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**UNIVERSITÄT
BERN**

Institut für Informatik und
angewandte Mathematik
Universität Bern

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IAM Annual Report 12/13



IAM Annual Report
Academic Year 2012/2013

August, 2013

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1 Institute of Computer Science and Applied Mathematics (IAM)

1.1 Address

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www: <http://www.iam.unibe.ch>

1.2 Personnel

Members

Dr. I. Aad; I. Alyafawi; C. Anastasiades; M. Anwander; S. Beffa; P. Bertholet; P. Brambilla; Prof. Dr. T. Braun; G. Budweiser; Dr. J. Cakareski; A. Caracciolo; A. Chis; B. Choffat; D. Dhillon; Dr. D. Dimitrova; D. Donatsch; S. Eberhard; D. Esser; Prof. Dr. P. Favaro; D. Flumini; A. Gomes; Prof. Dr. G. Jager; Dr. A. Jamakovic-Kapic; A. Kashev; I. Keller; C. Knaus; I. Kokkinis; J. Kurš; Dr. R. Kuznets; Z. Li; D. Lima do Rosario; Dr. M. Lungu; T. Macicas; D. Mansour; M. Manzi; M. Marti; Dr. R. McKinley; N. Milojkovic; Prof. Dr. O. Nierstrasz; H. Osman; S. Ott; T. Papadimitri; F. Perin; D. Perrone; Dr. D. Probst; F. Ranzi; J. Rattia; F. Rousselle; Dr. K. Sato; Dr. Y. Savateev; D. Schroth; N. Schwarz; Dr. A. Sellent; Dr. M. Sorel; B. Spasojevic; A. Szabo; Prof. Dr. Th. Strahm; PD Dr. Th. Studer; Dr. N. Thomos; J. Werner; E. Wernli; Z. Zhao; R. Zumbrunnen; 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

Markus Anwander (until December 2012); Peppo Brambilla; Alexander Kashev (since January 2013).

In memoriam Prof. Walter Nef (21/01/1919 - 12/04/2013)

Mit Prof. Walter Nef - eigentlich "Näf" - hat unser Institut in diesem Frühjahr seinen Gründer und langjährigen ersten Direktor verloren. Seine akademische Laufbahn umfasste fast 70 Jahre und kann ziemlich klar in drei Abschnitte eingeteilt werden:

Walter Nef war ein richtiger "Senkrechtstarter": Geboren in Winterthur, absolvierte er sein Mathematikstudium an der Universität Zürich und an der Brown University. Sein damaliges Hauptforschungsgebiet war die Funktionentheorie der Quaternionen, der Leiter seiner Dissertation war Rudolf Fueter. 1946 - d. h. bereits mit 27 - wurde er als Extraordinarius für höhere Mathematik an die Universität Freiburg (CH) berufen. 1948 wechselte er an die Universität Bern, wo er zwei Jahre später zum Ordinarius ernannt wurde. Also ein sehr beeindruckender Karrierestart. Dies umso mehr, da er in dieser Zeit auch seine Familie gründete und im Rahmen seiner Offizierslaufbahn, in der er später bis zum Oberst i. Gst. befördert wurde, sehr viel Militärdienst leistete.

Der zweite Abschnitt umfasst die Zeit, in welcher Walter Nef "sein" Institut gründete und leitete. Er war zwar durchaus ein "reiner" Mathematiker, interessierte sich aber auch immer für Anwendungen, insbesondere in Zusammenhang mit den seit den 50er Jahren aufkommenden Computern. Nach einem Aufenthalt am National Bureau of Standards in Washington D. C. beantragte er die Gründung eines auf angewandte Mathematik ausgerichteten Instituts und die Beschaffung eines gemeinsamen Computers für die Universität und die kantonale Finanzverwaltung. Beides wurde 1958 realisiert. Am neuen, von Walter Nef geleiteten "Institut

für angewandte Mathematik" (IAM) konnte der erste Computer der Verwaltung des Kantons Bern - ein Bull Gamma 3 - in Betrieb genommen werden. Aus diesen bescheidenen Anfängen entwickelte sich das kantonale Rechenzentrum, seit 1970 als Bernische Datenverarbeitung AG (BEDAG), mit Walter Nef als ihrem ersten Verwaltungsratspräsidenten. Am neuen Institut wurden von Anfang an innovative computergestützte Forschungsprojekte durchgeführt, z. T. mit militärischen Zielsetzungen. Davon zeugt u. a. das 1971 von Walter Nef zusammen mit Kurt Bauknecht herausgegebene Buch "Digitale Simulation". Einige vielversprechende Ergebnisse dieser Projekte - z. B. eine alternative Form von Splines - wurden leider nicht rechtzeitig international bekannt gemacht. Im Laufe der 70er Jahre wurde immer deutlicher, dass Informatik als Studienfach auch an der Universität Bern Einzug halten sollte. Es ist zu einem guten Teil der Initiative von Walter Nef zu verdanken, dass - trotz beachtlicher Widerstände - Informatik 1981 Nebenfach und 1983 Hauptfach wurde. Im Hinblick auf diese Neuorientierung des Instituts wurde 1979 mit Hansjürg Mey die erste Professur für Informatik an der Universität Bern besetzt. Für Walter Nef war klar, dass Prof. Mey von Anfang an auch gleich die Leitung des Instituts übernehmen sollte. So geschah es, und das Institut bekam seine neue Ausrichtung. Es wurde jetzt zum "Institut für Informatik und angewandte Mathematik" und erhielt 1985 auch offiziell diesen Namen.

Zwei weitere Ereignisse im zweiten Abschnitt seien ebenfalls erwähnt: Erstens erschien 1966 auf Deutsch und 1967 auf Englisch Walter Nefs sehr erfolgreiches "Lehrbuch der linearen Algebra". Wenn ehemalige Studierende sich an Prof. Nef erinnern, so tönt das meistens sehr enthusiastisch: Es wird sein grosses didaktisches Geschick gelobt und es wird auch sofort an seine "Lineare Algebra" erinnert, als Muster eines mathematischen Lehrbuchs bezüglich Verständlichkeit und Nützlichkeit. Zweitens war Walter Nef im studentenpolitisch schwierigen Jahr 1972/73 Rektor der Universität Bern. Am Dies Academicus musste er eine allgemein verständliche Rede halten, was für einen Mathematiker naturgemäss nicht einfach ist. Er wählte als Thema "Spass mit dem Computer" - und stiess bei seinen Vorbereitungen auf ständig neue Fragestellungen, die ihn interessierten. Daraus ergibt sich der Übergang zum dritten Abschnitt:

Im letzten Teil seines langen beruflichen Lebens, der kurz vor seiner Rektoratszeit begann und ca. 35 Jahre dauerte, beschäftigte sich Walter Nef sehr intensiv mit einem einzigen Thema: Wie lässt sich eine - auch praktisch nutzbare - algorithmische Geometrie der Polyeder im n-dimensionalen euklidischen Raum begründen und auf dem Computer implementieren? 1978 erschien sein letztes Buch "Beiträge zur Theorie der Polyeder - mit Anwendungen in der Computergraphik", welches elegante

mathematische Grundlagen und erste Algorithmen enthält. Heute sind "Nef-Polyeder" und "Nef-Polygone" in der Computergeometrie feste Begriffe. Sie bilden den Kern von professionellen Softwarepaketen, die sich allerdings bislang auf die Dimensionen 2 und 3 beschränken. Vieles ist noch nicht genügend erforscht, insbesondere die Existenz von effizienten Algorithmen im Falle höherer Dimensionen. Walter Nef hat aber Ideen und Ansätze auf einem guten Stand hinterlassen. Seine Theorie der Polyeder ist weit mehr als ein Fragment.

Der Name "Walter Nef" ist am Institut, in der Phil.-nat. Fakultät und in der heutigen Bedag Informatik AG schon seit einiger Zeit nicht mehr geläufig, auch wenn noch vieles von dem weiterbesteht, was er initiiert hat. Das war für ihn kein Problem; er hat es nie geschätzt, wenn um seine Person viel Aufhebens gemacht wurde. Entweder machte er sich hinter seine - meistens selbst definierten - Aufgaben, weil sie ihm Spass bereiteten oder weil er sie für nötig hielt. Mit "servir et disparaître" wäre er nicht gut charakterisiert, mit "réaliser, jouir et disparaître" schon eher. Auf jeden Fall hat er es verdient, dass sein Name in Erinnerung bleibt. Während meiner ganzen beruflichen Laufbahn war Walter Nef mein wichtigster Berater und Begleiter. Mit grosser Dankbarkeit werde ich auch in Zukunft seiner gedenken.

Prof. em. Hanspeter Bieri



Prof. Walter Nef

2 Teaching Activities

2.1 Courses for Major and Minor in Computer Science

Autumn Semester 2012

- 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)

Software Engineering (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)

Proseminare (5 ECTS)

Anleitung zu wissenschaftlichen Arbeiten (5 ECTS)

- Master Courses

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

Mobile Communications (T. Braun, 5 ECTS)

Computational Photography (M. Zwicker, 5 ECTS)

Computer Vision (P. Favaro, 5 ECTS)
Justification Logic (Th. Studer, 5 ECTS)
Proof Theory (G. Jäger, 5 ECTS)
Graduate Seminar Logic and Information (G. Jäger, G. Metcalfe,
K. Stoffel, U. Ultes-Nitsche, 5 ECTS)
Seminar: Logic and Algebra (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)
Seminar: Logic and Computer Science (G. Jäger, 5 ECTS)
Seminar: Software Composition (O. Nierstrasz, 5 ECTS)
Computer Science Colloquium (Die Dozenten der Informatik)

- Service Course

Anwendungssoftware (Th. Studer, 3 ECTS)

Spring Semester 2013

- 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 (G. Jäger, 5 ECTS)
Praktikum in Software Engineering (Th. Studer, 5 ECTS)

- Bachelor 6th Semester

 - Anleitung zu wissenschaftlichen Arbeiten (5 ECTS)

 - Proseminare (5 ECTS)

- Master Courses

 - Compiler Construction (O. Nierstrasz, 5 ECTS)

 - Convex Optimization (P. Favaro, 5 ECTS)

 - Rendering Algorithms (M. Zwicker, 5 ECTS)

 - Network Performance and Modelling (T. Braun, M. Curado, 5 ECTS)

 - Complexity Theory (T. Strahm, 5 ECTS)

 - Proof Theory (G. Jäger, 5 ECTS)

 - Graduate Seminar Logic and Information (G. Jäger, G. Metcalfe, K. Stoffel, U. Ultes-Nitsche, 5 ECTS)

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

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

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

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

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

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

 - Computer Science Colloquium (Die Dozenten der Informatik)

- Service Course

 - Anwendungssoftware (R. McKinley, 3 ECTS)

2.2 Colloquium in Computer Science

- 09/08/2012 Fausto Guzzo da Costa
USP Universidade São Paulo
The Use of Unmanned Aerial Vehicles and Wireless Sensor Networks In Agricultural Application
- 14/08/2012 Dr. Tuan Trinh
Budapest University of Technology and Economics
Some Recent Advances in Energy Efficiency of Large-Scale Distributed Systems
- 20/08/2012 Muhammad Mahtab Alam
INRIA_IRISA - Université de Rennes I, France
Power-Aware Adaptive Techniques for Wireless Sensor Networks
- 01/10/2012 Gustavo Pessin
University of São Paulo, São Carlos
Towards Real-World Application of Robotic Groups Using Computational Intelligence
- 01/11/2012 Prof. Eduardo Cerqueira
Universidade Federal do Pará Belm
Real-Time Video Quality Estimator for Wireless Multimedia Systems
- 10/12/2012 Prof. Jo Ueyama
University of São Paulo, São Carlos
Towards Smarter Wireless Sensor Networks, UAV's and Smartphones: Our Experiences in São Carlos, Brazil
- 21/02/2013 Mahdad Hosseini Kamal (doctoral assistant)
EPFL Lausanne
Structured Sparsity Applied on Light Field Imaging
- 17/04/2013 Prof. Katerina Mitrokotsa
University of Applied Sciences of Western Switzerland
Authentication in Constrained Settings

2.3 Students

- Major Subject Students: AS 2012: 192, SS 2013: 200
- Minor Subject Students: AS 2012: 113, SS 2013: 114
- Ph.D. Candidates: AS 2012: 35, SS 2013: 35

2.4 Degrees and Examinations

- Ph.D.: 6
- Master: 10
- Bachelor: 14
- Completion of Minor Studies: 20 (90 E: 0, 60E: 4, 30E: 12, 25E: 0, 15E: 4 (660 ECTS))
- Semester Examinations AS 2012: 563 (2146 ECTS)
- Bachelor/Master Theses AS 2012: 5 (75 ECST)
- Semester Examinations SS 2013: 387 (1503 ECTS)
- Bachelor/Master Theses SS 2013: 9 (200 ECTS)

2.5 Activities

- Visitor program, Gymnasium Bündner Kantonsschule, Bern, October 2, 2012
- Contributing to the “National Future Day for Girls and Boys”, Bern, November 8, 2012
- Visitor program, Gymnasium Thun-Schadau, Bern, July 1, 2013

2.6 Awards

- Best Ph.D. Thesis in Computer Science/Mathematics Award 2012 from the the Faculty of Science, University of Bern for Philipp Hurni's PhD thesis “Traffic-Adaptive and Link-Quality-Aware Communication in Wireless Sensor Networks”

- IAM Alumni Prize 2012 for Samuel Bucheli's Ph.D. thesis "Justification Logics with Common Knowledge"
- IAM Alumni Prize 2012 for Simon Morgenthaler's Master's thesis "UAVNet: A Prototype of a Highly Adaptive and Mobile Wireless Mesh Network Using Unmanned Aerial Vehicles"
- IAM Alumni Prize 2012 for Sandro Beffa's Bachelor's thesis "Implementing and Evaluating Communication Protocols for Reliable Multicast in Wireless Sensor Networks"

