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Overview on Blockchain Work Performed at the CSG@Ifi of the UZH

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***Abstract*—Although blockchains as well as distributed ledgers are very often referred to as "Blockchain or Distributed Ledger Technology", they only denote an Abstract Data Type (ADT), which is defined as a linked list of data elements, each of which being linked by cryptographically constructed links — and that is the "modern" approach [87]. Thus, the quite exhaustive public perception of such basic computer science ADTs — without naming them that way — has lead to a hype of applications, which may or may not require a fully decentralized system's architecture for potentially non-trusted stakeholders at first.**
This short technical overview on selected blockchain work performed at the CSG@IfI of the University of Zürich UZH does briefly introduce blockchains and distributed ledges with respect to their key characteristics, does strive along a set of extended objectives, and finally does provide a short, in-depth overview of a set of selected, but different fields, applications, and technology developments related to Bitcoins and blockchains worked at since early 2014 until basically the upcoming end of 2018. Expected work for 2019 is already embedded in the outlook as far as related student theses already have started.

***Index Terms*—Blockchain, Bitcoin, Internet-of-Things (IoT), Temperature Measurements, Tracking and Tracing, Distributed Denial-of-Service (DDoS), Proof-of-Stake (PoS), Scalability, Agriculture Applications, eVoting, Publishing, International Coin Offering (ICO), Education, Coinblesk, BC4CC, BAZO, BloSS, PuRSCA, modum.io, ScienceMatters, and ICOnator.**

I. Blockchains and Distributed Ledgers

While the pure distributed ledger typically refers to a database, which is distributed remotely across many different machines around the globe — each of these machines is typically called "node" —, all replicate an identical copy of this ledger. Each participating node of a respective distributed ledger network updates this ledger by either contributing to it or listening to other nodes updating it, thus, no central authority is responsible for achieving this coherent view of the ledger. Therefore, an appropriate consensus mechanism is needed to work in such a decentralized setting.

Additionally, blockchains can be considered as defining one dedicated form of a distributed ledger by applying digitally secured links between blocks. However, since not all distributed ledgers may utilize a chain of independent blocks (they may be organized in traditional data base records otherwise), only a real blockchain supports a secure and distributed consensus mechanism for any non-trusted stakeholder willing to participate. Thus, the underlying Abstract Data Type (ADT) is defined as a linked list of data elements (these blocks may contain one or many transactions), each of which being linked by cryptographically constructed links, for which the respective cryptographic algorithms enables the construction of very hard to forge links by hash values based on previous blocks content.

Such a pure blockchain is distributed across and managed fully by an underlying peer-to-peer network and a related protocol to reach a fully distributed consensus. Thus, a pure blockchain exists without any centralized authority or server managing it, it allows for any stakeholder to participate, and its data quality can be maintained by a widespread ledger replication across any network and computational trust.

This type of purity is termed "public" resulting in a "public blockchain" — in contrast to a "private blockchain" (sometimes referred to as a "permissioned blockchain" or a "consortium blockchain"), where nodes performing the consensus algorithm have to be known and, thus, are to trusted and in which no unknown stakeholder can participarte as is.

Thus, the key design requirements set forth by the early designers of the Bitcoin blockchain (a "public blockchain" in a dedicated application set-up, basically the Grandfather blockchain) was (a) to ensure immutability of the data persisted, (b) to avoid central (thus trusted) checking needs for a double spending attack, and (c) to enable the participation of any individual without any initial trust requirements, at the cost of (1) an extremely hard to forge or counterfeit cryptographic linking of all transactions into the Bitcoin distributed ledger and (2) a compute-intense, thus, energy-demanding consensus mechanism. As of today, any smallest change of these requirements (or even parts thereof) or a minimization of costs will lead to a dramatic change of either the set of requirements (or flavors thereof) or of these costs and vice versa.

II. Extended Objectives

The CSG@IfI is since early 2014 on the research and prototyping path (combined with various evaluations) to shed light and in-depth standing on core technical characteristics of blockchains (*e.g.*, scalability and IoT-related capabilities, security and verifiability, or performance and feasibility), while indicating the evolutionary approach taken and putting emphasis on the fact that the non-trusted stakeholder's assumption combined with a full distribution of all data elements was reached by investing heavily into cryptographic means — determining the Bitcoin Blockchain as the first of its kind —, which is especially reflected in a very high computational demand.

