - first- and second-order arithmetic - (admissible) set theory - explicit mathematics - operational set theories - class theory - theories of partial truth Although this project builds upon the research work done within the scope of the previous project SNF Nr. 200020-119759, it also addresses two new research streams: - a proof theory of class theories in relationship to systems of second order arithmetic - a new unified truth-theoretic view of weak explicit formalisms The project is organized in three parts as follows:

1. Reflections and inductive definitions

2. Operational set theory and explicit mathematics

3. Feasible and (sub-)recursive proof and type systems

Research staff: D. Flumini, G. Jäger, F. Ranzi, T. Rosebrock, K. Sato, Th. Strahm, R. Zumbrunnen

Financial support: Swiss National Science Foundation

Structural Proof Theory and the Logic of Proofs

The Logic of Proofs has been introduced by Artemov to solve a longstanding problem of a classical provability semantics for intuitionistic logic. The main idea of his approach was to introduce proof polynomials into the

object language in order to represent the structure of proofs. The idea has proved itself fruitful and resulted in the formal study of proof structure in this and other contexts, including self-referentiality of modal reasoning, epistemic paradoxes, and logical omniscience problem. In this proposal, we continue expanding the benefits of using the more expressive language of the Logic of Proofs to various areas of computer science, focusing on temporal logics, traditionally used for describing properties of reactive systems, and belief revision, which studies operations for changing agents' beliefs in accordance with new information. We also continue our investigation of the applications of proof polynomials to logics of common knowledge and dynamic epistemic logics, which describe internal epistemic attitudes of rational agents and groups of agents in static and dynamic epistemic scenarios. The new Track B of this proposal sets forth a foundational study of fixed points in the constructive modal framework. While both intuitionistic modal logics and modal mu-calculus have received attention from the scientific community (the latter more than the former), there is virtually no study on constructive modal fixed-points, making the line of investigations proposed in Track B pioneering in this respect.

Research staff: G. Jäger, A. Kashev, I. Kokkinis, R. Kuznets, M. Marti, Th. Studer

Financial support: Swiss National Science Foundation

Logics for Privacy

Consider a system of communicating agents where each agent has his own set of knowledge. An agent may share some part of this knowledge with other agents and he may consider some information as sensitive and thus keep it private. The privacy problem for an agent consists in sharing as much knowledge as possible while at the same time protecting all sensitive information. If an agent is asked about knowledge that he considers private, he has two options to keep the secret: 1. he can refuse to answer the question, or 2. he can give an incorrect answer, that is he can lie. The answering protocol determines whether a query is answered truthfully or whether (and how) the answer is distorted or refused. In this project we study the privacy problem for description logic knowledge base systems and we develop algorithms for various privacy strategies. In particular, we investigate controlled query evaluation mechanisms for ontological knowledge base systems.

Research staff: Th. Studer, J. Werner

Financial support: Swiss National Science Foundation

Operational Set Theory

This six months project has been focusing on three main topics in the context of operational set theory, which require the development of conceptually new approaches: ontological properties, generalized inductive definitions, operational systems for a recursively inaccessible universe. In view of the limitation to six months, only first conceptual and methodological preliminary studies have been possible. A detailed treatment of these topics from a broader perspective will follow later.

Research staff: U. Buchholtz, G. Jäger

Financial support: Swiss National Science Foundation

Computational Structure of Higher-order sequent calculi (Ambizione)

The Curry-Howard correspondence, also known as the proofs-as-programs or propositions-as-types correspondence, is the observation that proofs are computational objects, and that the formulae they prove can be viewed as types guaranteeing good properties of those programs. The most fully developed correspondence of this kind is between intuitionistic logic (roughly, logic without the law of excluded middle) and typed lambda calculus, where proofs in natural deduction correspond to functional programs. A proof deriving a formula A from a set of assumptions Γ can be viewed as a program with parameters Γ, deriving data of type A. In this setting, computation is normalization: a process of removing detours from a proof which simplifies its logical structure. The correspondence applies for propositional, first-order and higher-order logics/type theories, and has been the source of numerous useful insights in both proof theory and programming language design. In particular, the unified semantical theory of proofs/programs in this setting (interpretation in a cartesian-closed category) gives a way to say when two proofs (or two programs) are essentially the same.

The project Computational structure of classical duality, funded by the SNF under the Ambizione scheme from March 2010 to February 2013, was established to make contributions to the understanding of classical logic in the proofs-as- programs paradigm. There was at the time no general understanding of classical proofs as programs: instead, there are a multitude of proof-calculi for classical logic, some with their own different computational readings, and some with no computational reading at all. The project aims to find a unified language for expressing these different proof-systems, and thereby give a unified presentation of the computational meaning of classical proof, starting from a game-like understanding of proofs involving the classical quantifiers as message-passing, backtracking strategies.

Our success in this direction has come from an unexpected direction, which deserves further investigation. It arises from the following insight: the robust computational understanding of intuitionistic proofs as functional programs arises because we can immediately understand a natural deduction system with well-behaved introduction/elimination rules as a typed version of a higher-order functional programming language. On the other hand, the rules of a sequent systems are typically ad-hoc constructions which lack an immediate reading computationally. That is, the question asked in the project can be redirected, instead of looking for a computational interpretation of classical sequent proofs, we can look for a computational interpretation of a general class of sequent systems with well-behaved pairs of dual rules, of which the various classical sequent calculi are extensions/typing disciplines.

The Ambizione follow-up project "Computational Structure of Higher-order sequent systems" funded by the SNF from March 2013 to February 2014, was established to study the properties of so-called higher-order sequent systems: sequent systems containing a mechanism for abstracting over certain classes of sequent proofs. In these systems the structural rules are, as in natural deduction, managed by multiple use of abstracted variables: in effect, a higher-order sequent system is a "sequent-system in natural deduction style". The goals of the project are to develop these systems, which exist in linear, intuitionistic, and classical forms, giving the usual structural analyses (cut-elimination, strong normalization, confluence) and to use them to further explore the Curry-Howard correspondence and its relation to computation beyond the functional paradigm.

This project ended in February 2014.