3 Research Group on Communication and Distributed Systems

3.1 Personnel

Head:	Prof. Dr. T. Braun	Tel.: +41 31 511 2631 email: braun@iam.unibe.ch
Office Manager:	D. Schroth	Tel.: +41 31 511 2630 email: schroth@iam.unibe.ch
Scientific Staff:	Dr. I. Aad *	Tel.: +41 31 511 7645 email: aad@iam.unibe.ch (since 01.06.2013)
	I. Alyafawi*	Tel.: +41 31 511 7631 email: alyafawi@iam.unibe.ch
	C. Anastasiades*	Tel.: +41 31 511 2635 email: anastasi@iam.unibe.ch
	M. Anwander*	Tel.: +41 31 511 2634 email: anwander@iam.unibe.ch (until 31.12.2012)
	S. Beffa*	email: beffa@iam.unibe.ch (01.02.2013-01.07.2013)
	Dr. J. Cakareski*	Tel.: +41 31 631 8681 email: cakareski@iam.unibe.ch (01.12.12 - 31.03.13)
	Dr. D. Dimitrova*	Tel.: +41 31 511 2633 email: dimitrova@iam.unibe.ch
	A. Gomes*	Tel.: +41 31 511 2636 email: gomes@iam.unibe.ch (since 01.11.2012)
	Dr. A. Jamakovic-Kapic*	Tel.: +41 31 511 2637 email: jamakovic@iam.unibe.ch
	Z. Li*	Tel.: +41 31 511 2638 email: li@iam.unibe.ch
	D. Mansour*	Tel.: +41 511 2634 email: mansour@iam.unibe.ch (since 01.03.2013)
	D. Lima do Rosario*	Tel.: +41 31 511 2632 email: rosario@iam.unibe.ch

	T. Macicas*	Tel.: +41 31 631 8681 email: macicas@iam.unibe.ch
	S. Ott*	Tel.: +41 31 631 8681 email: ott@iam.unibe.ch (until 01.02.2013)
	Dr. N. Thomos*	Tel.: +41 31 511 7645 email: thomos@iam.unibe.ch
	Z. Zhao*	Tel.: +41 31 511 2639 email: zhao@iam.unibe.ch
External		
Ph.D. Students:	A. Antonescu M. Thoma	email: antonescu@iam.unibe.ch email: thoma@iam.unibe.ch
Guests:	V. Bernardo	University of Coimbra, Faculty of Science and Technology, Portugal August - September 2012
	Dr. T. Trinh	Budapest University of Technology and Economics, Department of Telecommunications and Media Informatics, Hungary August 2012
	Dr. N. Meratnia	University of Twente, Faculty of Electrical Engineering, Mathematics and Computer Science, The Netherlands October 2012
	Dr. M. Curado	University of Coimbra, Faculty of Science and Technology, Portugal February - July 2013
	Dr. B. Bellalta	Universitat Pompeu Fabra, Department of Information and Communication Technologies, Spain July 2013

* with financial support from a third party

3.2 Overview

The research group for Communication and Distributed Systems (formerly: Rechnernetze und Verteilte Systeme, RVS) has been active since 1998 in several areas of computer communications and distributed systems. We are investigating how multimedia applications and cloud computing services with high demands on the quality, reliability and energy efficiency of mobile communication systems and networks can be supported. Moreover, we are investigating localization mechanisms for wireless devices as well as 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. The MCN project was launched in November 2012 for a period of 36 months. In total top-tier 19 partners from industry and academia commit to jointly establish the vision of Mobile Cloud Networking.

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. Translated into a research problem, 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 3GPP 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 the work package on Dissemination, Exploitation, Standardisation activities.

The scope of work within WP3 (T3.5) of the project is to offer comprehensive testing framework for the LTE radio access network (RAN). In particular, the framework should allow the development of novel algorithms for the RAN such as load balancing among virtualised base stations, cooperation between different radio technologies (LTE, WiFi) and collection of metrics to support mobility and content prediction models. To achieve the goal existing simulation and emulation LTE frameworks will be extended with novel functionality required to represent the network virtualisation. Since the framework should enable demonstration scenarios and its composition depends on the developed RAN architecture, we are actively involved in these two activities within WP2. The purpose is, on the one hand, to develop a novel testing platform for virtualized LTE radio access and, on the other hand, in developing computational models for virtualized LTE base stations.

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 network in a cloud computing environment. The research within this work package has three directions, enabling the development of a complex vision on the future cloud-based mobile core networks. First, the components of the Mobile Core Cloud network and their interaction are designed considering the new flexibility characteristics of the underlying cloud platform. Second, a set of algorithms specific to the management of the Mobile Core Cloud network will be developed. Third, the functionality for the deployment of the mobile core network as a service will be studied including the interaction with the subscribers.

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. Content-distribution networks as well as Information-Centric Networking

are two technologies, which are used to design and implement the follow-me cloud concept. This allows strategic movement and placement of contents/services as well as caching. We have led the architecture development within Task 5.2 "Follow-Me Cloud and Algorithms for Distribution and Migration of Content and Applications", which also influenced the overall Mobile Cloud Networking architecture. Thus, we contributed to the WP2 (Scenarios, Requirements, Business Models, and Overall Architecture) deliverable on "Reference Scenarios and Technical System Requirements Definition".

Research staff: Almerima Jamakovic-Kapic, Desislava Dimitrova, Imad Aad, Andre Gomes, Denis Rosario, Dima Mansour, Torsten Braun, Alexandru-Florian Antonescu (external)

Financial support: EU FP7 Large-scale Integrating Project (IP), contract number CNECT-ICT-318109

Authentication, Authorization, Accounting and Auditing in Wireless Mesh Networks

The Authentication, Authorization, Accounting and Auditing in Wireless Mesh Networks (WMNs) project (A⁴-Mesh) has been carried out as part of the AAA/SWITCH-e-Infrastructure for e-Science programme. It is an interdisciplinary collaboration between SWITCH and two networking research groups, CDS at University of Bern and IIUN at University of Neuchatel (UniNE) plus several WMN users, namely the environmental researchers from UniBE GIUB and the IT services from UniBE IT and UniNE SITEL.

The goal of the A⁴-Mesh project was the development and the integration of innovative authentication and authorization, auditing, and accounting (A⁴) mechanisms into a fully functional wireless mesh network infrastructure, and its deployment in several application scenarios. The first application scenario considered an environmental monitoring scenario in the Swiss Alps. The setup of the wireless mesh network in the Crans-Montana-Sierre region (Valais) consisted of seven wireless mesh nodes interconnecting the hydrological sensors to the university campus network. As a result researchers were able to access their measurement devices and onsite data storages directly from the university. In addition, the network users being on-site were able to access the Internet at any

time. The second application scenario considered the deployment of two outdoor pilot networks, one at UniBE and another at UniNE. These outdoor networks were used for extending campus network connectivity at UniBE, and for testing the backup connectivity between buildings at UniNE.

Furthermore, the integration of the authentication and authorization mechanisms into the A⁴-Mesh wireless mesh network made it possible to access the deployed networks in a secure way because of its integration into the authentication and authorization infrastructure (AAI) of Swiss higher education based on SWITCHaaI mechanisms. Furthermore, the A⁴ mechanisms offered detailed accounting functions, which provided information about traffic consumptions of each particular network user. The A⁴-Mesh monitoring infrastructure allowed the monitoring of every parameter provided by the ADAM wireless mesh node operating system: it might be an amount of free memory on the ALIX node, or number of retransmissions on the particular interface. The monitoring web interface had the ability to be easily configured by the administrator.

Research staff: Markus Anwander, Torsten Braun, Almerima Jamakovic-Kapic, Sandro Beffa, Teodor Macicas

Financial support: AAA/SWITCH Project UNIBE.6

Easily Deployable A⁴ Wireless Mesh Networks

The Easily Deployable A⁴ Wireless Mesh Networks (WMNs) project (eA⁴-Mesh) has been carried out as part of the AAA/SWITCH-e-Infrastructure for e-Science programme. The eA⁴-Mesh project is an extension of the A⁴-Mesh project, in which a collaboration between the project partners of the A⁴-Mesh project and a new user group of environmental researchers of the Centre for Hydrogeology and Geothermics from University of Neuchatel (UniNE CHYN) took place.

The A⁴-Mesh project and its extension eA⁴-Mesh considered several application scenarios of wireless mesh network technologies. The main application scenario has been focusing on support for environmental research. In the A⁴-Mesh project, the A⁴-Mesh network has been deployed in the Crans-Montana-Sierre region (Valais), while in the eA⁴-Mesh project the network was deployed in the area of Emmental, both to support

environmental research. Specifically, in eA⁴-Mesh, the wireless mesh network was used to investigate how ground water flow systems used for water supply will react to dry periods that are expected to occur more frequently under future climatic conditions. Here the wireless network infrastructure, which was used to continuously transfer environmental data measured by various environmental sensors, was in addition coupled to a database feeding a hydrogeological modeling and simulation system with the aim to make the environmental research process more efficient.

Similar to the A⁴-Mesh project, special care was taken to allow easy access to the wireless mesh network by integrating authorisation and authentication into SWITCH's own authentication and authorisation infrastructure (AAI), grouped into a federation and based on Shibboleth (SWITCHaai). Furthermore, the accounting function provided specific traffic statistics, which contribute to the traffic based charging module. It operates in a SWITCHaai compatible wireless mesh network, which allows the network administrator to have full visibility of the forwarded traffic including the source, destination, and the forwarding nodes (organizations) involved. With this data the organisations can be properly charged for their traffic.

Research staff: Markus Anwander, Torsten Braun, Almerima Jamakovic-Kapic, Sandro Beffa, Teodor Macicas

Financial support: AAA/SWITCH Project UNIBE.10

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". For the A⁴-Mesh contribution to the project, the main goal is to perform a feasibility study on the A⁴-Mesh integration into the Swiss Academic Compute Cloud to become a platform for storage and processing of the collected sensor data.

The A⁴-Mesh network, deployed in two Swiss regions, namely Valais and Emmental, stores the environmental sensor data continuously on a server at UniBe CDS group premises. This is the typical use case where a researcher stores the data on his/her own infrastructure. Additionally, once

the researcher has left, it is often very difficult for other persons to reuse the data. Hence, the primary aim of this project is to investigate a solution for users who may benefit from storing their experimentation data on a distributed computing and/or data storage infrastructure, such as Grid and/or Cloud. In addition, it will output a feasibility study on the possibility of using SwissACC as a processing platform for the collected sensor data to be fed into the modeling and simulation system to make the environmental research process more efficient.

Research staff: Almerima Jamakovic-Kapic, Teodor Macicas, Torsten Braun

Financial support: AAA/SWITCH Sustainability Project

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 the devices. Concerning the first issue most if not all available software only deals with the downlink; concerning the second issue network operators take special measures to protect the identity of their users, which aggravates the problem.

In the first year of the project we developed a GSM sensor that is able to intercept GSM signals on the downlink and tested it for several locations in cooperation with our partners. Prior to the development we performed detailed analysis of the GSM specification to gain insights about signal processing during system design. In the second year we extended the GSM sensor for uplink scanning. During the testing process we came across other interesting research challenges such as impact of user diversity and power distributions. In terms of TDOA investigations we first tested the hardware ability to support the algorithm, which was followed by detailed analysis on the achievable synchronisation accuracy. We developed a novel algorithm that allows highly precise time synchronisation evaluations and that can be used for a larger range of applications and not only localisation. Subsequently, we are working on the comparison

of two methods for accurate timestamping, which should allow us to establish a minimum theoretically achievable positioning accuracy as well as practically achievable results.

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. Ongoing efforts focus on tracking a single mobile user, testing the performance of the TDOA algorithm in different propagation environment and UMTS feasibility analysis.

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

Financial support: Eurostars E!6429, BBT Vertragsnummer INT.2011.0035

Enhanced Mobile Communication with Content-Centric Networks

Content-Centric Networking (CCN) as a new paradigm for the Future Internet is a promising approach for opportunistic communication because routing is not based on specific forwarding nodes but content names. If an individual forwarder becomes unavailable, any node in the vicinity that has overheard the content transmission or holds the corresponding content may replace the former forwarder's functionality. In opportunistic networks, storage management is important because of two reasons: limited memory on resource constrained devices and lacking continuous connectivity between network nodes.

In the first year of the project, we started to implement a memory extension that can store incomplete content on persistent storage and resume it later from where it stopped. In the second year, we refined the implementation and deployed it on wireless mesh nodes. Evaluations showed that the

developed extension enables content transmission even in case of short opportunistic contacts, where regular content transmission is not possible, at the expense of no additional overhead. The extension can differentiate between real-time and delay-tolerant traffic based on the content's validity time, which is defined by the *freshnessSeconds* parameter. Although all received objects are stored in the cache and a LRU replacement strategy is applied, only delay-tolerant traffic is stored on persistent storage. Real-time traffic is automatically removed if new content is received.

A planned task in the second year was the application of energy-efficient operation to avoid battery depletion of resource constrained devices. We evaluated the energy consumption of wireless mesh nodes for different roles, i.e. requester, content source, passive bystander that does not send any messages, during unicast and multicast transmission. The results showed that multicast communication requires considerably more energy than unicast communication if there is one requester and one content source but that the relative energy consumption drops drastically the more requesters concurrently request the content.

Since mobile environments may change quickly, forwarding entries defining where to forward received Interests, cannot be configured statically or by using prefix announcements that are distributed via Internet link-state interior gateway protocols such as OSPF. A task that was planned for the third year was the automatic inclusion of data prefixes from overheard multicast communication. This functionality has already been implemented in the second year and was tested on wireless mesh nodes. To limit the processing overhead and FIB size, several optimizations were implemented such as merging of multiple similar prefixes, limiting the validity time and number of entries of dynamically included FIB entries as well as limiting the processing frequency of overheard packets without storing additional state information. The processing overhead was low on wireless mesh nodes and negligible on devices with faster processing capabilities.

Since opportunistic communication is based on one-hop communication, requests need to be forwarded in case of lacking direct connection. We designed and implemented an agent-based content retrieval for delay-tolerant communication. In a three-way handshake protocol a requester can find and select an appropriate agent node that will request the content for him/her. The agent stores the retrieved content including meta information and signatures of the original publisher in the repository

of his/her mobile device and informs the original requester when the complete content is retrieved. The repository on the agent's mobile device is regularly synchronized with the agent's content proxy, which is his/her home repository continuously connected to the Internet. If in range, the original requester can retrieve the content from the agent directly or if connected to the Internet from the content proxy. We are currently deploying and testing this mechanism on Android smart phones.

We have previously shown that content-centric data discovery is advantageous in opportunistic networks, where the same content objects may be stored on one or multiple hosts. By expressing Interests in name space prefixes, a user can request content that is stored on multiple hosts concurrently. The more name components a name space has, the more subsequent Interest requests need to be transmitted and consequently more time is required to discover available content objects in the name space. In dynamic environments, it is important to detect available resources quickly because contacts may be short. Therefore, two different supporting mechanisms are proposed: a naming scheme and content notifications. The naming scheme comprises broadcast components and alias mappings. The same broadcast components can be used by multiple publishers to describe content or publishers enabling quick discovery of alternative content sources. Alias mappings are content objects that link descriptive ambiguous specifiers comprising broadcast components to unique content names. Content notifications are important if a content source needs to quickly inform multiple nodes about events such as alarms or the availability of content. Since regular content-centric communication is request based, two notification mechanisms are developed based on Interest and Data messages. Due to lacking scalability of emulation frameworks and wireless test beds, we are currently evaluating both mechanisms in large mobile scenarios using our CCN-OmNeT++ simulator implementation. To get more meaningful simulation results, the implementation was extended by a more accurate application layer implementation including our memory management scheme as well as more realistic mobility models.