Additionally, the work performed at CSG raises the awareness that such distributed ledgers assume important prerequisites, which result in certain effects and impacts from which different applications can benefit [74], but at a cost to be named explicitly, too. Other applications may not see any ben-

eficial operation, since core assumptions are neither met nor useful to be made.

While selected applications with the CSG — as outlined below — include amongst others Coinblesk [7], ColdChain [8], BloSS [71], [73], PuRSCA [68], and eVoting [58], their respective systems and main achievements are outlined briefly as well as their dedicated performance view is investigated and discussed on a higher level. Typically, the trade-off between centralized and decentralized approaches and the balance of these trade-off decisions needs a much closer look at, which will determine additional future research steps as well. Due to sustainability as well as scalability concerns observed, many projections of the usefulness of a general blockchain applicability remain today slightly unrealistic or even compromise the full decentralization again.

As a consequence, the work at CSG will always address selected and major challenges of blockchains as well as measurable risks of such an approach as of today and will write new observations and trends as well as important measurable facets of functionality into the open book of new requirements to be carefully looked into.

III. CSG@IFI BLOCKCHAIN WORK OVERVIEW

The following subsections describe the set of blockchain-related applications and systems developments at the CSG as well as investigations combined with teaching, tutorials, and publications as well as student theses provided so far. This overview is not intended to replace each and every of these theses and papers written, however, they are brought together to determine the wider range of dependent and interrelated subjects. Thus, for many additional and necessary technical details refer to the provided references of the respective publication as indicated.

A. Bitcoin Application "Coinblesk"

The work on blockchains and especially bitcoins started within the CSG in early 2014 when Bitcoins had been used only rarely and the public perception was still at a low level. The development of a Mobile Bitcoin Payment Solution (MBPS) [59] was continued in late 2014 while naming the project ***CoinBlesk***, an application being able to transfer wirelessly and fast Bitcoins [7], [18], which saw two public trials performed at the UZH cafeteria in 2014 [26], which was presented at the Zürich-based Scientifica in 2015 [19], and which was demonstrated at the German International Computer and Information Technology Fair CeBIT 2016 [21], [13]. As a researcher, the development of this app — once listed in Google's Play Store — was discontinued due to new and different fascinating blockchain aspects to address.

The first full version of the CoinBlesk approach "A Mobile NFC Bitcoin Payment System" appeared in 2015 [92][1], security concerns of contact payment systems had been analyzed in [40], and a modern user interface have been added in 2016 [41]. Protocol improvements have been performed within Coinblesk, such that a minimization of communication delays was reached [26], a decentralization of many functions resulting in Coinblesk 2.0 were implemented [1] (this version was demonstrated publicly at the industrial CeBIT Fair 2016), and a transaction fee reduction for Coinblesk was designed and integrated in 2017 [86]. Final steps on Coinblesk included Coinblesk's UX improvements as well as an integration of federations and payments [81].

B. Blockchain-based Temperature Measurements, the UZH Start-up modum.io, and Blockchain Interoperability

Another step taken on the application of blockchains to commercial services resulted in work on utilizing the Ethereum blockchain within the transport and logistics domain, especially for the measurement of medical drugs, which need to be 100% temperature-controlled within the transport from EU and neighboring countries since 2016. Thus, the ***UZH start-up modum.io*** [60] was prepared in late 2015, formally founded mid 2016 as an AG[2], and it raised in September 2017 in an ICO 13.5 million USD [26]. Since then Burkhard Stiller runs as a Senior Advisor to modum.io, Thomas Bocek (a former CSG PostDoc) is a Member of the Board to modum.io, and a number of former CSG students now work for modum.io, especially Marc Heimgartner [35], [36], Andreas Knecht [44], [45], [46], Sebastian Stephan [86], Tim Strasser [90], and Sacha Uhlmann [91].