Research staff: R. McKinley

Refining Reasoning via Justification Extraction: A Proof-Theoretic Approach (Ambizione)

This project aims to extend the scope of Justification Logic to areas where traditionally Modal Logic has been applied—such as artificial intelligence, multi-agent systems, belief revision, dynamic epistemic logic, knowledge representation, program specification and verification, etc. Despite the popularity of the modal language, it has well-known drawbacks such as the Logical Omniscience Problem and lacks expressivity to deal with the "Justified" part of the famous "Knowledge as Justified True Belief" paradigm. Justification Logic provides a solution by refining the language with syntactic objects that are interpreted as justifications (or proofs, or witnesses) and by introducing a formal machinery for handling them.

The success of Modal Logic is due in part to its versatility: the modal language can be used to describe different phenomena by varying the axioms within the same language. Thus, it is necessary to provide a translation not only for the modal language in general, but also for individual theories in the modal language that are used in various applications. This process of translating modal reasoning into reasoning with justifications is called realization. Unfortunately, the applicability scope of the currently known realization algorithms is greatly narrowed by the fact that they require that the modal logic being translated have a purely syntactic and cut-free proof system. In particular, the most commonly used axiomatic, Hilbert-style representation of modal reasoning is not suitable for these realization algorithms.

Since developing cut-free proof systems has proven to be difficult, this project proposes to develop new cut-tolerant realization techniques. A natural way of achieving this goal is by using the tools of structural proof theory: manipulating symbolic representations of proofs and devising algorithms for obtaining representations with required structural properties. The success of this project will allow automating justification extraction for a wide range of modal logics, especially those that resist cut elimination, including temporal modal logics and public announcement logics.

This project ended in December 2013.

Research staff: R. Kuznets

Logic and Computation

This very general project deals with the close connections between mathematical logic and certain parts of computer science, and emphasis is put on a proof-theoretic approach to some of the central questions in this area of research. These include the development of perspicuous and feasible logical frameworks for studying typical questions in computer science like termination and correctness of functional programs, properties of distributed systems and the like.

We study applicative theories as well as strongly typed formalisms and are interested in the connections to constructive and explicit mathematics. Furthermore, we are interested in analyzing the close connections between the complexities of computations and proofs in suitable formalizations, ranging from propositional calculi up to abstract frameworks for computations (in higher types).

Research staff: All members of the research group

5.4 Ph.D. Theses

- P. Brambilla: Proof Search in Propositional Circumscription and Default Logic

- D. Flumini: Weak Well Orders

- R. Zumbrunnen: Contributions to Operational Set Theory

5.5 Bachelor's Theses

- A. Kleemans: Umsetzung der Konzepte aus der Vorlesung Diskrete Mathematik und Logik in eine Toolbox für Studierende

- T. Rathgeb: Eine Verallgemeinerung des Satzes von Rice

5.6 Further Activities

Editorial Boards

Gerhard Jäger

- Member of the Editorial Board of Archive of Mathematical Logic

- Member of the Editorial Board of Logica Universalis

Thomas Strahm

- Member of the Consulting Board of Dialectica

Technical and Research Committees

Gerhard Jäger

- Swiss Delegate to the IFIP Technical Committee 1 (Foundations of Computer Science)

- Board Member of the Platform Mathematics, Astronomy and Physics (MAP) of the Swiss Academy of Sciences

- Member of the Scientific Council of the European Association for Computer Science Logic

- Member of the Kantonale Maturitätskommission

- Expert for Maturitätsprüfungen Mathematik und Informatik

Roman Kuznets

- PC Member of Symposium Advances in Proof Theory 2013, Bern, 2013

Richard McKinley

- Member of the Thesis Defence Committee of Nicola Guenot, Ecole Polytechnique, France, 2013

Dieter Probst

- PC Member of the CSL-LICS Workshop Proof, Structure and Computation 2014, Vienna, 2014

- Expert for Maturitätsprüfungen Mathematik und Informatik

Thomas Strahm

- President of the Swiss Society for Logic and Philosophy of Science (until December 2013)

- Member of the reading committee of Ulrik Buchholtz' PhD thesis, Stanford University, December 2013

Thomas Studer

- Secretary of the Swiss Society for Logic and Philosophy of Science (until December 2013)

- President of the Swiss Society for Logic and Philosophy of Science (since January 2014)

- Swiss representative in the International Union of History and Philosophy of Science

- Expert for Maturitätsprüfungen Mathematik und Informatik

Jan Walker

- Board Member of the Swiss Graduate Society of Logic and Philosophy of Science

Organized Events

Gerhard Jäger

- Together with D. Probst and P. Schuster. Humboldt-Kolleg Proof, Bern, September 2013.

Ioannis Kokkinis

- Münchenwiler Seminar, Münchenwiler, November 2013 and June 2014.

Roman Kuznets

- Together with G. Metcalfe. Gentzen Systems and Beyond 3, Vienna, July 2014.

Dieter Probst

- Together with G. Jäger and P. Schuster. Humboldt-Kolleg Proof, Bern, September 2013.

Thomas Strahm

- Together with Th. Studer. Advances in Proof Theory 2013, Bern, December 2013.

Thomas Studer

- Together with Th. Strahm. Advances in Proof Theory 2013, Bern, December 2013.

5.7 Publications

- Luca Alberucci, Jürg Krähenbühl, and Thomas Studer. Justifying induction on modal μ-formulae. *Logic Journal of the IGPL*, In Press. 2014.

- Sergei Artemov and Roman Kuznets. Logical Omniscience As Infeasibility. *Annals of Pure and Applied Logic*, 165(1):6–25, 2014.

- Sebastian Eberhard. A feasible theory of truth over combinatory algebra. *Annals of Pure and Applied Logic*, 165(5):1009–1033, 2014.

- Sebastian Eberhard. Applicative theories for logarithmic complexity classes. *Theoretical Computer Science*, In Press. 2013.

- Dandolo Flumini and Kentaro Sato. From hierarchies to well-foundedness. *Archive for Mathematical Logic*, In Press. 2014.

- Gerhard Jäger and Dieter Probst. A proof-theoretic analysis of theories for stratified inductive definitions. In Reinhard Kahle and Michael Rathjen, editor, *Gentzen's Centenary: The Quest for Consistency*. Springer, In Press. 2014.

- Gerhard Jäger and Rico Zumbrunnen. Explicit mathematics and operational set theory: some ontological comparisons. *The Bulletin of Symbolic Logic*, In Press. 2014.