Research staff: Carlos Anastasiades, Arian Uruqi, Tobias Schmid, Jürg Weber, Alexander Striffeler, Wafaa El Maudni El Alami, Torsten Braun

Financial support: Swiss State Secretariat for Education and Research (SER), SER No. C10.0139

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 coordinates research efforts of national and international projects in the area of Wireless Networking for Moving Objects (WiNeMO). In the context of the research action Dr. Boris Bellalta from the Polytechnical University of Catalunya visited the CDS group to discuss collaboration in the area of cooperation among heterogeneous wireless sensor networks. Vitor Bernardo, PhD candidate from the University of Coimbra, also visited the group related to joint research on energy-efficient networking. Other related activities include our ongoing work on Enhanced Mobile Ad-hoc Communication with Content-Centric Networks and Opportunistic Routing for highly Mobile Ad-hoc Networks.

The diversity of wireless sensor networks (WSNs) nowadays is large enough to validate questions such as "Do we need all data?", "Which data is relevant?", "How can I use this data?". The answers are further challenged by the large numbers of mobile phones that can act as sensors themselves. In order to answer such questions one needs to deal with data semantics and data (content) representation as well as with formalising the communication among heterogeneous nodes. Formal representation of content is necessary to allow the easy extraction of relevant parameter and the quick decision on whether the data is of interest for an external network. For example, if we consider monitoring systems for fire detection they can rely on information from specifically deployed for the purpose sensors but also on reading from meteorological sensors. Moreover, the data collected by the sensors may be of interest for other networks to optimise their performance. Such scenario will require collaboration between the different, diverse networks on several layers, including content discovery and (aggregated) data propagation. The foundations of establishing such collaboration, together with defining an application scenario, were discussed during the research visit.

During his research visit at the CDS group Vitor Bernardo addressed work in the area of energy-efficiency for moving devices with IEEE 802.11n connectivity. The opportunity to connect various sensors, actuators and other devices to the Internet, usually referred to as Internet of Things (IoT), raises new challenges in the deployment of those devices. One of the most important challenges is related to the device's battery lifetime, directly affected by the communication activity. The work conducted during the research visit focused on the optimization of energy consumption in end-user devices by investigating on the usability of techniques such as aggregation mechanisms, power saving mechanisms and error correction techniques.

Research staff: Torsten Braun, Carlos Anastasiades, Desislava Dimitrova

Financial support: European Science Foundation, COST Action IC0906

Energy Efficiency in Large Scale Distributed Systems

The COST Action IC0804 proposes realistic energy-efficient solutions to share distributed information technology resources. As large scale distributed systems gather and share more and more computing nodes and storage resources, their energy consumption is exponentially increasing. While much effort is nowadays put into hardware specific solutions to lower energy consumptions, the need for a complementary approach is necessary at the distributed system level, i.e., middleware, network and applications. The Action characterizes the energy consumption and energy efficiencies of distributed applications. Our research group is contributing to the Action's Focus Group on Energy-efficient Wireless Networking, which aims to investigate energy efficient concepts for wireless communication. Related work in this area has been performed in our research project on Authentication, Authorization, Accounting and Auditing in Wireless Mesh Networks and Traffic Adaptivity in Wireless Sensor Networks. In a joint research activity together with the Universities of Würzburg and Coimbra, we have investigated trade-offs of energy efficiency and Quality-of-Experience for video transmission over wireless networks.

Research staff: Torsten Braun, Markus Anwander, Philipp Hurni, Almerima Jamakovic-Kapic

Financial support: European Science Foundation, COST Action IC0804

Service-Centric Networking

Content-centric network (CCN) is a new and promising networking paradigm. CCN aims at moving from host-to-host communication style to a new paradigm that focuses on content as the building block of the Internet rather than hosts. In other words, CCN is about what users want, not where it is. With this new paradigm, the concepts of security, routing, and group communication are more natural and robust because of decoupling senders from receivers. The goal of CCN is to achieve a network architecture that better suits the common use of networks today with respect to content distribution and mobility.

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.

Research staff: Dima Mansour, Torsten Braun

Financial support: Swiss National Science Foundation Project No. 146376

Opportunistic Routing for highly Mobile Ad-hoc Networks

In the first two project years of ORMAN, we proposed and developed a framework for simulating and analyzing opportunistic routing protocols. Based on that, we implemented different OR protocols and evaluated their performance using our framework. In the third project year of ORMAN, we continued our work to design and evaluate a Topology and

Link quality-aware Geographical opportunistic routing protocol for mobile wireless ad-hoc networks.

Most of the existing OR protocols define a candidate list such that only the nodes within the list can compete for packet forwarding. However, the idea of pre-defining a candidate list reduces the freedom of opportunism and the list will be no longer valid when nodes are mobile. This is because the list is built statically prior to data transmission to learn link conditions, and when a node moves, the network topology will change. Therefore, the prediction of the candidates' priorities can not reflect the real situation at the moment of packet transmission. Additionally, due to node mobility, the predefined priority list will not hold any more. This list will also prevent that a non-listed node might move to a better position and become a more suitable candidate. Based on this observation, TLG does not include a candidate list when selecting the relay node. All nodes could participate in packet relaying during the process of packet transmission.

TLG takes different network metrics into account to make a joint routing decision. It uses the idea of dynamic forwarding delay (DFD) by considering link quality, node progress, and remaining energy to compute the dynamic delay function. When the source node has data to transmit, it includes the geographical information of itself and also of the final destination into the packet and broadcasts it. The neighbors that receive the packet will first check whether they are closer to the final destination than the last hop. If not, they drop the packet. Otherwise, they are considered as possible relay nodes, and apply a DFD function. DFD was designed to give a delay timer before a node rebroadcasts the received packet. The node that generates the smallest delay will rebroadcast the packet first. By overhearing this transmission, other candidates stop the scheduled transmission and drop the packet. In the meantime, the re-broadcasted packet is used as a passive acknowledgement, and the sender knows which node has been selected as the forwarder. Therefore, the sender transmits subsequent packets using unicast to reduce the drawbacks introduced by broadcasting. In TLG, the duration of this unicast transmission should depend on the validity time of the link between the sender and the selected relay node.

To validate the performance of the proposed proposal, we evaluate TLG under both static and mobile wireless ad hoc networks using both Quality of Service (QoS) and Quality of Experience (QoE) metrics. We compare TLG with well-known existing solutions and simulation results show

that TLG can provide efficient and robust routing in both static and mobile environments, and it outperforms others in terms of both QoS and QoE metrics.

Research staff: Zhongliang Zhao, Denis Lima do Rosario, Torsten Braun

Financial support: Swiss National Science Foundation Project No. 200021-130211

Mobile Multi-Media Wireless Sensor Networks

This project, Mobile Multi-Media Wireless Sensor Network (M3WSN), combines the research experiences of both University of Science and Technology of China (USTC) in China and University of Bern (UBERN) in Switzerland. M3WSN aims to integrate several testbeds and experimentation facilities to a single one, which can host and support more complex experiments.

First, we built a comprehensive experimentation infrastructure to experiment with Internet of Things and wireless sensor networks. We implemented a heterogeneous wireless network test-bed. Second, we designed and implemented a general multi-tier network architecture for mobile multi-media sensing. Our architecture consists of different types of sensors deployed in different hierarchical layers and the higher layer sensors are only woken up by the lower layer sensors when needed. Based on that, we evaluated a multi-media sensor system for object detection and tracking based on steerable cameras that are triggered and steered based on discrete sensor data.

Simulation results show that the proposed multi-media sensor system is more energy-efficient and achieves better scalability and reliability. Last, we designed and implemented a new opportunistic routing mechanism for forwarding multimedia packets in a mobile network. Simulation results show that our proposal outperforms other solutions in terms of throughput, delay, and quality of experience metrics.

Research staff: Zhongliang Zhao, Denis Lima do Rosario, Torsten Braun

Financial support: Joint research project of Nano-Tera.ch and the Sino Swiss Science and Technology Cooperation (SSSTC)

Low-Cost Network Coding for Collaborative Video Streaming

The widespread deployment of wireline/wireless communication systems and the proliferation of digital media created the recent surge in multimedia streaming research. With emerging applications such as wireless low-power surveillance, multimedia sensor networks, and portable devices with multimedia coding and communication capabilities, the traditional multimedia coding and streaming architectures are being challenged. For efficient multimedia streaming in overlay networks many often contradictory tools as video coding, channel coding, coding strategies at intermediate network nodes and network protocols should be considered. Specifically, video coding aims at removing data redundancy to reduce the volume of the transmitted data, while channel coding adds some redundancy to the stream to make it more resilient to errors. Network protocols offer efficient transmission mechanisms to cope with the best-effort nature of networks which does not guarantee any quality of services. However, such protocols demand for knowledge of the end-to-end network statistics and are difficult to be maintained due to network dynamics. To this aim, coding at peers such as network coding becomes popular as it assists communications systems to improve network throughput, reduce delay and eliminate the need for reconciliation among peers. Essentially network coding is a special class of channel codes that permits on-the-fly adaptation of the added redundancy. Despite the appealing features of network coding, its efficient application is not straightforward and many challenging problems should be still addressed.

This project focuses on the deployment of low-cost network coding methods for video streaming in overlay networks. It is the follow up work of the Ambizione project with reference number PZ00P2-121906. Here, we plan to continue the exciting work and promising developments of the early part of the project that due to time limitations we were not able to complete. In the PZ00P2-121906 project, we have proposed among others low complexity network coding schemes, prioritized network code to address clients heterogeneity, inter-session network codes, and techniques for approximate network codes decoding. In details, we have already presented a low-cost network coding method based on

Raptor codes that first achieves close to linear decoding and encoding times. For decentralized systems, we have proposed another system that employs randomized network coding and restricts the coding operations in selective positions. It is shown that few network coding nodes in large overlay networks are enough to notice large gains in terms of throughput and delay. To keep the computational complexity low all other nodes are store-and-forward. We have defined a game that decides about the network coding positions based on the willingness of network nodes to perform network coding. We have coped with the problem of clients receiving insufficient number of packets to fully recover the transmitted data. Thus, we have developed a method that uses data correlation to enhance data reconstruction. This scheme is the only that provides a systematic framework for data recovery in case of severe losses that is applicable to various types of data. We have also considered the case of multiple concurrent streams that compete for the network resources and first present a general methodology that scales to any arbitrary number of sources. Finally, we have designed a receiver driven UEP protocol based on network coding for video communication. This distributed system solves a simple optimization algorithm to find the optimal coding strategy at nodes. It allows system users to improve their experience and exploit better their resources.

The developed randomized network coding method for multiple concurrent streams requires centralized knowledge about network topology and statistics. In this project, we will extend this technique to distributed systems. For low complexity, we will also consider the application of Raptor network coding. Novel source and channel rate allocation algorithm will be devised to take into account the multiple concurrent sources and remove the need for resource allocation algorithms that pre-allocate the bandwidth to the concurrent streams. We have shown that in many cases the sparse application of network coding is very efficient. Here, to further improve resiliency of the developed network coding techniques to network dynamics we will apply online learning methods. This will enable on-the-fly decision about the optimal coding operations and provide maximal quality streams with minimal delay. The designed approximate decoding techniques have made apparent that for rank deficient systems and correlated sources, decoding is possible by taking into account the correlation. To further enhance the performance of systems employing approximate decoding, we propose to benefit from the data correlation at encoding. For example, in wireless communication nodes can exploit overheard data from other nodes and the fact that they interfere with each other.

Research staff: Nikolaos Thomos

Financial support: Ambizione project from Swiss National Science Foundation (PZ00P2-137275)

Adaptive Network Coding for Video Communications

During the past decade the emergence of peer-to-peer and social networks has provided a new means of communications. Network users connect through ad-hoc overlay networks to exchange multimedia data (images, video, music, etc.) with other users. This explosion of the communicated time-sensitive data challenges current streaming architectures and creates a surge for novel data distribution algorithms that respect the delivery deadlines of the multimedia. The latter is especially critical for real-time streaming applications, as data arriving after the decoding deadline is useless. Network coding is an example of techniques that enable timely delivery of multimedia data. It compensates for the missing quality of services of the best effort IP. Network coding departs from the typical paradigm followed by today's networks where network nodes simply forward the received packets. Network coding permits nodes to combine the received packets deterministically or randomly in finite fields enhancing this way the exploitation of the available resources. With network coding the max-flow min-cut limit of the underlying communication graph can be reached. In parallel, network coding can improve the error resiliency, remove the need for complex scheduling algorithms and decrease the delivery delay. However, the application of network coding is not trivial. There is a tradeoff among the improved throughput, decoding delay and communication overhead. Furthermore efficient communication systems should deal with the heterogeneous needs of the network users, which typically have different demands in terms of multimedia data and qualities.

The main disadvantage of the current network coding based streaming approaches is that they assume the existence of a single generation per time instant in the network. However, such an assumption might lead to suboptimal coding decisions, as each Group of Pictures (GOP) of the video is associated with a different expiration time (a client should decode the packets of a generation before their expiration time) which depends on the generation order in the video sequence and its initial playback time. To overcome the above drawback, we have studied the transmission of scalable video in

overlay networks under the realistic assumption that multiple generations may concurrently flow in the network. We have developed a framework that works for a server-client scenario that is based on Markov Decision Processes (MDP) to decide what is the optimal coding policies and the optimal streamed video quality. Here, we plan to extend our framework to the multiple-servers multiple-clients case, considering the bandwidth constraints. In order to allow the application of our framework to real-time systems we will explore the application of online learning methods instead of MDP. In addition, in order to accelerate the convergence time, we will examine quantization of the state and action space of the MDP model. As a final step of the project, we will adapt the proposed algorithms to large overlay networks. This is a challenging task, as in general we cannot predict precisely the current state of each node's buffer.

