Blockchain Application Design and Development, and the Case of Programmable Money

CLOSER'21 Keynote

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Technische Universität Berlin

Agenda

- Blockchain basics and terminology
- Designing and developing blockchain applications
  - Architecture & design
  - Model-driven engineering
- Blockchain and Services:
  - Integrating Blockchain-based Applications with Services
  - Blockchain-as-a-Service
  - Service-orientation vs. Smart Contracts
- Programmable money
- Blockchain adoption

Preliminaries and Definitions

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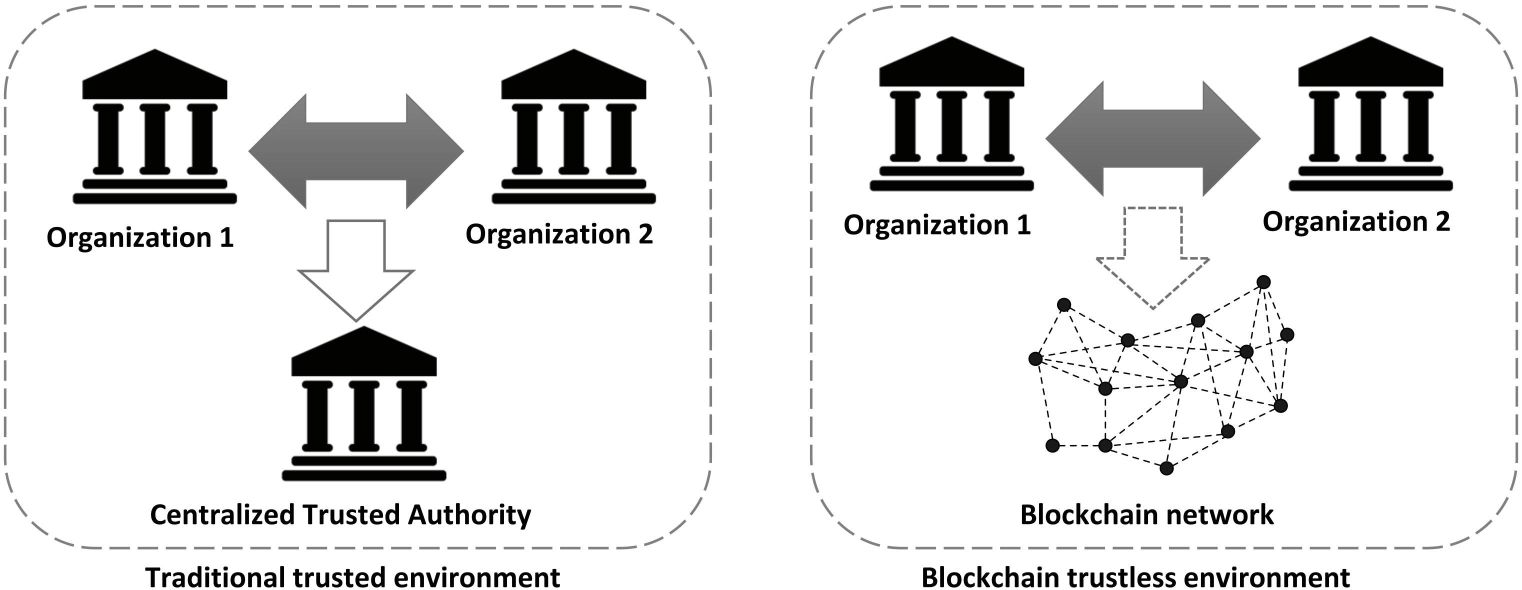
Blockchain – replacing centralized trusted authority