The underlying architecture for the former ***ColdChain*** project was developed by CSG in terms of a set of different student theses utilizing blockchains (especially the Ethereum one) to persist temperature measurements, which are related to a transport, a certain number of medical drugs, a dedicated driver/truck of a logistics operator, and health authorities [8]. The securing of goods distribution was developed with Smart Contracts (SC) and sensors [44], [90], looked into the reduction of counterfeit products by applying blockchains [91], and saw improvements on security and usability of this goods distribution system [36]. Furthermore, improvements of IoT devices' stability and its Android applications were performed [45], a redesign and improvements had been applied to the blockchain system for temperature monitoring [35], and a security analysis of the applied IoT-enabled hardware temperature logger was performed [46].

This work is now being extended by modum.io and complemented with a tamper-proof sensor and additional functionality. Therefore, these sensor-related activities can be considered as a part of the Internet-of-Things (IoT) area, here coupled with a dedicated use case to well-determined parameters. Additionally, a subsequent KTI (now Innosuisse) project "***Blockchains for Coldchains (BC4CC)***" [6] between CSG and modum.io works on the development of a blockchain-agnostic architecture, which foresees an Open API (Application Programming Interface) for blockchain applications, which shall foster interoperability of applications on top of different blockchains [34], [79], [94]. Respective extensions cover the policy-based blockchain framework for a cold-chain temperature monitoring [49].

C. General Blockchain-related Overviews, Analysis, as well as Teaching and Education

In the meantime ***blockchain overview papers*** had been written as well as dedicated technical papers on selected aspects, which are based especially on Coinblesk as well as ColdChain experiences collected until today.

The work on "Smart Contracts — Blockchains in the Wings" [10] started late 2016 (and was published in early

[1]This Bachelor Thesis received in 2015 the best Bachelor Thesis Award of KuVS, the German-speaking Communications and Distributed Systems expert group of the German Society for Computer Science (GI) [20].

[2]The core technical idea prepared by the CSG for modum.io was awarded at the "ETH Entrepreneur Club" the 2nd place in May 2016 [22] and won the 1st place at the "Kickstart Accelerator" in November 2016 in the "Future Emerging Technologies (FET)" vertical, while being considered the best out of originally submitted 850+ applications earlier in 2016 [23].

2018 as a book chapter) to indicate the by then main problems and concerns contrasted to the Smart Contract advantages of blockchains. It is partially based on the White Paper "Blockchains and Smart Contracts — A Valuable Alternative for Distributed Data Bases?", which appeared in the FUTURIUM blog of the European Commission's sites at the end of 2016 [87].

The ***analysis*** of the "Use of Blockchains: Application-Driven Analysis of Applicability" [74] indicates much more recent work on an overview of main blockchain application areas by providing examples and by discussing from the technical perspective on how and which conditions the use of blockchains can be useful for a successful use case.

Furthermore, ***teaching and course work (tutorials)*** had been established in the blockchain domain, especially within the "Blockchains and Overlay Networks" course — [88] refers to the 2018 instance, earlier ones covered blockchain details already since 2015 —, the one day content on "Blockchains and Clouds" of the Certified Advanced Studies (CAS) on "Big Data and Machine Learning" [89], and the tutorials on "Programming Smart Contracts" [9], on "Blockchain and Smart Contracts – From Theory to Practice" [69], and on "Information Management in the Blockchain Era: Challenges and Opportunities" [76].

The list of blockchain-related ***keynotes, invited presentations, or panels*** given by CSG members are found within the references section, see item [96] to [127].

D. The Research Cryptocurrency "Bazo"

An additional area of design and prototyping work in the context of blockchains addresses the development of a new ***research cryptocurrency termed Bazo***, which is now currently being used to investigate further blockchain scalability aspects and an integration into payment systems. Initially designed in late 2017 [84], Bazo covered the main functionality of a cryptocurrency, since the intended use case was addressing a royalty card application — in collaboration with the Aduno Group, Switzerland, a Swiss cashless payment and transactions service provider —, which could be used across multiple participating companies and their customers. Due to the inherent sustainability concerns with the Proof-of-Work (PoW)-based consensus mechanism of blockchains, investigations revealed in early 2018 that a Proof-of-Stake (PoS) approach can be done and was integrated into Bazo as outlined in [5]. In addition, a mobile light client for Bazo was designed and prototyped [16]. To enable the use of Bazo in an easy-to-use manner, a Progressive Web App (PWA)-based mobile wallet was designed [93] and, additionally, the respective Bazo blockchain explorer was introduced [11].