Research staff: Nikolaos Thomos

Financial support: Hasler Foundation

YouStream 3D: Immersive Context-Aware Personal Communications

We are witnessing an integration of computer-communication technologies on an unprecedented scale. People, devices, and computers interact in ways unforeseen before. Future predictions speak of even more fundamental changes lying ahead spurred by the ever increasing amount of digital content pervading our lives. At the heart of these technological advances lies our drive to interconnect and share information, anywhere and anytime. In particular, social networking applications are increasingly becoming a landmark of our online existence. For instance, according to recent statistics, we spend on average 15 minutes on YouTube every day and more content is uploaded there in 60 days than all three major US networks created in 60 years. The unparalleled scale and massive content production of online social networks raise a new set of challenges for the reliable delivery and understanding of content in such environments. Even the most powerful content delivery networks today such as Akamai and Limelight are not capable of serving such large audiences, simultaneously. The anticipated personalization of the streaming process in the future, according to different viewing times, client devices, and viewing angles, e.g., as in online games, will only augment the complexity of the problem further. Equally important, the fusion of online communities and media

sharing sites has brought to the forefront unfamiliar phenomena such as audience-content interaction and interdependencies. Finally, the proliferation of smart mobile devices has promoted yet another layer of complex context-driven time-varying interrelations between people, locations, and data. The project investigated intelligent multimedia systems that will address the new engineering and scientific challenges that are introduced by the fusion of community sites, content production tools, the proliferation of multi-camera arrays, and the advent of virtual worlds.

Research staff: Jakov Cakareski

Financial support: Ambizione project from Swiss National Science Foundation (PZ00P2-143101)

Velo Sensor

The Velo Sensor project has been performed in collaboration with Sciyent GmbH, Zürich. We implemented a system that is able to detect the presence of a bicycle, which is equipped with a sensor node. Moreover, it should be possible to query the system for the overall time, which the bicycle was in the perimeter of one of the system's base stations. The used sensor node of the bicycle should have the longest possible lifetime, therefore the system has to be optimized concerning the energy-efficiency of the bicycle sensor node.

We choose the Z1 sensor node from Zolertia as the development platform. This platform features the same hardware as the well-know TmoteSky platform, except an additional accelerometer. Contiki was chosen as the operating system running on the sensor. To detect a bicycle, a base station is needed to be deployed in the parking area. We choose ALIX x86 embedded PC, which is developed and distributed by PCEngines. Voyage Linux, which is a Debian derivate, is the operating system running on the base station.

A central server is used to collect the data from the base station. The server is running in our group lab as a XEN virtual machine. On this VM, Apache and MySQL are running to maintain the real-time data collected from the base station. Besides, to show the results in a user-friendly way, we also developed a simple web application using CakePHP. This web

application implements a web service to receive the data pushed by the server.

Research staff: Sandro Beffa, Zhongliang Zhao, Torsten Braun

Financial support: Sciyent GmbH

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 enterprise integration platform, 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, allowing a domain expert to model a business process or business rules easily without the need of having specific technical knowledge about the sensing devices. First evaluation results show that the performance of the platform is very promising and the overhead imposed by the semantic layer is reasonable compared to alternatives such as WSDL.

Research staff: Matthias Thoma (external Ph.D. student), 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, our research group 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 infrastructure. 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

WSN Lab

The Nano-tera Wireless Sensor Network Laboratory project (WSN Lab) used and extended the existing Wisebed wireless sensor network (WSN) test-bed facility to support hands-on programming and experimentation exercises in wireless sensor networks. The implemented course modules are available for Master level students in Computer Science or related fields such as Electrical Engineering. The extension of the existing

Wisebed test-bed sites at University of Bern and University of Geneva are conducted in the following ways: the integration of established WSN test-bed sites into SWITCHaai has been done; a development environment allowing compilation and linking of sensor node programs has been provided; WSN test-bed was complemented by multiple sensor types; a number of course modules were implemented to train Master level students in designing, implementing, and testing WSN mechanism.

The developed course modules include topics on time synchronization protocols, WSN routing protocols, forward error correction mechanisms, topology control protocols, message authentication mechanisms, and clustering algorithms.

Research staff: Zhongliang Zhao, Torsten Braun

Financial support: Nano-Tera.ch E&D project

3.4 Ph.D. Theses

- Markus Anwander: "Reliability in Energy-efficient Wireless Sensor Networks", December 18, 2012
- Gerald Wagenknecht: "Energy-efficient Management of Heterogeneous Wireless Sensor Networks, May 6, 2013

3.5 Bachelor's Theses

- Sandro Beffa: "Implementing and Evaluating Communication Protocols for reliable multicast in Wireless Sensor Networks", August 28, 2012
- Jürg Weber: "Automatic Detection Of Forwarding Opportunities In Intermittently Connected Content-Centric Networks", March 13, 2013
- Tobias Schmid: "Data Exchange In Intermittently Connected Content-Centric Networks", March 13, 2013

3.6 Awards

- Best Paper Award, EE-LSDS 2013 conference for Vitor Bernardo, Marilia Curado and Torsten Braun for the paper entitled "Enhancing IEEE 802.11 Energy Efficiency for Continuous Media Applications", April 2013
- AAA/SWITCH Award, AAA/SWITCH - e-Infrastructure for e-Science program for the A4-Mesh project as *The project overcoming the most hurdles in getting started*, June 2013

3.7 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 the COST Action IC 0804 Energy-Efficiency In Large Scale Distributed Systems
- Management committee member of the COST Action IC 0906 Wireless Networking for Moving Objects (WiNeMO)
- 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-Verlag
- Editorial Board Member of Journal of Internet Engineering (Editor in Chief)
- Guest Editorial Board Member of Special Issue on "Deploying Real-Life WSN Applications: Challenges, Solutions, and Future Directions" in Hindawi's International Journal of Distributed Sensor Networks

Conference Chairs

Torsten Braun

- IEEE ICC Workshop Mobile Cloud Networking 2013, Budapest, Hungary, June 13, 2013
- Wired/Wireless Internet Communications 2013, Steering Committee, St Petersburg, Russia, June 5-7, 2013
- 2nd Joint ERCIM eMobility and MobiSense workshop, St Petersburg, Russia, June 4, 2013
- International Symposium on Quality of Service 2013, Steering committee, Montreal, Canada, June 3-4, 2013

Desislava Dimitrova

- 2nd Joint ERCIM eMobility and MobiSense Workshop, St Petersburg, Russia, June 4, 2013

Almerima Jamakovic-Kapic

- IEEE ICC Workshop Mobile cloud Networking 2013, Budapest, Hungary, June 13, 2013

Conference Program Committees

Torsten Braun

- International Conference on Next Generation Wired/Wireless Advance Networking, St Petersburg, Russia, August 28-30, 2012
- ICCCN International Workshop on Sensor Networks, Munich, Germany, July 30 - August 2, 2012
- International Congress on Ultra Modern Telecommunications and Control Systems 2012, St Petersburg, October 3-5, 2012
- IEEE International Conference on Network and Service Management 2012, Las Vegas, USA, October 22-26, 2012
- Notere Colloque francophone sur l'ingénierie des protocoles 2012, Anglet, France, October 29-31, 2012
- IEEE Local Computer Networks 2012, Clearwater, USA, October 22-25, 2012
- International Workshop on Multiple Access Communications 2012, Dublin, Ireland, November 19-20, 2012
- IEEE Globecom 2012, Anaheim, USA, December 3-7, 2012
- Workshop on Secure and Dependable Middleware for Cloud Monitoring and Management (SDMCMM) held in conjunction with ACM/IFIP/USENIX ACM International Middleware Conference, Beijing, China, December 4, 2012
- IEEE IEEE Symposium on Network Cloud Computing and Applications, London, UK, December 3-4, 2012
- IEEE Globecom Workshop Wireless Networking and Control for Unmanned Autonomous Vehicles, Anaheim, USA, December 7, 2012
- IEEE Consumer Communications and Networking Conference, Las Vegas, USA, January 11-14, 2013
- Omnet++ Workshop 2013, Cannes, France, March 5th, 2013
- Networked Systems 2013, Stuttgart, Germany, March 11-15, 2013

- IEEE Infocom International Workshop on Emerging Design Choices in Name-Oriented Networking (NOMEN 2013), Torino, Italy, April 14-19, 2013
- Energy Efficiency in Large Scale Distributed Systems, Vienna, Austria, April 22-24, 2013
- IEEE International Workshop on Hot Topics in Mesh Networking, Madrid, Spain, June 4, 2013
- IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks, Madrid, Spain, June 4-7, 2013
- Wired/Wireless Internet Communications 2013, St Petersburg, Russia, June 5-7, 2013
- Conference on Future Internet Communications 2013, Coimbra, Portugal, May 15-16, 2013
- IEEE International Symposium on Quality of Service, Montreal, Canada, June 3-4, 2013

Desislava Dimitrova

- 5th International Workshop on Multiple Access Communications, Dublin, Ireland, November 19-20, 2012
- AIMS 2013 - PhD Workshop, Barcelona, Spain, June 25-28, 2013

Nikolaos Thomos

- IEEE QoSTREAM 2013 (in conjunction with ICC'13)

Denis Lima do Rosario

- TCP of Simposio Latinoamericano en Infraestructura, Hardware y Software

Ph.D. Jury Memberships

Torsten Braun

- Olof Rensfelt, Uppsala Universitet, October 12, 2012
- Peter Dely, Karlstads Universitet, December 14, 2012
- David Palma, Universidade de Coimbra, March 8, 2013
- Andrei Aurel Vancea, Universität Zürich, February 22, 2013

Project and Person Reviewing Activities

Torsten Braun

- European Coordinated Research on Long-term Challenges in Information and Communication Sciences & Technologies ERA-Net (EU CHIST-ERA)
- Committee member for faculty position at Uppsala Universitet
- Reviewer for Norwegian Core Competence and Value Creation in ICT (VERDIKT) program
- Project Reviewer for 7th Framework Programme of the European Community for research, technological development and demonstration activities
- Hasler Foundation
- Swiss National Science Foundation

Journal Article Reviewing Activities

Torsten Braun

- Elsevier Computer Communications
- IEEE Communications Magazine

Desislava Dimitrova

- IEEE Communications Letters
- IEEE Transactions on Mobile Computing
- Elsevier Computer Communications
- Elsevier Computer Networks
- Elsevier Performance Evaluation
- International Journal of Distributed Sensor Networks
- Journal on Wireless Communications and Networking

Almerima Jamakovic-Kapic

- Elsevier Transportation Research Part C Journal
- Elsevier Physica A: Statistical Mechanics and its Applications.
- Oxford Journal of Complex Networks

Denis Lima do Rosario

- British Journal of Mathematics & Computer Science
- IEEE Transactions on Wireless Communications

Invited Talks and Tutorials

Alexandru-Florian Antonescu

- SLA Driven Dynamic Orchestration and Composition for Distributed Cloud-Based Services, 7th Workshop on Cloud-based Service Platforms for the Future Internet, Winterthur, November 29, 2012

Torsten Braun

- Information-Centric Networking in Wireless/Mobile Networks, IFIP/ACM LANC 2012, 7th Latin America Networking Conference, October 5, 2012
- Die Evolution des Internet, 30 Jahre Freundeskreis Hans-Furler-Gymnasium Oberkirch (Germany), October 19, 2012
- Mathematik und Algorithmen für die drahtlose Internet-Kommunikation, Hans-Furler-Gymnasium Oberkirch (Germany), October 19, 2012
- Telematiknetze, Kaderkurs Telematik, Bundesamt für Bevölkerungsschutz, Schwarzenburg, Switzerland, November 13, 2102
- UAVNet: A Mobile Wireless Mesh Network Using Unmanned Aerial Vehicles, COST Action IC 0906 Meeting Dublin, November 20, 2012
- Software-Defined Networking for Mobile Network Services, Panel Presentation at 19th IEEE LANMAN Workshop, Brussels, Belgium, April 10-12, 2013
- Information-Centric Networking in Mobile Networks, Universität Zürich, February 22, 2013

- Easily Deployable A4 Wireless Mesh Networks (eA4-Mesh), eA4Mesh Final Dissemination Event, Neuchâtel, April 5, 2013
- Content-Centric Networking in Opportunistic and Mobile Networks, Alcatel-Lucent Bell Labs, Holmdel, NJ, USA, May 23, 2013

Desislava Dimitrova

- Active vs Passive Localisation Strategies, 2nd Joint ERCIM eMobility and MobiSense Workshop, St Petersburg, Russia, June 4, 2013

Almerima Jamakovic-Kapic

- A4 Wireless Mesh Networks, SWITCH - ICT Focus, Solothurn, October 22, 2012

Nikolaos Thomos

- Network Coding for Multimedia Communications, University of Glasgow, UK, April 2013
- Network Coding for Multimedia Communications, Alpen-Adria-Universität Klagenfurt & Lakeside Labs, Austria, May 2013
- Network Coding for Multimedia Communications, University of Essex, UK, May 2013

Andre Gomes

- Follow Me Cloud and Virtualization of (Multimedia) Services and Applications: Challenges and Possible Solutions, Future Network & Mobile Summit 2013, Lisbon, Portugal, July 3-5, 2013

Organized Events

- 2nd Joint ERCIM eMobility and MobiSense Workshop, co-located with the 11th International Conference on Wired/Wireless Internet Communications WWIC 2013, St Petersburg, Russia, June 4, 2013
- Workshop Mobile Cloud Networking and Services 2013, co-located with the IEEE International Conference on Communications 2013 (ICC 2013), Budapest, Hungary, June 13, 2013
- Computer Science Summer School seminar, organised together with the Dependable Systems and Networks group and Distributed Systems group of University Neuchâtel, Les Plans-sur-Bex, Switzerland, June 26-28, 2013.

3.8 Publications

Publications submitted in the academic year 2012/2013 and appearing in the following academic year are not listed.