- Michel Marti and George Metcalfe. A Hennessy-Milner Property for Many-Valued Modal Logics. In *Advances in Modal Logic*. College Publications, In Press. 2014.

- Florian Ranzi and Thomas Strahm. A note on the theory $SID_{<\omega}$ of stratified induction. Submitted. 2013.

- Kentaro Sato. Forcing for Hat Inductive Definitions in Arithmetic – One of the Simplest Applications of Forcing –. *Mathematical Logic Quarterly*, In Press. 2014.

- Kentaro Sato. Relative predicativity and dependent recursion in second-order set theory and higher order theories. *The Journal of Symbolic Logic*, In Press. 2014.

- Kentaro Sato. Full and Hat Inductive Definitions Are Equivalent in NBG. Submitted. 2013.

- Kentaro Sato and Rico Zumbrunnen. A New Model Construction by Making a Detour via Intuitionistic Theories I: Operational Set Theory without Choice is Π_1-equivalent to KP. Submitted. 2014.

- Yury Savateev. Proof Internalization for Generalized Frege Systems for Classical Logic. *Annals of Pure and Applied Logic*, 165(1):340–356, 2014.

- Thomas Studer and Johannes Werner. Censors for Boolean Description Logic. Submitted. 2014.

6   Software Composition Group

6.1   Personnel

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6.2   Overview

Software developers automate almost every process in our society and provide intelligence and analytics to a multiplicity of activities. From scheduling complex airplane routes, to routing delivery fleets, and monitoring patient health and athlete activity. Yet their own endeavour, which is one of the most complex conceptual activities, still lacks adequate tool support. The Software Composition Group carries out research that aims to strengthen and diversify the tools that software developers use when

engineering software and provide intelligence and analytics to software developers. We are particularly interested in approaches that are orthogonal, composable, and support the graceful evolution of software systems by considering change to be the constant at the center of the software development.

6.3   Research Projects

Agile Software Assessment

A significant portion of software development effort is devoted to reading and understanding code. Mainstream integrated development environments (IDEs), in which a developer spends a large amount of his time, focus on low-level programming tasks rather than on supporting program comprehension and decision-making during software evolution. Source code is still treated as text in many circumstances, high-level design is still specified semi-formally but manually checked, and the individual developer has no automated intelligent aids to help him glean knowledge from analyzing the evolution related and connected projects. At the other end of the spectrum, generic off-the-shelf analysis tools are often not appropriate for the large diversity of software assessment problems.

This project aims to increase the efficiency and effectiveness of software developers that are faced with software assessment tasks which include understanding legacy code, taking decisions about the system design and architecture, and making sure that these decisions are respected during the evolution of the system. To support this level of decision making, developers should be able to swiftly build dedicated tools that automate tedious software analysis tasks.

We aim to offer practitioners a baseline of composable tools and techniques that enable the rapid automation of knowledge-intensive software-related tasks by constructing, querying and manipulating software models. We accentuate the need for "agility" in this process since the pressures of deadlines tend to discourage developers from investing time honing the tools of their trade. The expected long term benefits of this research are improved developer efficiency, enhanced tool support during software development, and better quality software.

To this end, we are working on four orthogonal research tracks. In the last year we have been making progress in each of the tracks that is summarized here:

- **Meta-Tooling**. Developers ask detailed and domain-specific ques-

tions about the software systems they are developing and maintaining and often they are limited to using generic tools to answer these questions. At the core of a developer's toolset, and as generic as it was since the days of the Smalltalk-80 environment, is the program debugger. In a series of empirical studies we showed that a largre number of applications (e.g. debugging parsers, message-passing infrastructures, and information visualization infrastructures) can benefit greatly from having customized debuggers. Our solution to building easily customizable debuggers and parsers is a meta-debugging environment that allows the rapid composition and adaptation of debuggers for the particularities of the individual task. We call it a moldable debugger.

- **Agile Modeling**. A key bottleneck to effective software assessment is the construction of appropriate software models from program source code and the associated data sources. We have developed two novel parsing techniques that allow us to quickly construct such models: (1) bounded islands enable the construction of reusable and composable parsers targeting common programming language classes while enabling parser refinement with island grammars; (2) semi-automated inference of structural features of program and data sources (e.g. analyzing lexical features such as indentation and textual content, and analyzing the frequency of occurrence of lexemes in the program corpora) simplify the task of specifying a grammar for an unknown language; and, (3) layout sensitive parsing expression grammars support the principled specification of languages like Haskell and Python.

- **Large-Scale Software Analysis**. Complex software systems exist within larger software ecosystems consisting of competing system variants, and are part of a network of upstream and downstream systems that they are interrelated with and interdependent on. Being able to query, data mine, and monitor the evolution of an entire ecosystem can improve tool support for developers and provide a series of analytic results that can eventually improve software reliability and reduce development friction. We have developed solutions that take into account information about the entire ecosystem to improve the documentation and navigation of the source code of individual systems. We have also shown that by data-mining the ecosystem we can on one hand (1) detect recurring bug patterns across software systems; and on the other hand (2) successfully provide type

annotation information in programming languages where such information is not existent, thus easing the understanding of third party code.

- **Architectural Monitoring**. The architecture of a software system consists of the design constraints that guarantee non-functional properties, such as ease of evolution, good run-time performance, and rapid build times. Unfortunately architecture is rarely explicit in code, hence it must be specified and tracked, sometimes at great cost in developer time. Research in specifying architecture using architecture description languages (ADL) has failed until now to grab a stronghold in the practice of software engineering. To increase the chance of adoption for architecture monitoring methods we took a pragmatic approach. We conducted interviews and surveys with software architects, we categorized and ranked their needs, and based on these empirical results we proposed a novel solution: an extensible and unified architecture specification language that is powerful enough to express any architectural rule and still simple enough that actual practitioners would find it practical to use.

Research staff: All members of the research group.

Duration: Jan 1, 2013 – Dec. 30, 2015

Financial support: Swiss National Science Foundation,
Project #200020-144126/1

For further details, please consult:
`http://scg.unibe.ch/asa`

6.4 Ph.D. Theses

- Niko Schwarz. *Scaleable Code Clone Detection*. PhD thesis, University of Bern, February 2014. URL: `http://scg.unibe.ch/archive/phd/schwarz-phd.pdf`.