Currently, the application of Bazo to the IoT use case happens in [3], an evaluation of an improvement of Bazo's scalability is performed in [51], and the design and implementation of a hierarchical payment system with BAZO Blockchain is under its way [14].

E. A DDoS Mitigation and Defense via BloSS

Furthermore, the work on security-related, blockchain-supported applications on a "***Cooperative, Multi-domain DDoS Defense by a Blockchain Signaling System (BloSS)***" has progressed, which is available as a prototype [70], [71], [72] and which is being prepared to function in an operational environment soon. In the meantime, BloSS was presented at the IEEE LCN 2017 during the demonstration track [73][1], which contains a number of functions, especially the basic prototype extended with tools by [12] and [15], a regional filtering system [85], a reputation system [32], [33], further ideas to operate such an approach as a "Mitigation-as-a-Service" model [54], [55], a security management and visualization of a collaborative defense [43], and an overall and in-depth evaluation [75].

F. Other Blockchain Application Design and Investigations

In the meantime, a variety of other application fields for a blockchain approach had been investigated. For each of those the key targets and systems view are summarized below.

Blockchain-based Systems for the Agriculture Sector: The "Smart Cow Paddock Journal" [4], provided a blockchain-based solution to herding cattle in Switzerland such that cattle can be tracked and traced following the formal Swiss requirements of cattle herding. Furthermore, [80] developed a system that allows farmers to request so-called "Direktzahlungen" ("direct payments", which are federal payments from the Swiss Government in Bern) for cattle herding, which are provided on a request-specific checklist to validate the request. In turn, the application executes the payout of direct payments through payment tokens, which are based on the Ethereum blockchain. The calculation of the amount for these direct payments is calculated in a Smart Contract, which is publicly available, since it is public money being spent on a well-defined quality of cattle herding. Thus, a simplification of paper-based documentation work in a reliable, electronic manner had been reached, while fully integrating the payment process. Of course, volatility aspects of the cryptocurrency applied remain for future research.

Supply chain management and product tracking is being addressed within the BLW (Bundesamt für Landwirtschaft, Federal Office for Agriculture) project between the CSG and the Foodways Consulting AG [28] on "Application Options of Blockchains in the Swiss Agriculture and Food Sector". Thus, the work included the design and development of an Android-based supply chain tracking application for diary products of high quality milk farmers [52], [64]. Further steps are way to provide by early 2019 a public prototype, especially the design and implementation of a blockchain-based supply chain tracking platform [45].

Blockchain-based Internet-of-Things (IoT) Systems: The use of temperature sensors for the medical drugs transport (cf. Section. B) already addresses in a dedicated manner the use of sensors, formally considered an important part of IoT-based systems. While these devices had been analyzed with respect to their security functionality and stability [45], [46], the use of general sensors had been extended to quality measurements of the environment [38], [67], which showed that a blockchain-based solution can immutably at least collect data, persist their collection parameters (such as date, time, location, and value for a given sensor type), and can provide the basis for a world-wide accessible raw data set of environmental or pollution data. Of course, such data may be maliciously falsified, but governmental and private data sets may become comparable to add in the future analysis functionality for verification purposes on top of the blockchain-based storage. Additionally, [67] shows that the use of LoRaWAN (Long Range Wide Area network, with the key feature of low power

[1]This demonstration received in 2017 the best Demonstration Award of the 42nd IEEE LCN Conference, Singapore [25].

demands) is highly suitable for such wide-spread and publicly accessible measurement networks.

Blockchain-based eVoting System: The use of distributed voting systems has raised a larger public attention within Switzerland during the past two years, since the reputation of the basic democratic values and reliability of an election's outcome are considered to be at stake. Thus, as shown, the approach to apply blockchain-based solutions can guarantee a certain combination of privacy, verifiability, and auditability [42], which was exploited to develop a blockchain-enabled eVoting prototype using the OAuth API [56], [58] in collaboration with the procivis AG, Switzerland [66]. More recently, the prototype in [57] presented an eVoting approach and system, which is addressing the "Cast-as-Intended Verifiability" in a blockchain-based eVoting, which specifically takes the Swiss national election requirements into account.