Books

- Alex Galis and Anastasius Gavras (Eds.); Almerima Jamakovic, Thomas Michael Bohnert, Georgios Karagiannis: Future Internet Assembly 2013: Validated Results and New Horizons Series, Lecture Notes in Computer Science, Vol. 7858, May, 2013, ISBN 978-3-642-38081-5

Reviewed Journal and Conference Papers

- Zhongliang Zhao, Denis do Rosario, Torsten Braun, Eduardo Cerqueira, Hongli Xu, Liusheng Huang: Topology and Link Quality-aware Geographical Opportunistic Routing in Wireless Ad-hoc Networks, The 9th International Wireless Communications and Mobile Computing Conference (IWCMC 2013), Cagliari, Italy, July 1-5, 2013, IEEE Press, ISBN 978-1-4673-2478-6
- Matthias Thoma, Alexandru-Florian Antonescu, Theano Mintsu, Torsten Braun: Linked Services for M2M Communications, Proceedings of the 9th International Wireless Communications and Mobile Computing Conference (IWCMC 2013), Cagliari, Italy, July 1-5, 2013, IEEE Press, ISBN 978-1-4673-2478-6
- Gustavo Pessin, Fernando S. Osório, Jefferson R. Souza, Jó Ueyama, Fausto G. Costa, Denis F. Wolf, Desislava Dimitrova, Torsten Braun, Patrícia A. Vargas: Investigation on the Evolution of an Indoor Robotic Localization System Based on Wireless Networks, Applied Artificial Intelligence Journal, Vol. 27, Nr. 6, July, 2013, ISSN 0883-9514
- Alexandru-Florian Antonescu, Andre Gomes, Philip Robinson, Torsten Braun: SLA-Driven Predictive Orchestration for Distributed Cloud-Based Mobile Services, IEEE ICC'13 - 1st International Workshop on Mobile Cloud Networking and Services (MCN), pp. 748-753, Budapest, Hungary, June 9-12, 2013, IEEE Press, ISBN 978-1-4673-5753-1

- Alexandru-Florian Antonescu, Philip Robinson, Torsten Braun: Dynamic SLA Management with Forecasting using Multi-Objective Optimizations, IFIP/IEEE Integrated Network Management Symposium (IM 2013), pp. 457-463, Ghent, Belgium, May 27-31, 2013, IEEE Press, ISBN 978-1-4673-5229-1
- Markus Anwander, Torsten Braun: A Reliable, Traffic-adaptive and Energy-efficient Link Layer for Wireless Sensor Networks, IFIP Networking 2013, Brooklyn, New York, USA, May 22-24, 2013, ISBN 978-3-901882-55-5
- Dragan Milic, Torsten Braun: Guaranteed Greedy Routing in Overlay Networks, The Conference on Future Internet Communications (CFIC Coimbra 2013), Coimbra, Portugal, May 15-16, 2013, DOI 10.1109/CFIC.2013.6566327
- Denis do Rosario, Rodrigo Costa, Aldri Santos, Torsten Braun, Eduardo Cerqueira: QoE-aware Multiple Path Video Transmission for Wireless Multimedia Sensor Networks, 31th Brazilian Symposium on Computer Networks and Distributed Systems (SBRC), Brasilia, Brazil, May 6-10, 2013, ISSN: 2177-496X
- Almerima Jamakovic, Desislava Dimitrova, Markus Anwander, Teodor Macicas, Torsten Braun, Jan Schwanbeck, Thomas Staub, Benjamin Nyffenegger: Real-World Energy Measurements of a Wireless Mesh Network, Energy Efficiency in Large Scale Distributed Systems conference, Vienna, Austria, April 22-24, 2013, Springer, ISBN 978-3-642-40516-7
- Torsten Braun, Tuan Anh Trinh: Energy Efficiency Issues in Information-Centric Networking, Energy Efficiency in Large Scale Distributed Systems conference, Vienna, Austria, April 22-24, 2013, Springer, ISBN 978-3-642-40516-7
- Vitor Bernardo, Marilia Curado, Torsten Braun: Enhancing IEEE 802.11 Energy Efficiency for Continuous Media Applications, Energy Efficiency in Large Scale Distributed Systems conference, Vienna, Austria, April 22-24, 2013, Springer, ISBN 978-3-642-40516-7
- Regina B. Araujo, Carlos H. C. Ribeiro, Damla Turgut, Jo Ueyama, Torsten Braun: Deploying Real-Life WSN Applications: Challenges, Solutions, and Future Directions, International Journal of Distributed Sensor Networks, Vol. 2013, Nr. 610892, April, 2013,

pp. 7-8, Hindawi Publishing Corporation Editorial Article, DOI 10.1155/2013/610892

- Torsten Braun, Andreas Mauthe, Vasilios Siris: Service-Centric Networking Extensions, The 28th ACM Symposium on Applied Computing, pp. 583-590, Coimbra, Portugal, March 18-22, 2013, DOI 10.1145/2480362.2480475
- Denis do Rosario, Zhongliang Zhao, Claudio Silva, Eduardo Cerqueira, Torsten Braun: An OMNeT++ Framework to Evaluate Video Transmission in Mobile Wireless Multimedia Sensor Networks, 6th International Workshop on OMNET++, Cannes, March 5, 2013, ISBN: 978-1-4503-2464-9
- Markus Anwander, Torsten Braun, Philipp Hurni, Thomas Staub, Gerald Wagenknecht: User and Machine Authentication and Authorization Infrastructure for Distributed Wireless Sensor Network Testbeds, Journal of Sensors and Actuator Networks, Vol. 2, Nr. 1, pp. 109-121, March, 2013, DOI 10.3390/jsan2010109
- Matthias Thoma, Alexandru-Florian Antonescu, Theano Mintsi, Torsten Braun: Linked Services for Enabling Interoperability in the Sensing Enterprise, International Conference on Enterprise Interoperability (IWEI 2013), Vol. 144, March, 2013, Lecture Notes in Business Information Processing, Springer, DOI 10.1007/978-3-642-36796-0_12
- Zan Li, Desislava Dimitrova, Torsten Braun: TDOA-Based Localization System with Narrow-band Signals, PhD forum in Conference on Networked Systems (NetSys), Stuttgart, Germany, March, 2013
- Denis do Rosario, Philipe Lima, Kássio Machado, Eduardo Cerqueira, Zhongliang Zhao, Torsten Braun: Demo Abstract - Disseminating WMSN Data by Using Social Network and Web, 10th European Conference on Wireless Sensor Networks, Ghent, Belgium, February 13, 2013
- Tamara Tomic, Nikolaos Thomos and Pascal Frossard: Distributed Sensor Failure Detection in Sensor Networks, Elsevier Signal Processing, Vol. 93, No. 2, pp. 399-410, February, 2013, DOI 10.1016/j.sigpro.2012.07.028

- Hyunggon Park, Nikolaos Thomos and Pascal Frossard: Approximate Decoding Approaches for Network Coded Correlated Data, *Elsevier Signal Processing*, Vol. 93, No. 1, pp. 109-123, January, 2013, DOI 10.1016/j.sigpro.2012.07.007
- Philipp Hurni: Traffic-Adaptive and Link-Quality-Aware Communication in Wireless Sensor Networks, *PIK - Praxis der Informationsverarbeitung und Kommunikation*, Vol. 36, Nr. 1, pp. 3-8, February, 2013, De Gruyter, DOI 10.1515/pik-2012-0138
- Kássio Machado, Denis do Rosario, Eduardo Cerqueira, Antonio A. F. Loureiro, Augusto Neto, José Neuman de Souza: A Routing Protocol Based on Energy and Link Quality for Internet of Things Applications, *Sensors (Basel)*, Vol. 13, pp. 1942-1964, January, 2013, DOI 10.3390/s130201942
- Simon Morgenthaler, Torsten Braun, Zhongliang Zhao, Thomas Staub, Markus Anwander: UAVNet - A Mobile Wireless Mesh Network Using Unmanned Aerial Vehicles, *3rd International Workshop on Wireless Networking and Control for Unmanned Autonomous Vehicles*, pp. 1603-1608, Anaheim, CA, USA, December 3-7, 2012, IEEE Press, DOI 10.1109/GLOCOMW.2012.6477825
- Alexandru-Florian Antonescu, Philip Robinson, Torsten Braun: Dynamic Topology Orchestration for Distributed Cloud-Based Applications, *IEEE International Symposium on Network and Cloud Computing and Applications (NCCA 2012)*, pp. 116-123, Imperial College, London, UK, December 3-4, 2012, CPS (Conference Publishing Services), DOI 10.1109/NCCA.2012.14
- Denis do Rosario, Rodrigo Costa, Helder Paraense, Kássio Machado, Eduardo Cerqueira, Torsten Braun, Zhongliang Zhao: A Hierarchical Multi-hop Multimedia Routing Protocol for Wireless Multimedia Sensor Networks, *Network Protocols and Algorithms - Special Issue on 2nd IEEE Smart Communication Protocols and Algorithms*, Vol. 4, Nr. 4, pp. 44-64, December, 2012, Macrothink Institute, DOI 10.5296/npa.v4i4.2121
- Matthias Thoma, Sonja Meyer, Klaus Sperner, Stefan Meissner, Torsten Braun: On IoT-services: Survey, Classification and Enterprise Integration, *2012 IEEE International Conference on*

Green Computing and Communications (GreenCom), pp. 257-260, Besancon, France, November 20-23, 2012, IEEE Press, DOI 10.1109/GreenCom.2012.47

- Carlos Anastasiades, Arian Uruqi, Torsten Braun: Content Discovery in Opportunistic Content-Centric Networks, 5th International Workshop on Architectures, Services and Applications for the Next Generation Internet, pp. 1048-1056, Clearwater, FL, USA, October 22-25, 2012, IEEE Press, DOI 10.1109/LCNW.2012.6424042
- Zhongliang Zhao, Torsten Braun, Denis do Rosario, Eduardo Cerqueira, Roger Immich, Marilia Curado: QoE-aware FEC Mechanism for Intrusion Detection in Multi-tier Wireless Multimedia Sensor Networks, 1st International Workshop on Wireless Multimedia Sensor Networks (WMSN), pp. 689-696, Barcelona, Spain, October 8-10, 2012, IEEE Press, DOI 10.1109/WiMOB.2012.6379150
- Zhongliang Zhao, Björn Mosler, Torsten Braun: Performance Evaluation of Opportunistic Routing Protocols: A Framework-based Approach using OMNeT++, 7th Latin America Networking Conference, pp. 28-35, Medellín, Colombia, October 4-5, 2012, ACM, ISBN 978-1-4503-1750-4
- Gustavo Pessin, Fernando Osorio, Jefferson Souza, Fausto Costa, Jo Ueyama, Denis Wolf, Torsten Braun, Patricia Vargas: Evolving an Indoor Robotic Localization System Based on Wireless Networks, 13th International Conference on Engineering Applications of Neural Networks, pp. 61-70, London, UK, September 20-23, 2012, Springer, DOI 10.1007/978-3-642-32909-8_7
- Nikolaos Thomos and Pascal Frossard: Towards one Symbol Network Coding Vectors, IEEE Communications Letters, Vol. 16, No. 11, pp. 1860-1863, November, 2012, DOI 10.1109/LCOMM.2012.092812.121661
- David Hock, Vitor Bernardo, Thomas Zinner, Florian Wamser, Karin Hummel, Marilia Curado, Rastin Pries, Torsten Braun, Phuoc Tran-Gia: Evaluating the Trade-off Between Energy Efficiency and QoE in Wireless Mesh Networks, 4th International Conference on Communications and Electronics (ICCE), pp. 233-238, Royal city of Hue, Vietnam, August 1-3, 2012, DOI 10.1109/CCE.2012.6315904

Technical Reports

- Hugues Mercier, Torsten Braun, Pascal Felber, Peter Kropf, Pierre Kuonen: 2013 Doctoral Workshop on Distributed Systems, Technical Report IAM-13-002, Les Plans-sur-Bex, Switzerland, July 15, 2013
- Denis do Rosario, Zhongliang Zhao, Eduardo Cerqueira, Torsten Braun, Aldri Santos: A Link Quality and Geographical-aware Routing Protocol for Video Transmission in Mobile IoT, Technical Report IAM-13-001, March 28, 2013
- Eirina Bourtsoulatze, Nikolaos Thomos, Pascal Frossard: Distributed Rate Allocation in Inter-Session Network Coding, available at <http://arxiv.org/abs/1212.5032>, Dec. 2012
- Nikolaos Thomos, Rethnakaran Pulikoonattu, Pascal Frossard: Intermediate Performance Analysis of Growth Codes, available at <http://arxiv.org/abs/1211.4014>, Nov. 2012
- Eirina Bourtsoulatze, Nikolaos Thomos, Pascal Frossard: Decoding Delay Minimization in Inter-Session Network Coding, available at <http://arxiv.org/abs/1211.0951>, Nov. 2012
- Hugues Mercier, Torsten Braun, Pascal Felber, Peter Kropf, Pierre Kuonen, Etienne Rivire: 2013 Doctoral Workshop on Distributed Systems, Technical Report IAM-12-003, La Vue-des-Alpes, Switzerland, September 10, 2012
- Alexandru-Florian Antonescu, Philip Robinson, Torsten Braun: Dynamic SLA Management with Forecasting using Multi-Objective Optimizations, Technical Report IAM-12-002, September 5, 2012

4 Computer Vision Group

4.1 Personnel

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* with financial support from a third party

4.2 Overview

Prof. Dr. P. Favaro joined the IAM and established the computer vision group in June 2012. In computer vision researchers try to understand how the human visual system works, from the physics of light interaction and the biology of visual perception, to the psychology of semantic representation. There is not yet a recipe combining optics, light sensors, processors and algorithms, that works as well as the human visual system. However, fast progress is underway thanks to the availability of powerful sensing and computing technology. In particular, the CVG at the university of Bern focuses on research areas where progress is measurable. For example, they look at reconstructing metric quantities from images (e.g., 3D surfaces, 3D motion, texture, light fields) or identifying labels that have semantic meanings. A ground truth is typically available or measurable by other means, so accuracy can be evaluated by comparison.

4.3 Research Projects

Image Deblurring

Camera shake and object motion often generate blur in images. In photography motion blur is an unpleasant aesthetic artefact, but it also considerably reduces the accuracy of many classic computer vision applications, such as object registration, classification, recognition.

In this project we aim to restore a blur-free image from a single blurred image. Our goal is to build a general purpose deblurring algorithm, and establish the benefits that image deblurring gives to general computer vision applications.

In order to estimate a sharp image one has to estimate also some kind of information on the motion that generated the blurry image. This information can be represented mathematically as a function that represent each pixel of the blurry image as a convex combination of pixels of the sharp image. Unfortunately the estimation of the blur function and the sharp image is a really challenging problem, since the number of unknowns is larger than the dimension of the input image. If the blur function is known, the estimation of the sharp image is still an ill-posed inverse problem, i.e. it is highly sensitive to small measurement error or noise.

We approached the problem by firstly assuming that a partial knowledge of the blur function is given. This is often the case if the blur function is measured by inertial sensors or estimated by other deblurring methods. Nonetheless, when motion blur is known only up to some error, the restored sharp image might contain artefacts. This is also what happens when blur is not known at all, as one typically gradually improves the blur estimate via alternating minimisation. By introducing a novel image prior robust to blur errors we were able to drastically reduces artefacts in the reconstructed image.