Blockchain 2$^{\text{nd}}$ gen – Smart Contracts

- 1$^{\text{st}}$ gen blockchains: transactions are financial transfers

- Now Blockchain ledger can do that, and store/transact any kind of data

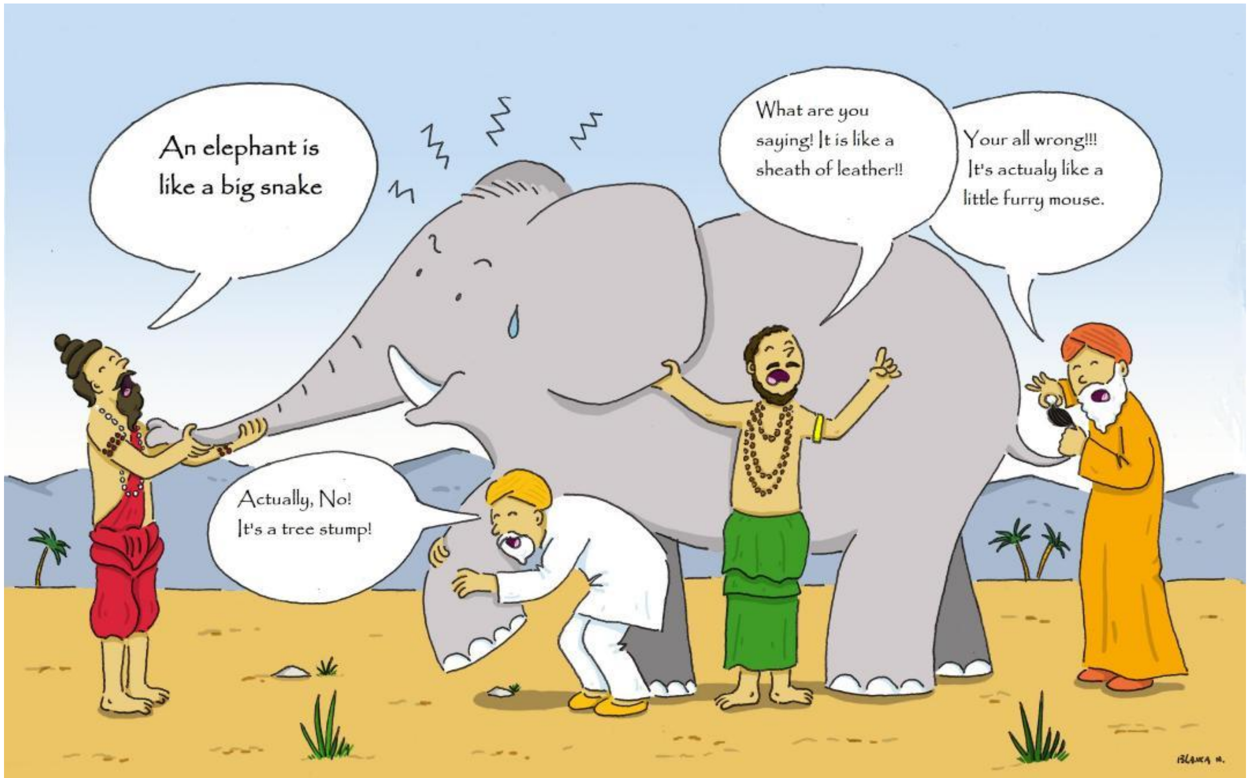
- Blockchain can deploy and execute programs: Smart Contracts
  - User-defined code, deployed on and executed by whole network
  - Can enact decisions on complex business conditions

  - Can hold and transfer assets, managed by the contract itself
  - Ethereum: pay per assembler-level instruction

So what?