Blockchain-based Certificate Storage: The educational blockchain developed for UZH [30], [31] provides a system in which certificates, such as Bachelor and Master degrees, can be stored and offered for a simple and fast verification against external requests, *e.g.*, for references and checks of future employers.

Smart Contract-based Applications and Frameworks: The use of SCs provides a wide are of applications, the assumption that the data verification and validity, especially if these originate from "outside" an electronically generated field, is possible otherwise. Therefore, the design and prototyping of a SC creator framework had been performed [50], which utilized to design a dedicated set of purchase and rental contract agreements based on SCs [82], which resulted in the peer-to-peer PuRSCA application [68]. A prototypical implementation of a Smart Contract-based Trading Platform [29] is under way as well as an Open Source and Smart Contract-based Know Your Customer (KYC) Platform [2].

Performance, Identity Management, Wallets, and SC Programming Languages: Since the costs to store data within a blockchain has risen in the past due to much higher values noted for cryptocurrencies, the storage of data off-chain had been investigated performance metrics [27]. Furthermore, the processing of Bitcoin blockchain data requires a slightly more sophisticated approach, here by using a Big Data-specific framework approach to optimize the analysis of economic questions [77]. Additionally, a comparative study had been performed to learn about the use of blockchains in the field of identity management [62]. The study on Android-based cryptocurrency wallets documented the wider range of technical solutions available [63]. The work on SC programming languages ranges in the theoretical field on defining a SC programming language, which will enable an in-language check with the primary focus on safety, auditability, and the intention to prevent as many of the known categories of vulnerabilities by design as possible [48], [47]. This approach will eventually minimize the deployment of unintentionally false code once deployed in a blockchain.

G. CSG Involvements in Additional Start-ups and Open Source Projects

"To ensure an unbiased review process, the identities of authors, editors, and reviewers are unknown to one another. Thus, scientific content alone matters [83]." In this sense the ***ScienceMatters*** start-up plans to revolutionize the publications section of scientific results. While the basic technical system of ScienceMatters was designed as a blockchain-based publishing system [65], the general platform to integrate the various stakeholders' roles and demands is currently way [95]. The current CTO is Thomas Bocek (at foundation times with CSG), its deputy the CSG student Lucas Pelloni [65], [95], and 5 CSG students acting as software and smart contract engineers: Vasileios Koukoutsas [61], Claude Müller [61], Simon Müller [4], [5], Andreas Schaufelbühl [95], and Severin Wullschläger [95].

Finally, ***ICOnator*** determines an easy, secure, configurable, and scalable open source ICO (International Coin Offering) engine [37], which is based on the ICO platform applied to modum.io's ICO [26] and which had been developed under the lead of Thomas Bocek while being at CSG. The former CSG Ph.D. student Guilherme Machado took this platform, founded the ICOnator open source project, and guides the current design and implementation of this ICO platform [61] — performed by Simon Müller, Vasileios Koukoutsas, and Claude Müller —, which is expected to become available in mid 2019.

IV. Status and Outlook

The work introduced above summarizes the major blockchain-related areas of work tackled by the CSG, while indicating CSG publications and related theses only (all as listed below in the reference section). Explicitly, this overview paper here does not collect and display on purpose the vast amount of related work, which in many of these dedicated applications tackled — as developed and introduced above — had become later publicly announced from different research and development teams, commercially operating companies, and research organizations, too.

Thus, the current work of CSG pursues on multiple grounds (such as systems, protocols, algorithms, theoretical foundations) the standing of technical, economic, partially legal facets of blockchain-based systems and applications. Having said that the relevance of this blockchain work is visible and foreseen to be embedded into the modum.io, Science Matters, and Iconator start-ups as well as other formal collaborations currently in operation with the KTI (Commission for Innovation and Technology, Bern, Switzerland, now Innosuisse) and the BLW (Swiss Federal Office of Agriculture, Bern, Switzerland). The new EU project CONCORDIA within the Call H2020-SU-ICT-2018-2020 (to be started in early 2019) will contain blockchain-related security work and may address a set of economically interesting questions in that field, too. The same holds for the new project (to be started in early 2019, too) between the UZH's Swiss FinTech Innovation Center on "Decentralized Digital Financial Ecosystem" and Bitmaintech Pte. Ltd., where the CSG will provide expertise in blockchain's technical and economic dimensions.