We also studied how to measure the performance of single image deblurring algorithms. Typically this is done by defining a certain discrepancy measure between the reconstructed image and the ideal sharp image. The choice of metric, however, has been a source of debate and has also led to alternative metrics based on human visual perception. While fixed metrics may fail to capture some small but visible artefacts, perception-based metrics may favour reconstructions with artefacts that are visually pleasant. To overcome these limitations, we proposed to assess the quality of reconstructed images via a task-driven metric. We considered object classification as the task and therefore used the rate of classification as the metric to measure deblurring performance. In our evaluation we used data

with different types of blur in two cases: Optical Character Recognition (OCR), where the goal is to recognise characters in a black and white image, and object classification with no restrictions on pose, illumination and orientation. Finally, we showed how off-the-shelf classification algorithms benefit from working with deblurred images.

As future work we want to propose a method to estimate the blur function. Current methods impose many restrictions on the nature of the blur that considerably limit their application in real world problems. Our goal is to relax these restrictions and therefore widen the possible applications of motion deblurring.

Research staff: Daniele Perrone, Paolo Favaro

Financial support: Google Research, Selex-Galileo

Uncalibrated Photometric Stereo

An image captures the interaction between light, geometry and photometry of objects in a scene. This project investigates the problem of 3D reconstruction of a scene from 2D images. In particular, we focus on Photometric Stereo. This technique computes the 3D geometry from at least 3 images taken from a fixed viewpoint under different illumination conditions. When the illumination is unknown (uncalibrated photometric stereo) the problem is ambiguous (generalized bas-relief ambiguity): different combinations of geometry and lighting give the same appearances (images). This is a 3 parameters ambiguity and additional assumptions and/or constraints need to be imposed in order to obtain the correct solution. Prior work solves the ambiguity by using heuristics that depend on the ambiguity itself, and thus give non-unique and non-consistent answers. We solve the problem by exploiting Lambertian reflectance maxima. These are points defined on curved surfaces where the normals are parallel to the light direction. We also perform experiments on real world scenes and achieve state-of-the-art results with the highest computational efficiency.

Recently we showed that under the perspective projection model the solution is unique. In other words, one can uniquely reconstruct the normals of the object and the lights given only the input images and the camera calibration (focal length and image center). We show that just by reparametrizing the normal map, the image formation model is identical as in the orthographic case. Indeed, our proposed technique is a generalisation of

the orthographic case: if the focal length is sent to infinity our solution becomes identical to the orthographic solution. Also, under the perspective projection, one can reconstruct the depth map from the normals up to a scale factor. The analysis is also paired with a robust and simple algorithm that achieves state-of-the-art performance in the reconstruction of the normal maps on real data.

Research staff: Thoma Papadimitri, Paolo Favaro

Learning Dynamic Event Categories

This project aims at the recognition of deforming objects such as fire, water, smoke, and steam. Videos of those objects are also known as dynamic textures, temporal textures, or textured motion. The recognition of categories of dynamic textures from video faces several fundamental challenges. Most notably, videos of scenes that belong to the same class can experience significant variability due to changes in viewpoint, scale, illumination, and occlusions. In this project we address such problems. We are developing novel feature extraction techniques that are invariant to changes in the recording conditions. We evaluate novel feature matching techniques that are robust to occlusion and background clutter; Last but not least we are looking into novel machine learning techniques that allow one to build probabilistic models of objects and scene backgrounds.

Research staff: Gabriel Jackson, Paolo Favaro

Shape Learning

The human visual system is a remarkable piece of machinery. It is not only capable of recognising what is on a picture, but it can also infer the 3D shape. Humans don't require two or three images to reconstruct the 3D information, a single one usually is enough. However, this is only possible if prior knowledge about the object shape is present. Luckily, humans are very efficient in acquiring this knowledge. A child only needs to be shown a few pictures of a giraffe, and he will recognise giraffes for the rest of his life.

State of the art image recognition algorithms are mostly concerned about the appearance of objects. They detect repeatable interest regions in the picture, compute a description of such regions, and represent the image as the collection of these descriptors. Machine learning techniques are used

to categorise these collections, and that makes object recognition possible. However, these algorithms disregard most of the spatial information available in the image.

3D reconstruction from multiple views of the same object is well established. The crucial part of reconstruction is to find corresponding points across different views. So far, most algorithms use local appearance to establish these correspondences and ignore semantic information.

Shape learning is very similar to 3D reconstruction. Given several input images, the 3D shape is to be reconstructed. However, in the shape learning case, the images are of different instances of the same category instead of different viewpoints of the same object. Establishing correspondences in this case is even more challenging than for 3D reconstruction. Our goal is to learn 3D models automatically from a set of given images of a category. We modify the current image recognition pipeline to include the 3D model. This can increase the accuracy of recognition, and also allows 3D pose and orientation estimation from a single input image.

Research staff: Attila Szabó, Paolo Favaro

Compressive Light Field Imaging

This project aims at developing novel technology for light field imaging. Upon an explosion of interest in 3D imaging and display, various 3D technologies have been proposed in Computer Vision, Computer Graphics, Optics and Optoelectronics. For these next-generation 3D displays to succeed it is of paramount importance to address challenges in 3D content acquisition: While conventional stereoscopic displays require only stereo images that can be obtained by two side-by-side cameras, the next-generation 3D displays will require multiple overlapping views or 3D scene models. Furthermore, to realistically portray the appearance of shiny objects it is necessary to capture a large number of views of the scene especially at viewing angles where highlights occur. Although existing methods to capture light field images have made good progress over past decades, there is no solution that can reconstruct light fields of realistic scenes with both spatial and angular coordinates at high resolution. One of the main objectives of this project is a study of methods and models for light field recovery of non-Lambertian surfaces. The outcomes of this work will be fundamental to indicate how 3D content can be captured with high fidelity and with practical and computationally efficient imaging technology.

Eventually, the objective is to design novel devices that can capture images and videos and provide a reconstruction at a resolution higher than that of the imaging sensor. In the shorter term, we are interested in the formalization of the design of such systems as a tractable optimization task with respect to sparsity.

This analysis will show how one can jointly design optics, coded masks and illumination for a novel light field imaging device to best capture light fields of a scene for the purpose of 3D rendering.

Research staff: Michal Sorel, Paolo Favaro

Financial support: Samsung South Korea

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 artefacts. 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 Awards

Paolo Favaro

- Best reviewer award at the Conference on Computer Vision and Pattern Recognition (CVPR) 2013

4.5 Further Activities

Invited Talks

Paolo Favaro

- Invited Talk at EPFL: Portable Light Filed Imaging
- Invited Talk at Hexagon/Leica, Heerbrugg: Image and Depth Reconstruction with the Light Filed Camera
- Invited Talk at Universita' di Roma - La Sapienza: Variational Reconstruction of Texture, Surfaces and Illumination from Images

Anita Sellent

- Invited Talk at University of Siegen: Confidence Measures in Optical Flow Estimation September 2012.

Editorial Boards and Steering Committees

Paolo Favaro

- IET Computer Vision - Associate Editor
- International Conference on Computational Photography - Finance Chair

Organised Events

Paolo Favaro

- CUSO Winter School in Computational Photography and Display, Lenk, January 2013

Reviewing Activities

Paolo Favaro

- British Machine Vision Conference (BMVC)
- Conference on Computer Vision and Pattern Recognition (CVPR)
- CVPR Workshop on Computational Cameras and Displays
- European Conference on Computer Vision (ECCV)
- ECCV Workshop on Depth Cameras
- Conference on Energy Minimization Methods in Computer Vision and Pattern Recognition (EMMCVPR)
- International Conference on Computational Photography (ICCP)
- International Conference on Computer Vision (ICCV)
- Indian Conference on Vision, Graphics and Image Processing (ICVGIP)
- Conference on Neural Information Processing Systems (NIPS)
- SIAM Journal on Imaging Sciences
- Signal Processing
- IEEE Transactions on Pattern Analysis and Machine Intelligence

Anita Sellent

- IEEE Transactions on Image Processing
- Winterschool of Computer Graphics

4.6 Publications

- S. Bomma, N. Robertson and P. Favaro: Sparse representation based action and gesture recognition, IEEE International Conference on Image Processing (ICIP), 2013
- T. Papadimitri and P. Favaro: A New Perspective on Uncalibrated Photometric Stereo, IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2013
- D. Perrone, D. Humphreys, R. Lamb and P. Favaro: Evaluation of image deblurring methods via a classification metric, Proc. SPIE Electro-Optical Remote Sensing, Photonic Technologies, and Applications VI, 2012
- P. Favaro and T. Papadimitri: A Closed-Form Solution to Uncalibrated Photometric Stereo via Diffuse Maxima, IEEE Conference on Computer Vision and Pattern Recognition (CVPR) 2012, pp.821-828
- D. Perrone, A. Ravichandran, R. Vidal and P. Favaro: Image Priors for Image Deblurring with Uncertain Blur, Proceedings of the British Machine Vision Conference, 2012
- P. Favaro: A split-sensor light field camera for extended depth of field and superresolution, Proc. SPIE Optics, Photonics, and Digital Technologies for Multimedia Applications II, 2012, pp.821-828

5 Logic and Theory Group

5.1 Personnel

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 Mathematisches Institut,
 Germany
 October and November 2012

Prof. Dr. F. Ferreira FCUL - Universidade de Lisboa,
 Departamento de Matematica,
 Portugal
 September until December 2012

Prof. Dr. W. Pohlers Westfälische Wilhelms-Universität
 Münster,
 Institut für math. Logik und
 Grundlagenforschung,
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 November 2012

* 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: S. Eberhard, D. Flumini, G. Jäger, F. Ranzi, K. Sato, Th. Strahm, R. Zumbrunnen

Financial support: Swiss National Science Foundation

Structural Proof Theory and the Logic of Proofs

The original idea that prompted Artemov to develop the Logic of Proofs LP was to solve a long-standing problem posed by Gödel more than half a century before. This goal has been achieved by introducing into the formal logical language new objects called proof polynomials or, in epistemic setting, evidence terms. They enable us to reason about individual proofs or about evidence within the logical language. The goal of this project is to extend the benefits of this more expressive language to the logics used to describe common knowledge, a phenomenon important for distributed systems, temporal logics, which are used in specification and verification of correctness of computation, and a more general formalism of the so-called modal μ -calculus. A new promising area of application for evidence terms is belief revision, i.e., the change in opinions, for instance, as a result of announcements. The standard approaches to modeling such changes lead to paradoxical situations: an announcement of a true fact may make this announced fact false. The more expressive language with evidence terms, which represent reasons for beliefs, is also capable of modeling beliefs, including higher-order beliefs about beliefs of other agents. At the same time, it provides natural syntactic means of distinguishing between the beliefs held before the announcement and those resulting from the announcement, means lacking in the standard setting. A public announcement is undeniably direct material evidence for the announced fact, albeit this evidence may not be conclusive. Thus, the use of a language capable of operating with such evidence is highly desirable.

We also study the relationship between the structure of proof polynomials and structural properties of formal proofs. Among other things, formal proofs allow for computer verification. This study includes automating the process of evidence extraction from a given formal proof of validity of a statement about provability or about agents' beliefs. Further, we plan to study a certain well-developed type of such formal proofs, called sequent proofs, and the process of the so-called cut-elimination, i.e., elimination of intermediate lemmas, which is central to this type of proofs. The goal of this study is to develop proof polynomials based on this particular type of formalism, whereas proof polynomials developed by Artemov are based on a different formalism, that of Hilbert proofs, and hence do not preserve

the structure of sequent derivations.

Research staff: G. Jäger, A. Kashev, R. Kuznets, M. Marti, Y. Savateev

Financial support: Swiss National Science Foundation

A Proof Theory for Modal Fixed Point Logics

Temporal logics are widely used to specify and verify the correctness of information systems when system reliability is crucial. Epistemic logics with common knowledge are important for reasoning about knowledge. Both types of logics are examples of modal fixed point logics. While these logics are well-understood semantically, our syntactic understanding of them is lacking. The state of proof theory for modal logics in general is widely recognised as unsatisfactory. For modal fixed point logics in particular there are no satisfactory cut-free sequent systems. Such systems generally are suitable for automated proof search and, together with their cut elimination procedures, can serve as a basis for declarative programming languages. We intend to address the problem of designing cut-free sequent systems for modal fixed point logics on two levels:

1. Whenever possible we plan to develop such systems together with syntactic cut elimination procedures. If possible, we aim for traditional sequent systems in Gentzen style, but if needed we will also employ ideas from richer proof theoretic formalisms such as the display calculus or deep inference.
2. On the other hand, if no cut-free systems exist for modal fixed point logics, we hope to gain a better understanding of why they do not exist. In this case we are interested in good syntactic approximations.

The development of a proof theory for modal fixed point logics is an important theoretical contribution to the understanding of inference and deduction in these logics, and thus in particular a relevant underpinning of specification and verification of information systems. It is central ground work concerning the procedural aspects of frameworks dealing with information.

Research staff: G. Jäger, K. Sato, Y. Savateev

Financial support: Hasler Foundation

Computational Proof Theory

This is a joint research project of the LTG group and the Department of Mathematical Logic and Theory of Algorithms in Moscow. Both groups have a strong background in mathematical logic - in particular proof theory, provability logic and general modal logics - and expertise in applying concepts and techniques of mathematical logic in connection with recent developments in (theoretical) computer science. Among the interests of both groups are the attempts to analyze existing formal systems in order to classify their expressive as well as proof-theoretic powers and to design new and more flexible formal frameworks. In doing this, interesting results about computational and logical complexities (lower and upper bounds) of algorithms developed within these frameworks can be obtained frequently. Although working towards similar aims, the research traditions of Moscow and Bern are quite distinct.

Berns approach is rooted in traditional Gentzen- and Schütte-style (infinitary) proof theory and the proof-theoretic analysis of subsystems of second order arithmetic, set theory, explicit mathematics and type systems and still pursuing this line. Moscow school of logic has its roots in the works of Kolmogorov, Novikov and Markov. It is traditionally strong in constructive logic and mathematics, algorithmic problems in algebra, various non-classical logics and their semantical and computational aspects, and in descriptive complexity and complexity of algorithms.

The following three research streams address topics of mutual interests:

1. Provability algebras, metapredicativity and impredicativity
2. Functionality and common knowledge in justification logic
3. Structurally enhanced proof-theory for modal and substructural logics

It is expected that the combination and integration of the conceptual approaches and methods of both groups will allow to clarify the general landscape and to solve some long-standing open problems.