- Erwann Wernli. *Run-time Variability with First-class Contexts*. PhD thesis, University of Bern, November 2013. URL: `http://scg.unibe.ch/archive/phd/wernli-phd.pdf`.

6.5 Master's Theses

- Erik Aeschlimann. St1-PL/1: Extracting quality information from PL/1 legacy ecosystems. Masters thesis, University of Bern, December 2013. URL: `http://scg.unibe.ch/archive/masters/Aesc13b.pdf`.

- Olivier Flückiger. Compiled compiler templates for V8 or: How I learned to stop worrying and love JavaScript. Masters thesis, University of Bern, February 2014. URL: `http://scg.unibe.ch/archive/masters/Flue14a.pdf`.

- Simon Vogt. Clone detection that scales. Masters thesis, University of Bern, February 2014. URL: `http://scg.unibe.ch/archive/masters/Vogt14a.pdf`.

6.6 Bachelor's Theses and Computer Science Projects

- Attieh Sadeghi Givi. Layout sensitive parsing in the PetitParser framework. Bachelor's thesis, University of Bern, October 2013. URL: `http://scg.unibe.ch/archive/projects/Sade13a.pdf`.

- Simon Marti. A platform for second language acquisition through free reading and repetition. Bachelor's thesis, University of Bern, August 2013. URL: `http://scg.unibe.ch/archive/projects/Mart13b-ZeeguuPlatformForSLA.pdf`.

- Michael Morelli. How to use javassist for polymorphism detection. Bachelor's thesis, supplementary documentation, University of Bern, September 2010. URL: `http://scg.unibe.ch/archive/projects/More13b-Javassist.pdf`.

- Michael Rüfenacht. Enabling the analysis of PHP metadata — parsing and analyzing annotations in PHP code. Bachelor's thesis, University of Bern, August 2010. URL: `http://scg.unibe.ch/archive/projects/Ruef13a-PHP.pdf`.

- Michael Rüfenacht. Enabling software analysis using PetitParser and Moose. Bachelor's thesis, supplementary documentation, University of Bern, August 2010. URL: `http://scg.unibe.ch/archive/projects/Ruef13b-PP.pdf`.

- David Wettstein. Analysing Java system properties. Bachelor's thesis, University of Bern, November 2013. URL: `http://scg.unibe.ch/archive/projects/Wett13a-AnalysingJavaSystemProperties.pdf`.

- David Wettstein. Analysing Java system properties — implementation. Bachelor's thesis, supplementary documentation, University of Bern, November 2013. URL: `http://scg.unibe.ch/archive/projects/Wett13b-AnalysingJavaSystemProperties-Implementation.pdf`.

6.7 Further Activities

Invited Talks

Oscar Nierstrasz

- Keynote Speaker at SCAM 2013 (13th IEEE International Working Conference on Source Code Analysis and Manipulation — Eindhoven, The Netherlands, 22-23 September 2013)

Mircea Lungu

- Invited Speaker at Universidad Diego Portales, Chile: Software Ecosystems – Challenges and Opportunities

- Invited Speaker at Simula Research Laboratory, Norway: Agile Software Assessment

Editorial Boards and Steering Committees

Oscar Nierstrasz

- AOSA – Aspect-Oriented Software Association (Steering Committee Member)

- AITO – Association Internationale pour les Technologies Objets (Member)

- CHOOSE – Swiss Group for Object-Oriented Systems and Environments (Board Member)

- JOT — Journal of Object Technology (Steering Committee Member)

- Moose Association (Board Member)

- SATToSE – Seminar Series on Advanced Techniques & Tools for Software Evolution (Steering Committee Member)

- SI – Swiss Informatics Society (Board Member)

- SIRA – Swiss Informatics Research Association (Board Member)

- SNF — Swiss National Science Foundation (Member of the Research Council)

Mircea Lungu

- Vice-President of CHOOSE – Swiss Group for Object-Oriented Systems and Environments

- Member of SI – Swiss Informatics Society

Program Committees

Oscar Nierstrasz

- PC Member of CSMR-WCRE-ERA (European Conference on Software Maintenance and Reengineering/Working Conference on Reverse Engineering — Antwerp, Belgium, Feb 3-7, 2014)

- PC Member of ICSM 2013 (29th International Conference on Software Maintenance — Eindhoven, The Netherlands, Sept 22-28, 2013)

Mircea Lungu

- Co-organizer of WEA 2014 (Second International Workshop on Ecosystem Architectures, co-located with ECSA 2014 in Vienna)

- PC Member of ICSE 2014 (Tool Demos), ICPC 2014, ICSME 2014 (ERA/TD Tracks), WCRE 2014 (ERA/TD Tracks)

- Program Chair of Vissoft 2014 (ERA/TD Tracks)

Reviewing Activities

Oscar Nierstrasz

- ACM TOSEM

- IEEE Software

- Springer Computer Science — Research and Development

- Elsevier Science of Computer Programming

- FWO (Research Foundation Flanders)

- DFG (Deutsche Forschungsgemeinschaft)

Mircea Lungu

- IEEE Transactions on Software Engineering

- IEEE Software

- FWO – Flanders Research Foundation

Haidar Osman

- ICSME ERA 2014

- CSMR-WCRE ERA 2014

- SLE 2014

- MSR 2014

- ICPC/ICSE posters track 2014

Andrea Caracciolo

- ICSME ERA 2014

- CSMR-WCRE ERA 2014

- DLS 2014

- ICPC 2014

- ICSE poster 2014

- IEEE Software article

Andrei Chis

- SLE, DLS, 2014

Nevena Milojkovic

- ICSME ERA 2014

- CSMR-WCRE ERA 2014

- DLS 2014

- SLE 2014

- MSR 2014

Jan Kurs

- ICSME ERA 2014

- DLS 2014

- SLE 2014

Boris Spasojevic

- ICSME ERA 2014

6.8 Publications

Journal Papers

- Mircea Lungu, Michele Lanza, and Oscar Nierstrasz. Evolutionary and collaborative software architecture recovery with Softwarenaut. *Science of Computer Programming*, 79(0):204 – 223, 2014. URL: `http://scg.unibe.ch/archive/papers/Lung14a.pdf`, `doi:10.1016/j.scico.2012.04.007`.