While the next steps in research, prototyping, and evaluations are manifold, the continuation of work addressing the scalability concerns of blockchains in general as well as their sustainability on a broader scale does see a certain priority, nevertheless, still enabling investigations on the application of blockchains in security-related support, Network Function Virtualization (NFV) system components [39], and Service Level Agreement (SLA)-based automated compensation mechanisms [78].

As mentioned above, a number of new student theses have been already started and they will become available later in 2019. These include more specifically the "Design and Prototypical Implementation of a Smart Contract-based Trading

Platform" [29], "Design and Prototypical Implementation of an Open Source and Smart Contract-based Know Your Customer (KYC) Platform" [2], "Design and Implementation of an Scalable IoT-based Blockchain" [3], "Design and Implementation of a Blockchain-based Supply Chain Tracking Platform" [53], "Design and Development of a Blockchain Interoperability API" [34], "Processing Bitcoin Blockchain Data using a Big Data-specific Framework" [77], "Evaluation and Improving Scalability of the Bazo Blockchain" [51], "Design and Implementation of a Hierarchical Payment System with Bazo Blockchain" [14], "Design and Implementation of a Blockchain-based Trusted VNF Package Repository" [39], and "Policy-based Blockchain Framework for a Cold-Chain Temperature Monitoring" [49].

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[44] Andreas Knecht: ***Securing Goods Distribution with Smart Contracts and Sensors;*** Bachelor Thesis, CSG@IfI, University of Zürich, Switzerland, Supervisors: Thomas Bocek, Andri Lareida, Burkhard Stiller, 2016.

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[46] Andreas Knecht: ***Security Analysis of an IoT-enabled Hardware Temperature Logger;*** Independent Study; CSG@IfI, University of Zürich, Switzerland, Supervisors: Thomas Bocek, Bruno Rodrigues, Burkhard Stiller, 2017.

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[52] Tanbir Mann: ***Design and Development of an Android-based Supply Chain Tracking Application;*** Master Basic Module, Independent Study, CSG@IfI, University of Zürich, Switzerland, Supervisors: Sina Rafati, Burkhard Stiller, 2018.

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[56] Raphael Matile: ***Blockchain-enabled Voting Using OAuth API;*** Master Basic Module, CSG@IfI, University of Zürich, Switzerland, Supervisors: Thomas Bocek, Bruno Rodrigues, Burkhard Stiller, 2017.

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[58] Raphael Matile, Christian Killer: ***Privacy, Verifiability, and Auditability in Blockchain-based E-Voting;*** Master Project, CSG@IfI, University of Zürich, Switzerland, Supervisors: Thomas Bocek, Bruno Rodrigues, Burkhard Stiller, 2018.

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[77] Daniel Sommer: ***Processing Bitcoin Blockchain Data using a Big Data-specific Framework;*** Bachelor Thesis, CSG@IfI, University of Zürich, Switzerland, Supervisors: Eder Scheid, Claudio Tessone, Burkhard Stiller, to appear 2019.

[78] Eder Scheid, Bruno Rodrigues, Lisandro Z. Granville, Burkhard Stiller: ***Enabling Dynamic SLA Compensation Using Blockchain-based Smart Contracts;*** to appear: 16th IFIP/IEEE International Symposium on Integrated Network Management (IM 2019), April 2019, Washington DC, U.S.A.

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[80] Moritz Schneider: ***Food Supply Chain Support with Smart Contracts;*** Master Thesis, CSG@IfI, University of Zürich, Switzerland, Supervisors: Thomas Bocek, Markus Hurschler, Sina Rafati, Burkhard Stiller, 2017.

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[90] Tim Strasser: ***Managing Goods Distribution with Smart Contracts;*** Bachelor Thesis, CSG@IfI, University of Zürich, Switzerland, Supervisors: Thomas Bocek, Andri Lareida, Burkhard Stiller, 2016.