Research staff: G. Jäger, R. Kuznets, F. Ranzi, Th. Strahm, Th. Studer

Financial support: SBF (Staatssekretariat für Bildung und Forschung)

Logics for Privacy

The problem of data privacy is to verify that confidential information stored in an information system is not provided to unauthorized users and, therefore, personal and other sensitive data remain private. The main challenge in such a context is to share some data while protecting other personally identifiable information. The aim of our project is to develop formal methods and the corresponding algorithms to enable automated reasoning about data privacy. Data stored in a relational database or knowledge base system usually is protected from unauthorized access. Users of such a system are then only allowed to access a limited portion of the stored information. In this situation the following important questions arise:

1. What can a user infer from the information to which he has access?
2. Can we guarantee that a user cannot obtain knowledge about certain sensitive information?
3. Is it possible to grant a user information access in such a way that she is able to fulfill her duties without letting her know secret information?

We will address these questions not in their full generality, but we intend to study the following concrete issue. Controlled query evaluation is an approach to privacy preserving query answering where the answer to a query is distorted if it would leak sensitive information to the user. We plan to develop a formal framework to enable controlled query evaluation for ontological knowledge base systems. To achieve this aim we will mainly use tools and techniques from modal logic in general and description logic in particular.

Research staff: Th. Studer, J. Werner

Financial support: Swiss National Science Foundation

Computational Structure of Classical Duality (Ambizione)

The Curry-Howard correspondence, also known as the proofs-as-programs correspondence, is the observation that logical proofs and computer programs are two ways of presenting the same mathematical objects. This project aims to extend the scope of the correspondence in two important directions: on the logical side, towards capturing classical logic,

the logic used in natural and mathematical reasoning, and on the computational side to the idea of a “process”; a program which interacts with many other programs by passing messages.

Background: In the 1930s, Alonzo Church developed a calculus (the lambda calculus) a language for writing down what we now call computable functions. At the same time Gerhard Gentzen was developing natural deduction; a language for writing down formal proofs. Both these languages were conceived as tools for exploring the foundations of mathematics, with the advent of computer science, representations of computable functions became a more practical concern. Lambda calculus was the inspiration for Lisp, the first functional programming language. Meanwhile, William Alvin Howard discovered a link between logic and functional programming: natural deduction proofs could be seen themselves as terms of the lambda calculus. In other words, a proof is a kind of computation, and a very well-behaved kind at that. This observation, known as the Curry-Howard correspondence, has led and continues to lead to an enormous body of theoretical and practical work in computer science and logic.

Goals of the project: Computer science has developed much since its inception, and we no longer think of computer problems as simply calculating a function, but more as interacting with a complex, varying environment comprised of users and other programs. The lambda calculus is unsuited for representing such programs, and other calculi (called process calculi) are used instead to reason about them. These calculi lack the elegant theoretic underpinning enjoyed by the lambda calculus. On the other hand, natural deduction fails to faithfully represent a fundamental reasoning mode: the ability to recognise that a statement is the same as its double negation. This property of logic is called “Duality”. A much better calculus for reasoning under duality, called the sequent calculus, was also developed by Gentzen, but its computational meaning has been difficult to discern.

This project aims to extend the proofs as programs correspondence by representing proofs using duality within a new, theoretically inspired language of processes.

This project ended in February 2013.

Research staff: R. McKinley

Financial support: Swiss National Science Foundation

Computational Structure of Higher-order sequent systems (Ambizione Follow-Up)

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.

Research staff: R. McKinley

Financial support: Swiss National Science Foundation

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.

Research staff: R. Kuznets

Financial support: Swiss National Science Foundation

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

- S. Eberhard: Weak Applicative Theories, Truth, and Computational Complexity
- R. Goetschi: On the Realization and Classification of Justification Logics

5.5 Bachelor's Theses

- Ö. Altin: A Comparison of Different Logics of Access Control
- A. Karper: A Programming Language Oriented Approach to Computability

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

- Research Council Member of the Swiss National Science Foundation (until September 2012)
- Vice President of the Fachausschuss Karrieren of the Swiss National Science Foundation (until September 2012)
- Member of the Steering Committee 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

- PC Member (Co-Chair) of the Humboldt-Kolleg Proof
- Member of the Kantonale Maturitätskommission
- Expert for Maturitätsprüfungen Mathematik und Informatik

Roman Kuznets

- PC Member of Symposium on Logical Foundations of Computer Science 2013
- PC Member of Symposium on Advances in Proof Theory 2013

Dieter Probst

- Expert for Maturitätsprüfungen Mathematik und Informatik
- PC Member (Co-Chair) of the Humboldt-Kolleg Proof

Thomas Strahm

- President of the Swiss Society for Logic and Philosophy of Science
- Expert for Maturitätsprüfungen Mathematik und Informatik

Thomas Studer

- Secretary of the Swiss Society for Logic and Philosophy of Science
- Swiss representative in the International Union of History and Philosophy of Science
- Expert for Maturitätsprüfungen Mathematik und Informatik

Organized Events

Gerhard Jäger

- Together with G. Metcalfe. CUSO Winter School in Mathematics and Computer Science "Proof and computation", Les Diablerets, January 2013.

Thomas Strahm

- Together with G. Sommaruga. Turing under Discussion, ETH Zurich, October 2013.

5.7 Publications

- Sergei Artemov and Roman Kuznets. Logical Omniscience As Infeasibility. *Annals of Pure and Applied Logic*, To appear. 2013.
- Kai Brännler and Thomas Studer. Syntactic cut-elimination for a fragment of the modal μ -calculus. *Annals of Pure and Applied Logic*, 163(12):1838–1853, 2012.
- Samuel Bucheli, Roman Kuznets, and Thomas Studer. Decidability for Justification Logics Revisited. In G. Bezhanishvili, S. Löbner, V. Marra, and F. Richter, editors, *Logic, Language, and Computation, 9th International Tbilisi Symposium on Logic, Language, and Computation, Tbilisi 2011, Kutaisi, Georgia, September 26-30, 2011, Revised Selected Papers*, volume 7758 of LNCS, pages 166–181. Springer, 2013.
- Sebastian Eberhard. Applicative theories for logarithmic complexity classes. Submitted.
- Sebastian Eberhard. A feasible theory of truth over combinatory logic. Submitted.
- Sebastian Eberhard and Thomas Strahm. Unfolding feasible arithmetic and weak truth. In T. Achourioti, H. Galinon, K. Fujimoto, and J. Martínez-Fernández, editors, *Axiomatic Theories of Truth*, Logic, Epistemology and the Unity of Science. Springer. To appear.
- Gerhard Jäger. Operational closure and stability. *Annals of Pure and Applied Logic*, 164(78):813 – 821, 2013.
- Roman Kuznets and Thomas Studer. Update as Evidence: Belief Expansion. In S. Artemov and A. Nerode, editors, *Logical Foundations of Computer Science, International Symposium, LFCS 2013, San Diego, CA, USA, January 6–8, 2013, Proceedings*, volume 7734 of *Lecture Notes in Computer Science*, pages 266–279. Springer, 2013.
- Richard McKinley. Canonical proof nets for classical logic. *Annals of Pure and Applied Logic*, 164(6):702–732, 2013.
- Richard McKinley. Proof nets for herbrand’s theorem. *ACM Trans. Comput. Log.*, 14(1):5, 2013.

- Kentaro Sato. Full and hat inductive definitions are equivalent in NBG. Submitted.
- Kentaro Sato. One of the simplest applications of forcing. Submitted.
- Kentaro Sato. Relative predicativity and dependent recursion in second-order set theory and higher order theories. Submitted.
- Yury Savateev. Proof internalization for generalized frege systems for classical logic. *Annals of Pure and Applied Logic*. To appear.
- Yury Savateev. Sequent calculus for justifications. *Journal of Logic and Computation*. To appear.
- Thomas Studer. A Universal Approach to Guarantee Data Privacy. *Logica Universalis*, 7(2):195–209, 2013.
- Thomas Studer. Decidability for some justification logics with negative introspection. *The Journal of Symbolic Logic*, 78(2):388–402, 2013.

6 Software Composition Group

6.1 Personnel

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*with financial support from a third party

6.2 Overview

The number, complexity and importance of the software systems on which society relies is ever increasing. Building and evolving these systems is a challenge which must be addressed with the right tools, be they programming languages, development environments, or reflective analysis frameworks. The Software Composition Group carries out research that aims

to strengthen and diversify the tools that software developers use when engineering software. We are particularly interested in approaches which 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. Unfortunately, mainstream integrated development environments (IDEs) focus on low-level programming tasks rather than on supporting program comprehension and decision-making during software evolution. Analysis tools, on the other hand, usually have a narrow scope of applicability.

This project aims to enable software developers to quickly and effectively analyze complex software systems with the help of tools to rapidly construct, query and manipulate software models. We refer to this goal as agile software assessment, since developers are under constant pressure to assess the state of the system at hand in a timely fashion in order to carry out development and evolution tasks. 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 related research tracks. Since the beginning of the year we have been working in the following directions:

- **Meta-Tooling.** Developers ask detailed and domain-specific questions about the software systems they are developing and maintaining. Specialized tools are needed to effectively answer these specific questions. To enable easily customizable developer tools we are working on a meta-tooling environment that allows the rapid composition of software development and assessment tools. As a first technological challenge we are developing a so-called *moldable* debugger which can be adapted to different debugging contexts. Furthermore, we are working towards an infrastructure that will automatically customize the debugging process based on the meta-annotations provided by the author of a given library or third-party system.
- **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 are developing parsing techniques that allow us to quickly construct such models by using reusable and composable parsers targeting common programming language classes, user-guided parser refinement using island grammars, and 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).

- **Large-Scale Software Analysis.** Complex software systems generally exist within even larger software ecosystems consisting of older versions of the systems, variants, and other client applications of the system or its parts. Being able to query and mine this large resource of information can improve tool support for developers and improve software reliability. We are working here in two directions at the moment: (1) we are modeling the evolution and usage of APIs in an entire ecosystem to facilitate the construction of tools for program understanding and forward development, which are particularly needed in dynamically-typed programming languages; and, (2) we are setting up an infrastructure which will allow us, based on mining past occurrences of bug fixes, to detect bugs in source code during development time.
- **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 propose a more empirical approach. We conducted interviews and surveys with software architects, we categorized and ranked their needs, and based on these results we will propose techniques to monitor architectural evolution and integrate monitoring into the development processes and environments.

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>

Synchronizing Models and Code

Successful software systems are under constant pressure to adapt to changing circumstances and requirements else they become obsolete. Adaptations may need to take effect over extreme variations in time scale and granularity: from fine-grained, short-term adaptations to resources and run-time contexts to long-term evolution of software that requires adaptation at the architectural level. In each of these cases we are faced with the challenge of keeping the source code and the running software synchronized with changes in the higher-level domain and requirement models.

This synchronization, is often difficult because current languages and run-time systems assume global consistency. This project explores various ways of synchronizing software source code with implicit application domain. During the last year we have successfully finalized the work in the following research tracks:

- **Dynamic meta-objects:** In this track we have explored the use of dynamic meta-objects to manipulate and adapt high-level representations of running software systems, thus providing an infrastructure for keeping applications in sync with their meta-level representation. We have developed Bifröst, an object-centric approach to reflection. Bifröst models meta-objects explicitly, exclusively targeting objects as the sole reflective unit of change. This model provides a unification of various approaches to reflection. We have validated Bifröst by demonstrating how it is well-suited to implement a number of key reflective applications in the domain of software development.
- **First-class, active contexts:** Software updates must be installed dynamically to avoid costly maintenance downtimes. We have developed an approach to dynamic updates called Theseus that structures objects and classes from distinct versions into distinct first-class contexts. Contexts prevent inconsistent execution of code from mixed versions. The update of the software is incremental and first-class contexts control the progressive migration from one version of the

software to the next. We have implemented prototypes of our approach for Smalltalk and Java. This work received the EAPLS best paper award at TOOLS 2012.

- **Linked, active source code:** Current software development tools fail to address synchronization of code shared between independent systems (medium-grained and medium-term as well as long-term adaptations). As software evolves, libraries, components and even fragments are frequently duplicated, adapted and specialized across software projects. We have developed a distributed infrastructure based on Hadoop together with a family of performant techniques for the detection of inter-system source code duplication. We have validated our techniques on all Java open-source projects indexed by the Ohloh online directory.

Research staff: All members of the research group.

Duration: Oct. 2010 – Sept. 2012

Financial support: Swiss National Science Foundation,
Project #200020-131827

For further details, please consult:

<http://scg.unibe.ch/research/snf10>

6.4 Ph.D. Theses

- Fabrizio Perin. *Reverse Engineering Heterogeneous Applications*. Phd thesis, University of Bern, November 2012. Available from: <http://scg.unibe.ch/archive/phd/perin-phd.pdf>.
- Jorge Ressia. *Object-Centric Reflection*. Phd thesis, University of Bern, October 2012. Available from: <http://scg.unibe.ch/archive/phd/ressia-phd.pdf>.

6.5 Bachelor's Theses and Computer Science Projects

- Manuel Leuenberger. Talented streams — objects composed from features. Bachelor's thesis, University of Bern, February 2013. Available from: <http://scg.unibe.ch/archive/projects/Leue13a-TalentedStreams.pdf>.

- Manuel Leuenberger. Talented streams implementation. Bachelor's thesis, supplementary documentation, University of Bern, February 2013. Available from: <http://scg.unibe.ch/archive/projects/Leue13b-TalentedStreamsImpl.pdf>.
- Pascal Maerki. Flexible dynamic ownership in Smalltalk. Bachelor's thesis, University of Bern, February 2013. Available from: <http://scg.unibe.ch/archive/projects/Maer13a-DynamicOwnership.pdf>.