- Oscar Nierstrasz and Jan Kurs. Parsing for agile modeling. *Science of Computer Programming*, 0(0):0–0, 2013. URL: `http://scg.unibe.ch/archive/papers/Nier13cAgileModeling.pdf`, `doi:10.1016/j.scico.2013.11.011`.

Conference Papers

- Erik Aeschlimann, Mircea Lungu, Oscar Nierstrasz, and Carl Worms. Analyzing PL/1 legacy ecosystems: An experience report. In *Proceedings of the 20th Working Conference on Reverse Engineering, WCRE 2013*, pages 441 − 448, 2013. URL: `http://scg.unibe.ch/archive/papers/Aesc13a-PL1Ecosystem.pdf`, `doi:10.1109/WCRE.2013.6671320`.

- Andrea Caracciolo, Mircea Filip Lungu, and Oscar Nierstrasz. How do software architects specify and validate quality requirements? In *Software Architecture*, volume 8627 of *Lecture Notes in Computer Science*, pages 374–389. Springer Berlin Heidelberg, August 2014. URL: `http://scg.unibe.ch/archive/papers/Cara14a-SpecifyValidateQualityRequirements.pdf`, `doi:10.1145/2642803.2642824`.

- Haidar Osman, Mircea Lungu, and Oscar Nierstrasz. Mining frequent bug-fix code changes. In *Software Maintenance, Reengineering and Reverse Engineering (CSMR-WCRE), 2014 Software Evolution Week - IEEE Conference on*, pages 343–347, February 2014. URL: `http://scg.unibe.ch/archive/papers/Osma14aMiningBugFixChanges.pdf`, `doi:10.1109/CSMR-WCRE.2014.6747191`.

- Erwann Wernli, Oscar Nierstrasz, Camille Teruel, and Stephane Ducasse. Delegation proxies: The power of propagation. In *Proceedings of the 13th International Conference on Modularity*, MODULARITY '14, pages 1–12, New York, NY, USA, 2014. ACM. URL: `http://scg.unibe.ch/archive/papers/Wern14a.pdf`, `doi:10.1145/2577080.2577081`.

Book Chapters

- Jan Kurs, Guillaume Larcheveque, Lukas Renggli, Alexandre Bergel, Damien Cassou, Stéphane Ducasse, and Jannik Laval. PetitParser: Building modular parsers. In *Deep Into Pharo*, page 36. Square Bracket Associates, September 2013. URL: `http://scg.unibe.ch/archive/papers/Kurs13a-PetitParser.pdf`.

- Oscar Nierstrasz, Alexandre Bergel, Damien Cassou, Stéphane Ducasse, and Jannik Laval. Regular expressions in pharo. In *Deep*

Into Pharo, page 21. Square Bracket Associates, September 2013. URL: `http://scg.unibe.ch/archive/papers/Nier13aRegEx.pdf`.

- Oscar Nierstrasz, Alexandre Bergel, Damien Cassou, Stéphane Ducasse, and Jannik Laval. Versioning your code with monticello. In *Deep Into Pharo*, page 27. Square Bracket Associates, September 2013. URL: `http://scg.unibe.ch/archive/papers/Nier13bMonticello.pdf`.

Workshop Papers

- Andrea Caracciolo, Mircea Filip Lungu, and Oscar Nierstrasz. Dicto: A unified dsl for testing architectural rules. In *Proceedings of the 2014 European Conference on Software Architecture Workshops*, ECSAW '14, pages 21:1–21:4, New York, NY, USA, 2014. ACM. URL: `http://scg.unibe.ch/archive/papers/Cara14b-Dicto.pdf`, `doi:10.1145/2642803.2642824`.

- Andrei Chiş, Oscar Nierstrasz, and Tudor Gîrba. Towards a moldable debugger. In *Proceedings of the 7th Workshop on Dynamic Languages and Applications*, 2013. URL: `http://scg.unibe.ch/archive/papers/Chis13a-TowardsMoldableDebugger.pdf`, `doi:10.1145/2489798.2489801`.

- Andrei Chiş, Oscar Nierstrasz, and Tudor Gîrba. The Moldable Inspector: a framework for domain-specific object inspection. In *Proceedings of International Workshop on Smalltalk Technologies (IWST 2014)*, 2014. URL: `http://scg.unibe.ch/archive/papers/Chis14a-MoldableInspector.pdf`.

- Nicole Haenni, Mircea Lungu, Niko Schwarz, and Oscar Nierstrasz. Categorizing developer information needs in software ecosystems. In *Proceedings of the 1st Workshop on Ecosystem Architectures*, pages 1–5, 2013. URL: `http://scg.unibe.ch/archive/papers/Haen13a-EcosystemInformationNeeds.pdf`.

- Nicole Haenni, Mircea Lungu, Niko Schwarz, and Oscar Nierstrasz. A quantitative analysis of developer information needs in software ecosystems. In *Proceedings of the 2nd Workshop on Ecosystem Architectures (WEA'14)*, pages 1–6, 2014. URL: `http://scg.unibe.ch/archive/papers/`

```
Haen14a-QuantitativeEcosystemInformationNeeds.pdf, doi:10.
1145/2642803.2642815.
```

- Jan Kurs, Mircea Lungu, and Oscar Nierstrasz. Top-down parsing with parsing contexts. In *Proceedings of International Workshop on Smalltalk Technologies (IWST 2014)*, 2014. URL: `http://scg.unibe.ch/archive/papers/Kurs14a-ParsingContext.pdf`.

- Mircea Lungu and Jan Kurs. On planning an evaluation of the impact of identifier names on the readability and maintainability of programs. In *USER'13: Proceedings of the 2nd Workshop on User evaluations for Software Engineering Researchers*, pages 13 – 15, 2013. URL: `http://scg.unibe.ch/archive/papers/Lung13a-Planning.pdf`.

- Leonel Merino. Adaptable visualisation based on user needs. In *SATToSE'14: Pre-Proceedings of the 7th International Seminar Series on Advanced Techniques & Tools for Software Evolution*, pages 71–74, July 2014. URL: `http://scg.unibe.ch/archive/papers/Meri14a.pdf`.

- Nevena Milojkovic. Towards cheap, accurate polymorphism detection. In *SATToSE'14: Pre-Proceedings of the 7th International Seminar Series on Advanced Techniques & Tools for Software Evolution*, pages 54–55, July 2014. URL: `http://scg.unibe.ch/archive/papers/Milo14a.pdf`.