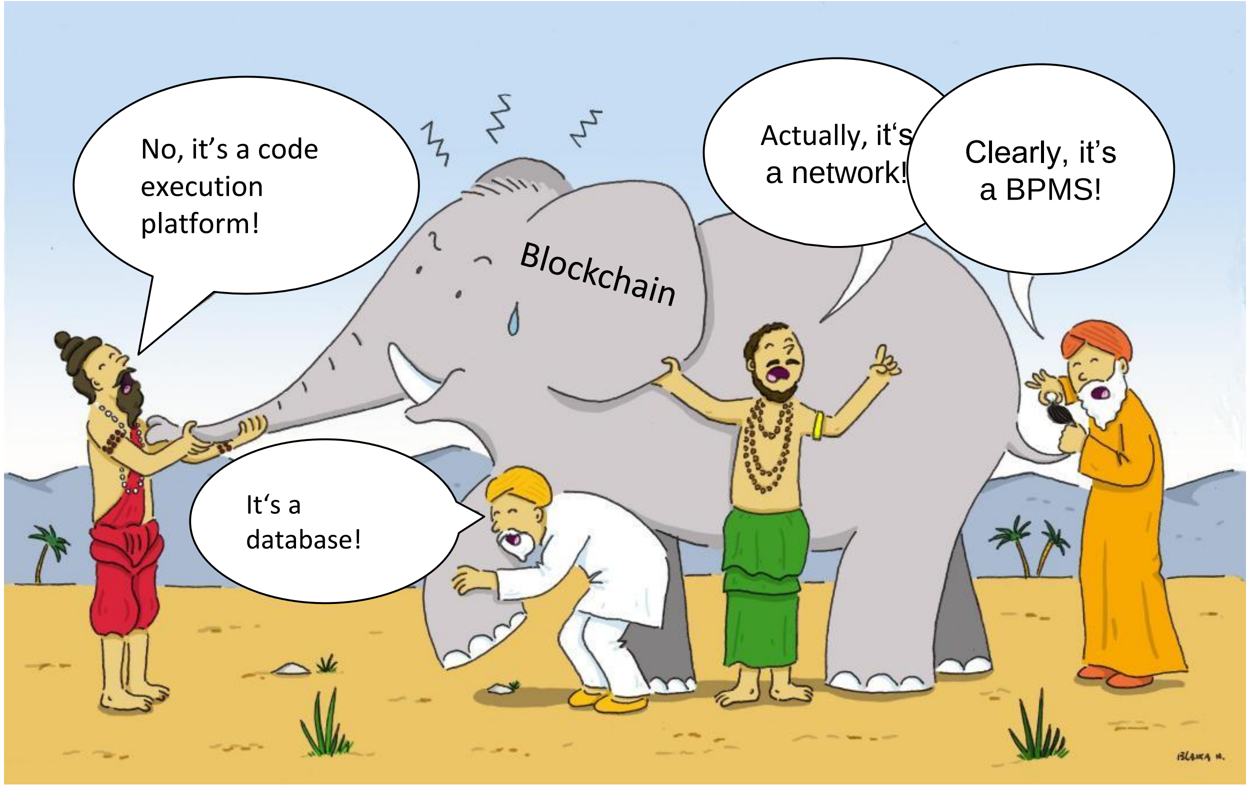
- Well, blockchains are exciting because they can be used as a new foundation for re-imagining systems:
  - Neutral infrastructure for processing transactions and executing programs
  - Potentially interesting for innovation at **all touch-points** between organizations or individuals
  - ➢ **Blockchain applications have the potential to disrupt the fabric of society, industry, and government**
- Blockchains can also be used as a technology platform to handle hard issues of data replication and system state synchronization with high integrity.

What is a blockchain?



Parable of the blind men and the elephant, see e.g., https://wildequus.org/2014/05/07/sufi-story-blind-men-elephant/ (source of figure)

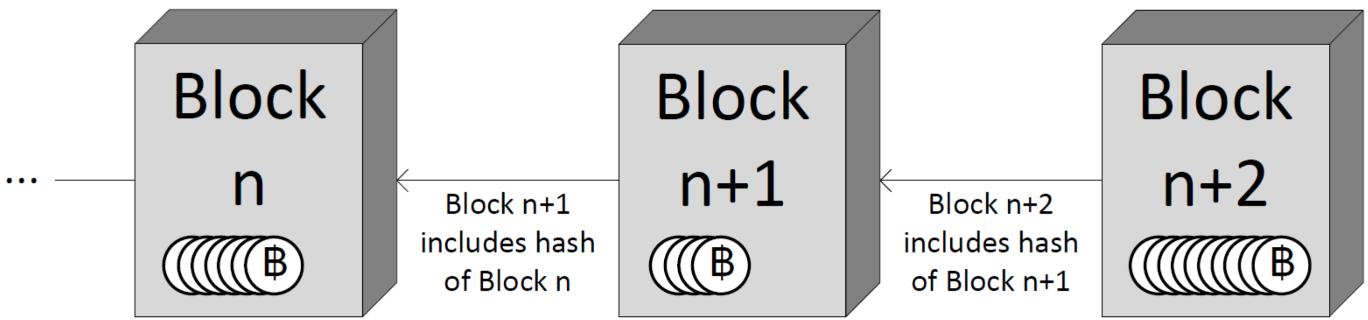
What is a blockchain?