6.6 Awards

- Dahl-Nygaard 2013 Senior Prize for contributions to the field of Object-Oriented Programming for Oscar Nierstrasz
- European Smalltalk User Group 2012 Technology Innovation Award (1st prize) for Object-Centric Debugging

6.7 Further Activities

Invited Talks

Oscar Nierstrasz

- Keynote Speaker at BENEVOL 2012 (11th BELgian-NEtherlands software eVOLution symposium — Delft, The Netherlands, Dec 3-4, 2012)
- Keynote Speaker at Karlsruher Entwicklertag 2013 (Karlsruhe, Germany, June 5-7, 2013)
- Keynote Speaker and PC Member of COOMPL 2013 (Second International Workshop on Combined Object-Oriented Modeling and Programming Languages, colocated with ECOOP 2013 — Montpellier, France, July 1, 2013)
- Keynote Speaker at ECOOP 2013 (27th European Conference on Object-Oriented Programming — Montpellier, France, July 1-5, 2013)

Editorial Boards and Steering Committees

Oscar Nierstrasz

- JOT — Journal of Object Technology (Editor-in-Chief, 2010-2013)
- SNF — Swiss National Science Foundation (Member of the Research Council)
- Springer LNCS – SL2 – Programming Techniques and Software Engineering (Series Editor, 2004-2012)
- SIRA – Swiss Informatics Research Association (Board Member)
- SI – Swiss Informatics Society (Board Member)
- AITO – Association Internationale pour les Technologies Objets (Member)
- CHOOSE – Swiss Group for Object-Oriented Systems and Environments (Board Member)
- ESEC – European Software Engineering Conference (Steering Committee Member)
- MoDELS – International Conference on Model Driven Engineering Languages and Systems (Steering Committee Member)
- SC – Software Composition Symposium (Steering Committee Member)
- SATToSE – Seminar Series on Advanced Techniques & Tools for Software Evolution (Steering Committee Member)
- Moose Association (Board Member)

Mircea Lungu

- CHOOSE – Swiss Group for Object-Oriented Systems and Environments (Board Member, Publicity Chair)
- SI – Swiss Informatics Society (Member)

Program Committees

Oscar Nierstrasz

- PC Member of ICSM 2012 (28th IEEE International Conference on Software Maintenance — Riva del Garda, Italy, Sept 23-30, 2012)
- PC Member of SLE 2012 Doctoral Symposium (At Software Language Engineering — Dresden, Germany, Sept 25, 2012)
- PC Member of GPCE 2012 (Generative Programming and Component Engineering — Dresden, Germany, Sept 26-28, 2012)
- PC Member of XM 2012 (Extreme Modeling Workshop, colocated with Models 2012 — Innsbruck, Austria, Oct 1, 2012)
- PC Member of SE 2013 (Software Engineering 2013 — Aachen, Germany, Feb 26 - March 1, 2013)
- Co-organizer of PharoConf — MooseDay — 2013 (Pharo Conference — Bern, Switzerland, April 2-4 2013)
- PC Member of LIVE 2013 (First International Workshop on Live Programming, colocated with ICSE 2013 — San Francisco, USA, May 19, 2013)
- PC Member of ICSE NIER 2013 (New Ideas and Emerging Results — San Francisco, USA, May 18-26 2013)
- PC Member of XP 2013 (14th International Conference on Agile Software Development — Vienna, Austria, June 3-7, 2013)
- PC Member of SC 2013 (International Conference on Software Composition 2013 — Budapest, Hungary, June 19, 2013)
- PC Member of WASDeTT-4 2013 (International Workshop on Advanced/Academic Software Development Tools and Techniques, colocated with ECOOP 2013 — Montpellier, France, July 1, 2013)
- Co-organizer of SATToSE 2013 (6th Seminar on Advanced Techniques & Tools for Software Evolution — Bern, Switzerland, July 8-10, 2013)
- PC Member of ICSM 2013 (29th International Conference on Software Maintenance — Eindhoven, The Netherlands, Sept 22-28, 2013)

Mircea Lungu

- Co-organizer of WEA 2013 (1st International Workshop on Software Ecosystem Architectures — Saint Petersburg, Russia, August 19)
- Co-organizer of PharoConf MooseDay 2013 (Pharo Conference Bern, Switzerland, April 2-4 2013)
- PC Member of OOPSLA 2013 (ACM SIGPLAN Conference on Object-Oriented Programming, Systems, Languages, and Applications — Indianapolis, USA, October 2013)
- PC Member of WASDeTT 2013 (International Workshop on Advanced/Academic Software Development Tools and Techniques — July 1st, 2013, in Montpellier, France)
- PC Member of CSMR 2013 (17th European Conference on Software Maintenance and Reengineering — March 58, 2013, Genova, Italy)
- PC Member of ICSM TD Track (29th IEEE International Conference on Software Maintenance — Eindhoven, The Netherlands, September 2013)
- PC Member of WCRE 2013 (20th International Working Conference on Reverse Engineering — Koblenz-Landau, Germany, October 2013)

Andrea Caracciolo

- PC Member of CSMR 2013 (17th European Conference on Software Maintenance and Reengineering — March 5 2013, Genova, Italy)

Reviewing Activities**Oscar Nierstrasz**

- FWO (Research Foundation Flanders)
- Elsevier Science of Computer Programming
- Empirical Software Engineering

Mircea Lungu

- Journal of Systems and Software (JSS), Elsevier

- Science of Computer Programming (SCP), Elsevier

Niko Schwarz

- ICSM ERA, ECOOP AEC

Erwann Wernli

- OOPSLA 2013, ICSE NIER 2013, XP 2013

Haidar Osman

- OOPSLA 2013, ICSM 2013, WCRE 2013

Andrea Caracciolo

- OOPSLA 2013, ICSM 2013, LIVE 2013, ICSE NIER 2013, SC 2013, SE 2013, WASDeTT-4 2013, XP 2013

Andrei Chis

- OOPSLA 2013, CSMR 2013, ICSE NIER 2013, XP 2013, SC 2013, LIVE 2013, WASDeTT-4 2013, ICSM 2013

Jan Kurs

- OOPSLA 2013, ICSM 2013, XP 2013, ICSE NIER 2013

Boris Spasojevic

- OOPSLA 2013, WCRE 2013, WASDeTT 2013

6.8 Publications

Journal Papers

- Amir Aryani, Fabrizio Perin, Mircea Lungu, Abdun Naser Mahmood, and Oscar Nierstrasz. Predicting dependences using domain-based coupling. *Journal of Software: Evolution and Process*, pages 1–27, 2013. Available from: <http://scg.unibe.ch/archive/papers/Arya13aJSME.pdf>, doi:10.1002/smr.1598.
- Lile Hattori, Marco D’Ambros, Michele Lanza, and Mircea Lungu. Answering software evolution questions: An empirical evaluation. *Information and Software Technology*, 55(4):755 – 775, jan 2013. Available from: <http://scg.unibe.ch/archive/papers/Hatt13a.pdf>, doi:10.1016/j.infsof.2012.09.001.

- Erwann Wernli, Mircea Lungu, and Oscar Nierstrasz. Incremental dynamic updates with first-class contexts. *Journal of Object Technology*, 12(3):1:1–27, August 2013. Available from: <http://scg.unibe.ch/archive/Wern13a.pdf>, doi:10.5381/jot.2013.12.3.a1.

Conference Papers

- Romain Robbes, Mircea Lungu, and David Roethlisberger. How do developers react to API deprecation? The case of a Smalltalk ecosystem. In *Proceedings of the 20th International Symposium on the Foundations of Software Engineering (FSE'12)*, pages 56:1 – 56:11, 2012. Available from: <http://scg.unibe.ch/archive/papers/Rob12aAPIDeprecations.pdf>, doi:10.1145/2393596.2393662.
- Jan Vraný, Jan Kurs, Marcel Hlopko, and Claus Gittinger. On the integration of smalltalk and java. In *Proceedings of the 4rd International Workshop on Smalltalk Technologies (IWST'12)*. ACM, 2012. Available from: <http://scg.unibe.ch/archive/papers/Vran12a.pdf>.
- Erwann Wernli, Pascal Maerki, and Oscar Nierstrasz. Ownership, filters and crossing handlers: flexible ownership in dynamic languages. In *Proceedings of the 8th symposium on Dynamic languages, DLS '12*, pages 83–94, New York, NY, USA, 2012. ACM. Available from: <http://scg.unibe.ch/archive/papers/Wern12c.pdf>, doi:10.1145/2384577.2384589.

Book Chapters

- Rogério Lemos, Holger Giese, Hausi Müller, Mary Shaw, Jesper Andersson, Marin Litoiu, Bradley Schmerl, Gabriel Tamura, Norha Villegas, Thomas Vogel, Danny Weyns, Luciano Baresi, Basil Becker, Nelly Bencomo, Yuriy Brun, Bojan Cukic, Ron Desmarais, Schahram Dustdar, Gregor Engels, Kurt Geihs, Karl Göschka, Alessandra Gorla, Vincenzo Grassi, Paola Inverardi, Gabor Karsai, Jeff Kramer, Antónia Lopes, Jeff Magee, Sam Malek, Serge Mankovskii, Raffaella Mirandola, John Mylopoulos, Oscar Nierstrasz, Mauro Pezzè, Christian Prehofer, Wilhelm Schäfer, Rick Schlichting, Dennis Smith, João Pedro Sousa, Ladan Tahvildari, Kenny Wong, and Jochen Wutke. Software engineering for self-adaptive systems: A second research roadmap. In Rogério Lemos, Holger Giese, Hausi Müller,

and Mary Shaw, editors, *Software Engineering for Self-Adaptive Systems II*, volume 7475 of *Lecture Notes in Computer Science*, pages 1–32. Springer Berlin Heidelberg, 2013. Available from: http://dx.doi.org/10.1007/978-3-642-35813-5_1, doi:10.1007/978-3-642-35813-5_1.

7 Computer Graphics Group

7.1 Personnel

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* with financial support from a third party

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, photoprotection, 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

Financial support: Swiss National Science Foundation, Sinergia program, grant nr. 132430

Multi-Dimensional Sampling for Image Synthesis

In this project we address research challenges that are still limiting the capabilities of image synthesis technology. In particular, we are developing more efficient algorithms for image synthesis by studying this problem from the perspective of multidimensional sampling.

Images represent distributions of light. While light in the physical world can be interpreted as a continuous quantity, it needs to be represented discretely for computer processing. This leads to the problem of sampling,

which is at the core of this project. Computer graphics deals with various forms of sampled light to achieve realistic and efficient image synthesis. This includes, for example, the notion of light paths that store the amount of light transmitted along paths including several reflections at surfaces; the concept of transport operators that describe how light is passed between pairs of surface points; or radiance distributions that represent the light that is reflected in each direction at each surface point. All three concepts represent multidimensional functions, which means that we need multiple parameters to identify each sample. Light paths are identified by their sequence of intersection points with surfaces. The dimensionality of a light path depends on the number of intersections, but is potentially unbounded. A sample of a transport operator can be identified by a pair of surface points. A surface point is given by two parameters, hence a pair of points is four-dimensional. Radiance distributions are functions of surface locations and directions, therefore they are also four-dimensional. This is to explain why multidimensional sampling plays a central role in image synthesis. Our research in this project focuses on two areas, realistic image synthesis and light transport for interactive rendering, which at their core involve multidimensional sampling issues. We analyse both topics from the perspective of multidimensional sampling, identify specific research challenges, and develop more efficient and flexible algorithms. Improvements of these core algorithms for image synthesis will find broad applications in computer graphics. They will reduce the resources required for realistic image synthesis, and enable more natural and effective interactive applications.

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

Financial support: Swiss National Science Foundation, grant nr. 127166

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 minimize 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

Financial support: Swiss National Science Foundation, grant nr. 143886

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: Gregor Budweiser, Matthias Zwicker

Financial support: Commission for Technology and Innovation CTI, grants nr. 12704.1 PFES-ES and 15592.1 PFES-ES

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 significantly 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

Video Stabilization for Hand-Held Cameras

Video footage produced using hand-held cameras often suffers from shaky camera motion. This is most common in material captured casually with small devices such as cell phones or compact cameras. Often, watching such videos can be a rather uncomfortable experience because of excessive camera shake. While it is possible to avoid such problems during

video capture using professional equipment such as steadicam stabilizing systems or sophisticated rigs, these are usually too expensive and too complex to use for casual videographers.

The goal of this project is to develop post-processing algorithms that automatically achieve a smooth camera motion after the fact. This is a challenging problem because it involves recovering the actual camera motion in three-dimensional space, obtaining a desired virtual camera motion that is smooth but still similar to the actual motion, and rendering an output video sequence from the perspective of the virtual camera.

Conventional approaches often try to extract information from static objects visible in the video data. The information gathered from static objects makes it possible to recover camera motion using standard techniques. In practice it is quite common, however, that input videos do not contain enough static objects for this to work. The goal of our approach, therefore, is to generalize such techniques to be able to process data that does not allow the extraction of information from static objects.

Research staff: Daniel Donatsch, Matthias Zwicker

7.4 Master's Thesis

- Peter Bertholet, Discrete exterior calculus - theory and applications (December 2012)

7.5 Bachelor's Theses

- Simon Baumann, Developing a rendering engine for Android devices (September 2012)
- Julian Schelker, Nonlinear disparity mapping for stereoscopic 3D (August 2012)
- Marcel Zingg, Analysis of subspace video stabilization (March 2013)

7.6 Further Activities

Editorial Boards

Matthias Zwicker

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

Conference Program Committees

Matthias Zwicker

- IEEE International Workshop on Computational Cameras and Displays, June 28, 2013, Portland, Oregon
- Eurographics Symposium on Rendering, June 19 – 21, 2013, Zaragoza, Spain
- Computer Graphics International, June 12 – 14, 2013, Hannover, Germany
- ACM SIGGRAPH Symposium on Interactive 3D Graphics and Games (I3D), March 21 – 23, 2013, Lake Buena Vista, Florida
- Pacific Graphics, October 7 – 9, 2013, Singapore
- Vision, Modeling, and Visualization, September 11 – 13, 2013, Lugano, Switzerland

Reviewing Activities

Claude Knaus

- ACM SIGGRAPH conference

Fabrice Rousselle

- ACM SIGGRAPH conference
- ACM Transactions on Graphics
- Pacific Graphics conference

Matthias Zwicker

- Swiss National Science Foundation
- European Research Council

- Hasler Stiftung
- ACM Transactions on Graphics
- IEEE Computer Graphics and Applications
- IEEE Transactions on Visualization and Computer Graphics
- IEEE Transactions on Circuits and Systems for Video Technology
- 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
- Eurographics 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
- Board 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

7.7 Publications

Journal Publications

- Fabrice Rousselle, Claude Knaus, Matthias Zwicker: Adaptive Rendering with Non-Local Means Filtering, ACM Transactions on Graphics (Proc. of SIGGRAPH Asia), 2012.
- Milinkovitch M.C., Manukyan L., Debry A., Di-Po N., Martin S., Singh D., Lambert D., Zwicker M.: Crocodile Head Scales Are Not Developmental Units But Emerge from Physical Cracking, Science, 2012.
- Fabrice Rousselle, Marco Manzi, Matthias Zwicker: Robust Denoising using Feature and Color Information, Computer Graphics Forum (Proc. of Pacific Graphics), *to appear*, 2013.

Refereed Conference Proceedings

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

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 Planning Board
Th. Strahm: Member of the Finance Board
Th. Studer: Member of the Planning 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