- Dennis Schenk and Mircea Lungu. Geo-locating the knowledge transfer in stackoverflow. In *Proceedings of the 5th International Workshop on Social Software Engineering*, pages 21–24, 2013. URL: `http://scg.unibe.ch/archive/papers/Sche13a-GeolocatingStackOverflow.pdf`.

- Boris Spasojevic, Mircea Lungu, and Oscar Nierstrasz. Towards faster method search through static ecosystem analysis. In *Proceedings of the 2nd Workshop on Software Ecosystem Architectures (WEA'14)*. ACM, August 2014. URL: `http://scg.unibe.ch/archive/papers/Spas14aFasterMethodLookup.pdf`, doi:10.1145/2642803.2642814.

7   Computer Graphics Group

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7.2   Overview

The Computer Graphics Group (CGG) focuses on fundamental methods to generate and manipulate images using computers. We develop algorithms and systems for realistic and real-time rendering, and animation and modeling of three-dimensional shapes. We are also interested in novel representations for 3D geometry, such as point-based representations. Finally, we investigate signal processing techniques, in particular for multi-view 3D displays. Our research has applications in digital entertainment, multimedia, and data visualization.

Rendering

Rendering, or image synthesis, is a core problem in computer graphics. We develop algorithms for efficient, physically-based rendering. We are also interested in rendering for interactive applications, and we investigate techniques to simulate light transport in real-time.

Animation and Modeling

Computer graphics scenes are composed of three-dimensional shapes that are stored in computer memory using mathematical representations. Our research is concerned with modeling and animating these three-dimensional shapes. We focus on developing sophisticated mathematical methods that allow for realistic shapes and motions, and intuitive user interfaces that make modeling and animation simple and efficient.

Point-Based Graphics

We are interested in novel mathematical representations of three-dimensional shapes. In our research, we show that point-based techniques are viable alternatives to conventional approaches, such as triangle meshes or parametric surfaces, for a variety of applications from rendering to modeling.

Multi-View 3D Displays

Automultiscopic displays show stereoscopic images that can be viewed from any viewpoint without special glasses. They hold great promise for the future of television and digital entertainment. We develop signal processing techniques to optimize image quality by reducing sampling artifacts and adapting the signal to the display properties. We are also interested in multi-view content creation and manipulation techniques.

7.3   Research Projects

UNITED LIVING COLORS.CH: Integrating Evolutionary Developmental Genetics, 3D Computer Graphics, and Natural Photonics for Deciphering Variation & Complexity in Reptilian Color Traits

This project integrates the expertise of three research groups in Switzerland (evolutionary and developmental geneticists, University of Geneva; 3D computer graphics scientists, University of Bern; and condensed-matter physicists, University of Geneva) to gain an improved understanding of the mechanisms generating variation, complexity, and convergence of color traits in animals, in particular reptiles.

A key issue in evolution is to understand how morphology and physiology are altered to produce new forms serving novel functions. Basically no study to date integrated genomics/transcriptomics, developmental genetics, quantitative genetics, and extensive phenotyping of corresponding traits in natural populations for a better understanding of the link between genotype and phenotype in an ecological and phylogenetic framework. The pigmentation system in vertebrates is promising for exploring that connection: closely-related species as well as natural populations exhibit astonishing variations in color and color patterns, and this variation is of great ecological importance as it plays critical roles in thermoregulation, photo-protection, camouflage, display, and reproductive isolation (hence, speciation). Other advantages of focusing on color traits are that they can be quantified and modeled objectively, some of the involved signalling pathways have been partly uncovered in model organisms, and they provide among the best examples of convergence within and among species.

In the context of this project, the Computer Graphics Group develops tools for the acquisition of both 3D geometry and color texture at very high resolution on living animals. Further, we perform the mathematical analysis of the acquired texture phenotypes, mathematical modeling of the mechanisms generating color patterns, as well as computer simulations of reaction-diffusion on 3D geometries acquired from real animals.

Research staff: Daljit Dhillon, Matthias Zwicker

Efficient Sampling and Reconstruction for Image Synthesis

The goal of image synthesis using light transport simulation is to compute images of virtual, three-dimensional environments such that, if it were possible to capture photographs of equivalent physical environments, the simulated images would be visually indistinguishable from the photographs. In an actual digital camera, the brightness of a pixel is determined by measuring the number of photons and their energy incident over the area of the pixel on the sensor. Photons can be thought of as particles that scatter in the physical environment with a certain randomness, tracing out paths from light sources to the camera lens and ultimately onto the sensor, where they are absorbed. The same intuition underlies Monte Carlo methods, a broad class of techniques to simulate light transport and image formation using virtual environments and virtual cameras. They construct light paths with a certain randomness and measure their contributions over some area.

In this project, we will develop novel algorithms for two specific approaches in Monte Carlo light transport simulation, progressive photon mapping and adaptive sampling and reconstruction. Our overall goal is to further reduce the computational effort that is required to reach a desired accuracy and to avoid visual artifacts. Photon mapping is one of the main Monte Carlo methods that is widely used in image synthesis. In many scenarios photon mapping techniques are considered superior to other Monte Carlo methods, that is, they can produce more accurate results using the same computation time. A core idea of photon mapping is to estimate generalized measurements of light energy over arbitrary locations in virtual scenes. Unfortunately, using such generalized measurements leads to bias, a systematic error in simulated images. While bias can be reduced by evaluating measurements over arbitrarily small areas, this increases variance, or noise. The conventional wisdom was that this bias-variance trade-off was a fundamental property and inherent disadvantage of photon mapping. Recently it has been shown, however, that a progressive variant of photon mapping can be formulated that manages to circumvent this problem and eliminate bias in the limit. In our own work, we developed a more general theory of progressive photon mapping that frames the approach in the context of a statistical technique that we call progressive density estimation. The goal of this project is to further develop this theory and to develop advanced algorithms that increase the efficiency and extend the applicability of progressive rendering schemes.