Parable of the blind men and the elephant, see e.g., https://wildequus.org/2014/05/07/sufi-story-blind-men-elephant/ (source of figure)

Defining Blockchain (1)

- **Distributed Ledger**
  - An "append-only" transaction store distributed across machines *(immutability)*
  - A new transaction might reverse a previous transaction, but both remain part of the ledger
- **Blockchain**
  - A distributed ledger structured into a linked list of blocks
  - Each block contains an ordered set of transactions
  - Use cryptographic hashes to secure the link from a block to its predecessor



Defining Blockchain (2)

- A **Blockchain System** consists of
  - A blockchain network of nodes
  - A blockchain data structure
    - For the ledger replicated across the blockchain network
    - Full nodes hold a full replica of the ledger
  - A network protocol
    - Defines rights, responsibilities, and means of communication, verification, validation, and consensus across the nodes in the blockchain network
    - Includes ensuring authorisation and authentication of new transactions, mechanisms for appending new blocks, incentive mechanisms

Defining Blockchain (3)

- A **Public Blockchain** is a blockchain system with the following characteristics:
  - Has an open network
    - Nodes can join and leave without requiring permission from anyone
  - All full nodes can verify new transactions and blocks
  - Incentive mechanism to ensure the correct operation
    - Valid transactions are processed and included in the ledger and invalid transactions are rejected
- A **Blockchain Platform** is the technology needed to operate a blockchain
  - Blockchain client software for processing nodes
  - The local data store
  - Alternative clients to access the blockchain network

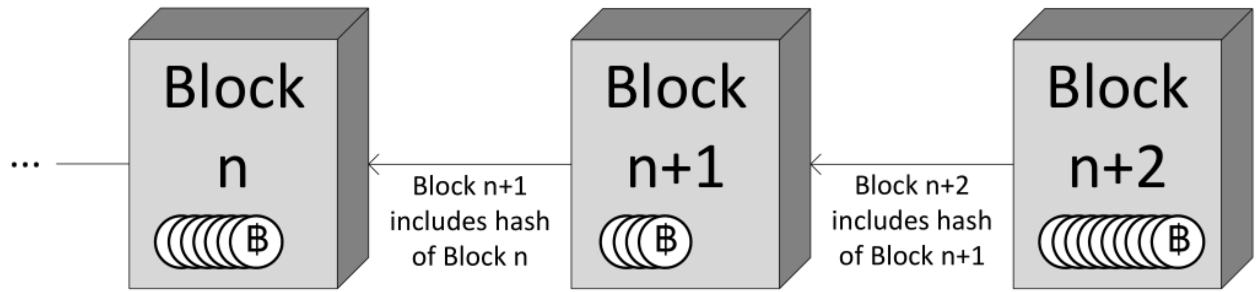
Decentralised Applications and Smart Contracts

- **Smart contracts**
    - Programs deployed as data and executed in transactions on the blockchain
    - Blockchain can be a computational platform (more than a simple distributed database)
    - Code is deterministic and immutable once deployed
    - Can invoke other smart contracts
    - Can hold and transfer digital assets
- **Decentralized applications** or **dapps**
    - Main functionality is implemented through smart contracts
    - Backend is executed in a decentralized environment
    - Frontend can be hosted as a web site on a centralized server
        - Interact with its backend through an API
    - Could use decentralized data storage such as IPFS
    - “State of the dapps” is a directory recorded on blockchain: https://www.stateofthedapps.com/

Blockchain defined (1/4)

Verbatim from the Book

- **Definition 1 (Distributed Ledger).** A Distributed Ledger is an *append-only store of transactions* which is distributed across many machines.
- **Definition 2 (Blockchain (Concept)).** A Blockchain is a *distributed ledger* that is structured into a *linked list of blocks*. Each block contains an ordered set of transactions. Typical solutions use cryptographic hashes to secure the link from a block to its predecessor.