[91] Sacha Uhlmann: ***Reducing Counterfeit Products with Blockchains;*** Thesis, CSG@IfI, University of Zürich, Switzerland, Supervisors: Thomas Bocek, Andri Lareida, Burkhard Stiller, 2017.

[92] Raphael Voellmy: ***CoinBlesk, a Mobile NFC Bitcoin Payment System;*** Bachelor Thesis, CSG@IfI, University of Zürich, Switzerland, Supervisors: Thomas Bocek, Daniel Dönni, Burkhard Stiller, 2015.

[93] Jan von der Assen: ***A Progressive Web App (PWA)-based Mobile Wallet for Bazo;*** Bachelor Thesis, CSG@IfI, University of Zürich, Switzerland, Supervisors: Thomas Bocek, Bruno Rodrigues, Burkhard Stiller, 2018.

[94] Patrick Widmer: ***Design and Implementation of a Blockchain Interoperability API;*** Master Basic Module, CSG@IfI, University of Zürich, Switzerland, Supervisors: Bruno Rodrigues, Eder Scheid, Burkhard Stiller, 2018.

[95] Severin Wullschläger, Andreas Schaufelbühl, Lucas Pelloni: ***Design and Implementation of a Blockchain-based Scientific Publishing Platform;*** Master Project, CSG@IfI, University of Zürich, Switzerland, Supervisors: Sina Rafati, Thomas Bocek, Burkhard Stiller, to appear 2019.

Note: All Bachelor Theses completed in 2018 or earlier as listed within this reference section above may be obtained typically from https://www.ifi.uzh.ch/en/research/publications/bachelors-theses.html, while respective Master Theses are normally available at https://www.ifi.uzh.ch/en/research/publications/masters-theses.html.

The list of **keynotes, invited presentations, and panel organizations/participations** on the blockchain topic compile as follows (listed in a reverse chronological order, youngest event comes first), while all blockchain topic-related conference paper presentations are not listed:

[96] Burkhard Stiller: ***Blockchain, Applications, and Their Qualitative Assessment;*** Research Colloquium, The University of Sydney, School of IT, November 2018.

[97] Bruno Rodrigues: ***Blockchain Applications and their Applicability;*** Keynote, Workshop on Blockchain and Smart Contracts: Technology, Applications and Legislation, Neuchâtel, Switzerland, November 2018.

[98] Burkhard Stiller: ***Blockchains and Their Applications – A Critical Review;*** Keynote, 3rd Symposium on Distributed Ledger Technology, Gold Coast, Australia, November 2018.

[99] Burkhard Stiller: ***A View on Blockchains, Their Applications, and an Informal Evaluation;*** Research Colloquium, University of New South Wales (UNSW), Kensington, NSW, Australia, October 2018.

[100] Burkhard Stiller: ***Blockchain Basics, Applications, and an Assessment;*** Research Colloquium, The University of Kansas, Lawrence, Kansas, U.S.A., September 2018.

[101] Burkhard Stiller: ***Blockchain Basics and Challenges versus Risks;*** Research Colloquium, DACS Group, University of Twente, Enschede, The Netherlands, August 2018.

[102] Burkhard Stiller: ***An Introduction to Blockchains - Basics, Challenges, and Risks;*** Invited Talk, CHAnGE Workshop, Zürich, Switzerland, August 2018.

[103] Burkhard Stiller: ***An Introduction to Blockchains - Basics, Challenges, and Risks;*** Keynote, CODE Jahrestagung, Blockchain Workshop, Neubiberg, Germany, Neubiberg, July 2018.

[104] Thomas Bocek: ***The Future of Blockchains in Science;*** Invited Talk, CODE Jahrestagung, Blockchain Workshop, Neubiberg, Germany, Neubiberg, July 2018.

[105] Burkhard Stiller: ***Blockchains in Practice - Already a Success?*** Panel Organizer, CODE Jahrestagung, Blockchain Workshop, Neubiberg, Germany, Neubiberg, July 2018.

[106] Burkhard Stiller: ***Blockchains, Start-up Experiences, and Challenges versus Risks;*** Keynote, Global Blockchain Conference, Seoul, South Korea, June 2018.