An important observation in image synthesis is that different pixels often

require varying amounts of computation to achieve the same level of accuracy. In other words, the number of light paths that need to be sampled and evaluated in each pixel may vary. Adaptively determining an appropriate number of samples for each pixel is known as adaptive sampling. In addition, neighboring pixels often use similar light paths. Hence light paths can be shared and averaged across several pixels without causing any visible error, which is known as adaptive reconstruction. Combining adaptive sampling and reconstruction often significantly reduces the number of light paths required to obtain images that are visually indistinguishable from ground truth results. In this project we will build on our previous framework for adaptive sampling and reconstruction, which strives to minimizes the error given a certain sample budget and achieves state-of-the-art performance. In particular, we will develop advanced reconstruction filters that will further increase the accuracy of our scheme. Finally, we will combine our approach with a broader range of rendering algorithms. As an overarching research objective, we are striving to develop algorithms that reduce image errors to a minimum under a given sample budget.

Research staff: Claude Knaus, Marco Manzi, Fabrice Rousselle, Matthias Zwicker

Signal Processing for Multi-View 3D Displays

In this project we develop a multi-dimensional signal processing framework and signal processing algorithms for multi-view 3D displays. Multi-View 3D displays offer viewing of high-resolution stereoscopic images from arbitrary positions without glasses. These displays consist of view-dependent pixels that reveal a different color to the observer based on the viewing angle. Although the basic optical principles of multi-view auto-stereoscopy have been known for over a century, it is only recently that displays with increased resolution, or systems based on multiple projectors, have made them practical.

Multi-view displays feature a number of advantages over competing autostereoscopic display technologies, such as stereo-projection systems using shuttered or polarized glasses. Most importantly, multi-view displays do not require users to wear any special glasses, which leads to a more natural and unrestricted viewing experience. They also do not require

head tracking to provide motion parallax; instead, they provide accurate perspective views from any point inside a viewing frustum simultaneously. They are truly multi-user capable, since none of the display parameters needs to be adjusted to a specific individual user.

As a disadvantage, the amount of data that needs to be processed, rendered, and transmitted to such displays is an order of magnitude larger than for stereo-pair projection systems. In this project we develop techniques that aim at performing these operations as efficiently as possible based on a multi-dimensional signal processing framework for multi-view displays. This approach provides a concise tool to study various aspects of data acquisition, processing, rendering, and compression, and it promises to eliminate several drawbacks of multi-view displays that have been unresolved in the past.

Research staff: Michael Pfeuti, Gregor Budweiser, Matthias Zwicker

Image Denoising using Dual-Domain Filtering

Image denoising, the reconstruction of the original image from a noisy image, is one of the most important problems in image processing. Noisy images may be produced by noise contamination through an analog process during acquisition or transport over analog media. The common simplifying assumption is that the image has been contaminated with additive white Gaussian noise (AWGN). This assumption includes that the noise is stationary and uncorrelated among pixels. Another common assumption is that the variance of the noise is known. Progress in image denoising has stagnated in recent years, with newer methods becoming more and more sophisticated but failing to signicantly improve in visible or numeric quality over previous research. We are investigating a novel type of denoising algorithm which we call dual domain image denoising, combining denoising in the spatial and a transform domain. We are developing a group of algorithms following this approach, which are much simpler than most current state-of-the-art algorithms, while producing results of similar quality. Besides designing practical and high quality algorithms, we are also interested in developing a more solid theoretical understanding of our dual domain approach.

Research staff: Claude Knaus, Matthias Zwicker

Hand-Held 3D Light Field Photography

The convergence of sophisticated digital cameras and powerful computers in mobile devices such as smartphones and tablet computers has led to a dizzying array of new applications and tools for consumer photography, some more experimental, others firmly established in the mainstream and used by millions of consumers. In academic research, the confluence of computation and photography has led to a new research field commonly known as "computational photography", which strives to extend the capabilities of conventional digital photography using sophisticated computational algorithms. But computational photography is not limited to operate on conventional 2D images. Instead, it can work with any representation of the distribution of light in a physical environment captured by a camera. Light fields are a natural extension of 2D images. Under the assumptions of geometric optics, they essentially represent the radiance of each light ray traveling in an environment. Light field photography has been first described more than a hundred years ago, but only recently this idea has started to show its full potential when combined with powerful computing devices. Today, various light field cameras are available for research and consumer applications. The main benefit of light field cameras is that they enable additional possibilities that are hard to achieve with conventional cameras, such as digitally refocusing images after the data has been captured. A disadvantage of light field cameras is that they require special hardware and optical systems. Practical designs need to make trade-offs between spatial and angular resolution, leading to systems that are usually not competitive with conventional cameras in terms of pure spatial image resolution.

The main idea of this project is to develop algorithms that allow casual users to capture light fields quickly and easily using conventional cameras and a simple interaction metaphor. In addition, we are developing novel algorithms to enable a variety of applications using the captured light field data. A fundamental assumption of our approach is to work with input data consisting of image sequences captured with conventional hand-held cameras along approximately linear trajectories. Users easily acquire such data by "sweeping" the camera along a roughly horizontal path. Camera trajectories may span a few centimeters to a few meters, depending on the scene. We assume the input data consists of a few dozen images captured at several frames per second, for example acquired using a burst

mode available in current digital cameras. Capturing such data is a matter of a few seconds and does not require any extra equipment or specialized hardware. Therefore, we believe the limited effort required for this approach will make it attractive to a wide range of users, and our approach will have an impact beyond research contributions to the academic community. While there exist previous techniques for hand-held light field photography, they require several minutes of user engagement and are not suitable for casual photography like our work. We are developing efficient methods to resample input image sequences from hand-held cameras into regularly sampled 3D light fields. These light fields then open up the possibility for a variety of further processing, such as refocusing, alpha matting, depth reconstruction, denoising, etc.

Research staff: Daniel Donatsch, Matthias Zwicker

Data-Driven Modeling in Computer Graphics

The objective of this project is to simplify the modeling process for computer graphics content, motivated by the observation that 3D content creation with today's tools is highly laborious and requires expert knowledge and training. We strive to make visual media production based on computer graphics available to non-specialists, fostering the development and proliferation of new types of visual media, and making visual storytelling using 3D computer graphics widely accessible. Our approach will leverage the concept of data-driven modeling, meaning that content stored in rich databases can be browsed, retrieved, edited, and recombined in intuitive ways. Currently, we are developing methods to acquire real-world 3D data for computer graphics modeling for different types of asset categories, including dynamic, functional part-based 3D objects and complex real-world environments.