Blockchain defined (2/4)
Verbatim from the Book

- **Definition 3 (Blockchain System).** A Blockchain System consists of:
  - a *blockchain network* of machines, also called *nodes*;
  - a *blockchain data structure*, for the ledger that is replicated across the blockchain network. Nodes that hold a full replica of this ledger are referred to as *full nodes*;
  - a network *protocol* that defines rights, responsibilities, and means of communication, verification, validation, and consensus across the nodes in the network. This includes ensuring *authorization and authentication* of new transactions, mechanisms for appending new blocks, incentive mechanisms (if needed), and similar aspects.

Blockchain defined (3/4)
Verbatim from the Book

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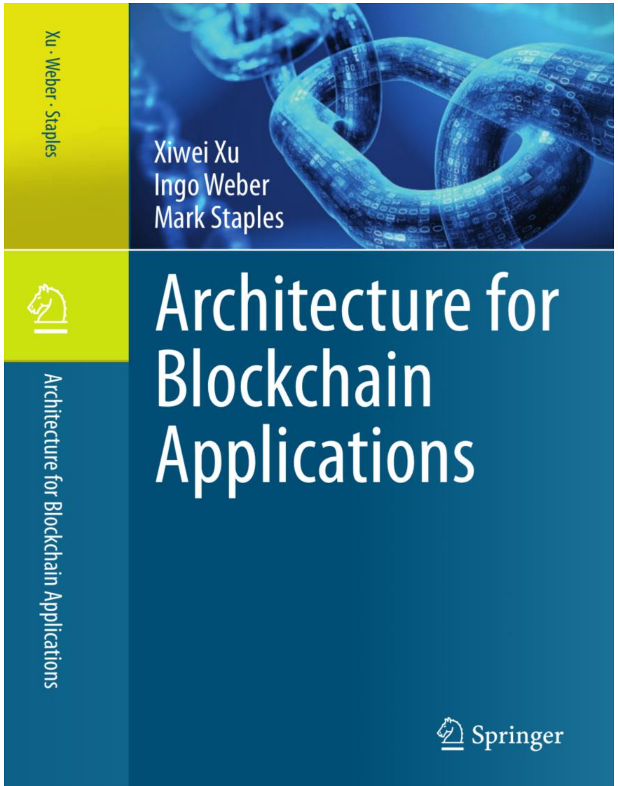
- **Definition 4 (Public Blockchain).** A Public Blockchain is a *blockchain system* that has the following characteristics:
  - it has an *open network* where nodes can join and leave as they please without requiring permission from anyone;
  - all full nodes in the network can *verify each new piece of data* added to the data structure, including blocks, transactions, and effects of transactions; and
  - its protocol includes an *incentive mechanism* that aims to ensure the correct operation of the blockchain system including that valid transactions are processed and included in the ledger, and that invalid transactions are rejected.

Blockchain defined (4/4)
Verbatim from the Book

- **Definition 5 (Blockchain Platform).** A blockchain platform is the *technology needed to operate a blockchain*. This comprises the blockchain client software for processing nodes, the local data store for nodes, and any alternative clients to access the blockchain network.
- **Definition 6 (Smart Contract).** Smart contracts are *programs* deployed as data in the blockchain ledger, and executed in transactions on the blockchain. Smart contracts can *hold and transfer digital assets* managed by the blockchain, and can invoke other smart contracts stored on the blockchain. Smart contract code is *deterministic and immutable* once deployed.
- **Definition 7 (dapp).** A decentralized application or dapp is a software system that is designed to provide its main functionality through smart contracts.