[107] Burkhard Stiller: ***Blockchains - Überblick, Herausforderungen, Risiken: Overview, Challenges, and Risks;*** Invited Talk, Informatiktage, Zürich, Switzerland, June 2018.

[108] Burkhard Stiller: ***Blockchains - A Technical Evolution Considered Revolution?*** Keynote, UZH Blockchain Center Foundation Event, Zürich, Switzerland, May 2018.

[109] Burkhard Stiller: ***Blockchains' Impact on Networking and Distributed Systems;*** Keynote, 16th IEEE/IFIP Network and Operations Symposium (NOMS 2018), Taipei, Taiwan, April 2018.

[110] Burkhard Stiller: ***Blockchain-based Management Services and Applications;*** Distinguished Expert Panel Speaker, 16th IEEE/IFIP Network and Operations Symposium (NOMS 2018), Taipei, Taiwan, April 2018.

[111] Burkhard Stiller: ***Blockchains - A Valuable Commercial Contribution or a Romanticized Technology Playground?*** Invited Talk, UZH Presentation Series on Digital Transformation, Zürich, Switzerland, November 2017.

[112] Burkhard Stiller: B***lockchains in the Wings - A Driver and Enabler for Trusted, Distributed Applications;*** Invited Talk, swissICT Symposium 2017, Luzern, Switzerland, November 2017

[113] Burkhard Stiller: ***eAuthentication and Blockchains;*** Invited Talk, eAuthentication Workshop, KPMG, Zürich, Switzerland, September 2017.

[114] Burkhard Stiller: ***Blockchain in the Wings;*** Invited Talk, Visit of a Prime Minister's Delegation of the Republic of Korea, EMPA, Dübendorf, Switzerland, June 2017.

[115] Thomas Bocek: ***Joining SDN and Blockchains for a Cooperative DDoS Defense;*** Invited Talk, 8th SDN Workshop, Zürich, Switzerland, June 2017.

[116] Thomas Bocek: ***Bitcoins, Ethereum, Blockchains;*** Invited Talk, Workshop on "Introduction to Internet and Security", Basel, Switzerland, May 2017.

[117] Thomas Bocek: ***Blockchain Projects at the University of Zurich;*** Invited Talk, Blockchain Gathering, Zürich, Switzerland, Zürich, Switzerland, April 2017.

[118] Thomas Bocek: ***Pharma Supply Chain & Blockchain Projects at UZH;*** Invited Talk, Blockchain Meetup Switzerland, Zürich, Switzerland, February 2017.

[119] Thomas Bocek: ***Combining IoT and Blockchain;*** Invited Talk, 13. Internationale Tagung Wirtschaftsinformatik, St. Gallen, Switzerland, February 2017.

[120] Bruno Rodrigues: ***A Blockchain-based Architecture for Collaborative DDoS Mitigation with Smart Contracts;*** Invited Talk, SWITCH Workshop, Zürich, Switzerland, February 2017.

[121] Thomas Bocek: ***Rethinking Pharma Supply Chain with Blockchains and IoT;*** Invited Talk, Stiftung TECHNOPARK Zürich, Switzerland, December 2016.

[122] Burkhard Stiller: ***Blockchains and Smart Contracts for Finance and Beyond;*** Invited Talk, Consecom AG, Annual Meeting, Zürich, Switzerland, November 2016.

[123] Thomas Bocek: ***Rethinking Pharma Supply Chain Processes;*** Invited Talk, DPD Innovation Days, Zürich, Switzerland, October 2016.

[124] Thomas Bocek: ***Rethinking Pharma Supply Chain Processes;*** Invited Talk, TechTuesday Zurich, Zürich, Switzerland, October 2016.

[125] Burkhard Stiller: ***Blockchains and Smart Contracts - Emerging Applications in Finance and Beyond;*** Distinguished Speaker Colloquium, Singapore University of Technology and Design (SUTD), Singapore, October 2016.

[126] Thomas Bocek: ***Bitcoins + Ethereum;*** Invited Talk, NCAU - Netcetera University, Zürich, Switzerland, May 2016.

[127] Burkhard Stiller: ***Bitcoins — Geld oder Spiel?*** Invited Talk, Admin Technology Meeting, Department of Informatics IfI, Zürich, Switzerland, November 2015.