Research staff: Peter Bertholet, Matthias Zwicker

7.4 Ph.D. Theses

- Claude Knaus, Dual-Domain Image Denoising

- Fabrice Rousselle, Image Space Adaptive Rendering

7.5   Master's Theses

- Markus Baumgartner, Light Path Splitting for Efficiently Rendering Participating Media (January 2014)

- Siavash Bigdeli, Hand-held 3d Light Field Photography and Applications (May 2014)

- Jonathan Charnas, Motion Blur Recovery in a Single Picture (September 2013)

- Marius Schwalbe, Design and Development of an Endoscope Calibration Method (October 2013)

7.6   Bachelor's Theses

- Oliver Eberhard, An elaboration of the Scale-Iinvariant Probabilistic Latent Component Analysis (September 2013)

- Nico Färber , Artistic Image Warps and Stereoscopy (March 2014)

- Stefan Moser, Random Parameter Filtering (February 2014)

- Michael Single, Diffraction Shaders (July 2014)

- Michele Wyss, Adaptive Filtering for Real-Time Ray Tracing (February 2014)

7.7   Further Activities

Editorial Boards

Matthias Zwicker

- Computer Graphics Forum: The International Journal of the Eurographics Association, Associate Editor

Conference Program Committees

Matthias Zwicker

- ACM SIGGRAPH Symposium on Interactive 3D Graphics and Games (I3D), March 14 – 16, 2014, San Francisco, California

- Eurographics Conference, April 7 – 11, 2014, Strasbourg, France

- Eurographics Symposium on Rendering, June 25 – 27, 2014, Lyon, France

- Computer Graphics International, June 10 – 13, 2014, Sydney, Australia

- Pacific Graphics, October 8 – 10, 2014, Seoul, Korea

- Vision, Modeling, and Visualization, October 8 – 10, 2014, Darmstadt, Germany

Ph.D. and Habilitation Jury Memberships

Matthias Zwicker

- Cyril Soler, Habilitation à diriger des recherches, June 24, INRIA Rhone-Alpes, Grenoble

- Torsten Lüdge, PhD mentor, Graduate School for Cellular and Biomedical Sciences (GCB), University of Bern

- Raphael Meier, PhD mentor, Graduate School for Cellular and Biomedical Sciences (GCB), University of Bern

- Sandro De Zanet, PhD mentor, Graduate School for Cellular and Biomedical Sciences (GCB), University of Bern

- Pascal Dufour, PhD mentor, Graduate School for Cellular and Biomedical Sciences (GCB), University of Bern

Reviewing Activities

Claude Knaus

- ACM SIGGRAPH conference

Fabrice Rousselle

- ACM SIGGRAPH conference

- ACM Transactions on Graphics

- Pacific Graphics conference

Matthias Zwicker

- ACM Transactions on Graphics

- IEEE Computer Graphics and Applications

- IEEE Transactions on Visualization and Computer Graphics

- Computer Graphics Forum, The International Journal of the Eurographics Association

- Computers & Graphics, An International Journal of Systems & Applications in Computer Graphics, Elsevier

- ACM SIGGRAPH conference

- ACM SIGGRAPH Asia conference

Technical and Research Committees

Matthias Zwicker

- Board member of SI-GRAVIS, Special Interest Group on Computer Graphics, Vision, and Visualization of the Swiss Informatics Society (SI)

- Expert for Matura Exams at Gymnasium Burgdorf

- Steering Committee member of "Prologo: Logo Programmieren in Primarschulen" funded by the Hasler Foundation

- Member of Expert Committee "Biomedical Sciences & Biomedical Engineering" for the Graduate School for Cellular and Biomedical Sciences, University of Bern

7.8 Publications

Journal Publications

- Claude Knaus, Matthias Zwicker: Progressive Image Denoising, IEEE Transactions on Image Processing, 23(7), 2014.

- Alexandre Chapiro, Simon Heinzle, Tunc Ozan Aydin, Steven Poulakos, Matthias Zwicker, Aljosa Smolic, Markus Gross: Optimizing Stereo-to-Multiview Conversion for Autostereoscopic Displays, Computer Graphics Forum, 33(2), 2014.

- Daniel Donatsch, Siavash Arjomand Bigdeli, Philippe Robert, Matthias Zwicker: Hand-held 3D light field photography and applications, The Visual Computer, 30(6-8), 2014.

- Daljit Singh Dhillon, Jeremie Teyssier, Michael Single, Iarsolav Gaponenko, Michel Milinkovitch, Matthias Zwicker: Interactive Diffraction from Biological Nanostructures, Computer Graphics Forum (to appear), 2014.

- Fabrice Rousselle, Marco Manzi, Matthias Zwicker: Robust Denoising using Feature and Color Information, Computer Graphics Forum, 32(7), 2013.

- Marco Manzi, Fabrice Rousselle, Markus Kettunen, Jaakko Lehtinen: Improved Sampling for Gradient-Domain Metropolis Light Transport, ACM Transanctions on Graphics (accepted for publication at SIGGRAPH Asia), 2014.

Refereed Conference Proceedings

- Claude Knaus, Matthias Zwicker: Dual-Domain Image Denoising, IEEE International Conference on Image Processing, 2013.

- Daljit Singh Dhillon, Jeremie Teyssier, Michael Single, Iaroslav Gaponenko, Michel Milinkovitch, Matthias Zwicker: Interactive Diffraction from Biological Nanostructures, Eurographics Poster, 2014.

8 Administration

University:

T. Braun:	Member of the Committee for Computing Services (Kommission für Informatikdienste)
	Representative of University of Bern in SWITCH Stiftungsrat

Faculty:

T. Braun:	Speaker of the Fachbereich Mathematik/Informatik in Faculty of Science
G. Jäger:	Member of the Strategy Board
Th. Strahm:	Member of the Finance Board
Th. Studer:	Member of the Strategy Board
M. Zwicker:	Member of the Board of Studies

Institute:

T. Braun :	Member of Hauskommission Engehalde
G. Jäger:	Managing Director of IAM
O. Nierstrasz:	Deputy Director of IAM
Th. Strahm:	Member of Library Committee Exakte Wissenschaften
	Member of Hauskommission Exakte Wissenschaften
M. Zwicker:	Director of Studies