Book: Architecture for Blockchain Applications



Xiwei Xu, Ingo Weber, Mark Staples.

Architecture for Blockchain Applications.

Springer, 2019. [1]

➔ Includes the definitions from the previous slides

Cryptocurrencies and Tokens

- **Cryptocurrencies**
  - ‘Baked in’ to the core platform of public blockchains -base currency of blockchains
  - Symbiotic relationship
    - Blockchain keeps track of the ownership of portions of that currency, e.g. Alice owned 2 Ether, transferred 1 Ether to Bob, offered 0.01 Ether to miner
    - Cryptocurrency enables the incentive mechanism for blockchain operations
- **Digital tokens**
  - Created and exchanged using smart contracts
  - Represent assets
    - Fungible asset: individual units are interchangeable, e.g. company share, gold
    - Non-fungible asset: represents a unique asset, e.g. cryptokitties, car title
- **Not all applications are the same:**
  - Transferring coins / tokens vs. tracking movement of physical goods
  - Core difference: where is the default version of the truth, on or off-chain?


Designing and Developing Blockchain Applications

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Overview

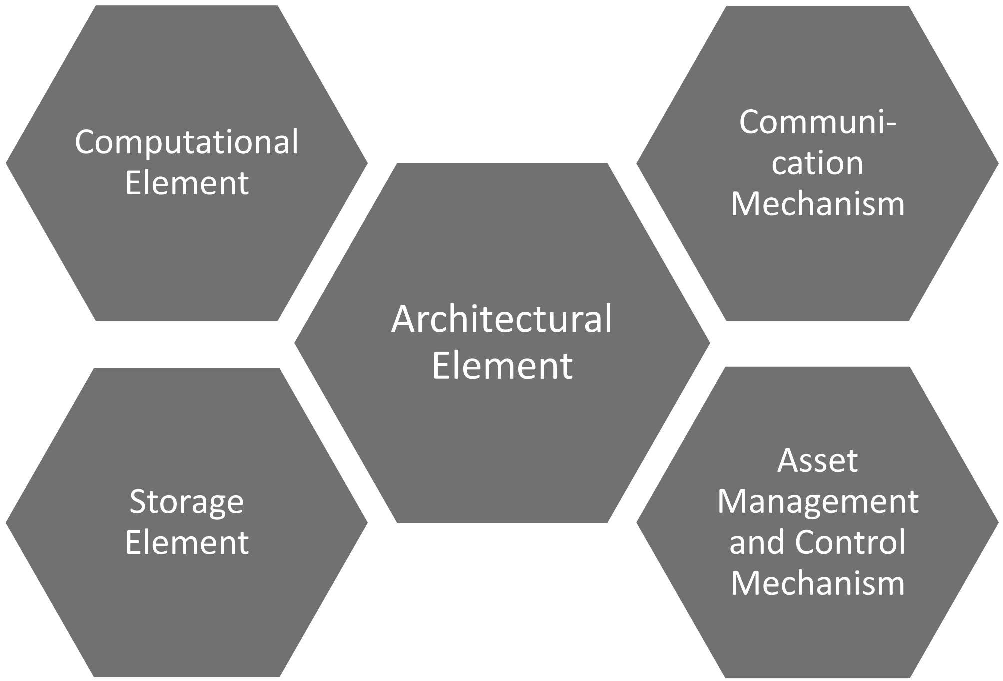
- Many **interesting applications** for Blockchain
  - Basically of interest in most lack-of-trust settings where a distributed application can coordinate multiple parties
  - Examples:
    - Supply chains
    - Handling of titles, e.g., land, water, vehicles
    - Identity
  - Many startups and initiatives from enterprises / governments
- ... but also many **challenges**
  - When to use blockchain
  - Trade-offs in architecture
    - Downsides: cost, latency, confidentiality
    - What to handle on-chain, what off-chain?

Work with my former and my new teams

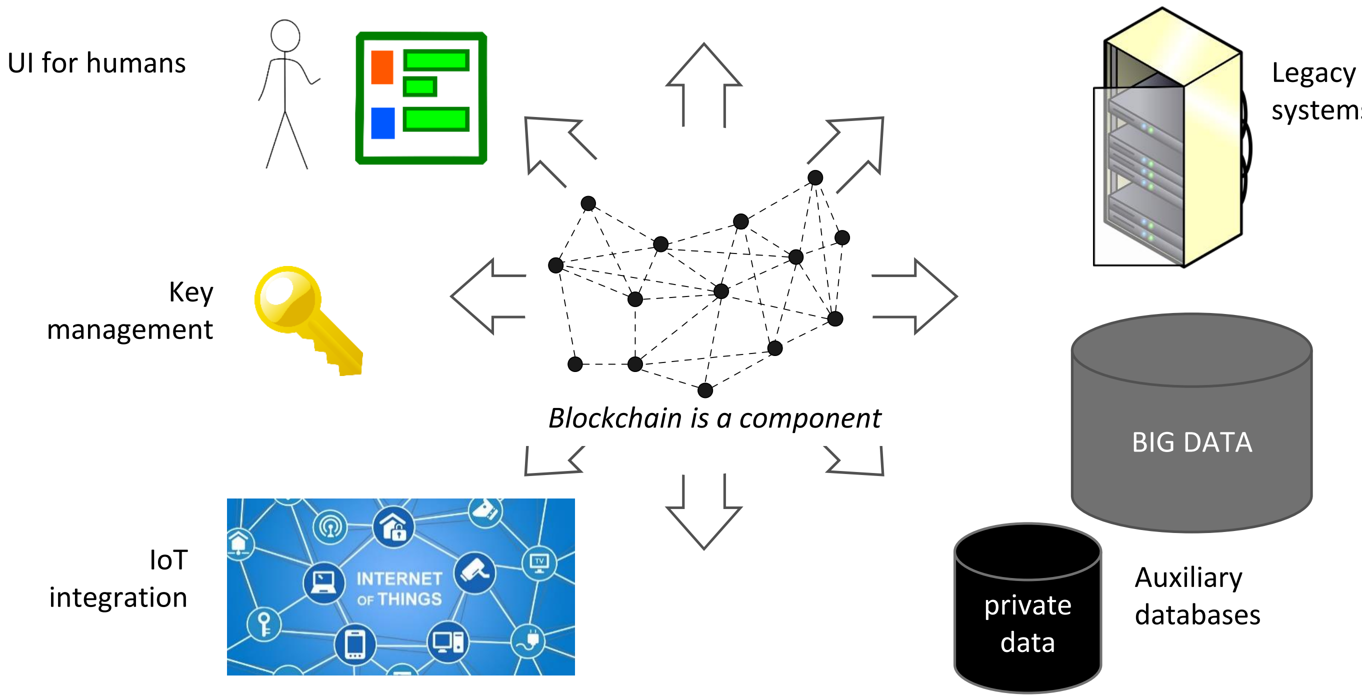
- Architecting applications on Blockchain:
  - Book [1]
  - Taxonomy and design process [5]
  - "Cost of Distrust": how much more expensive is blockchain? [7]
    - On some blockchains, cost and throuhgput are tightly linked
  - Availability analysis from viewpoint of dapps [11]
  - Latency: simulation under changes [12]
  - Multi-tenant applications on blockchain [13]
- Model-driven development of smart contracts
  - Business process execution (including the tools *Caterpillar* [6] and *Lorikeet* [10])
  - Model-based generation of code for data structures, non-fungible and fungible tokens, and UI components
  - Data extraction and analytics, e.g. Process Mining on blockchain data [3,4]
- Blockchain Patterns – reusable experience & inspiration [14,15]
  - https://research.csiro.au/blockchainpatterns/
- …

Functions blockchain can provide in an application architecture

- Blockchain as…



Blockchains are Not Stand-Alone Systems

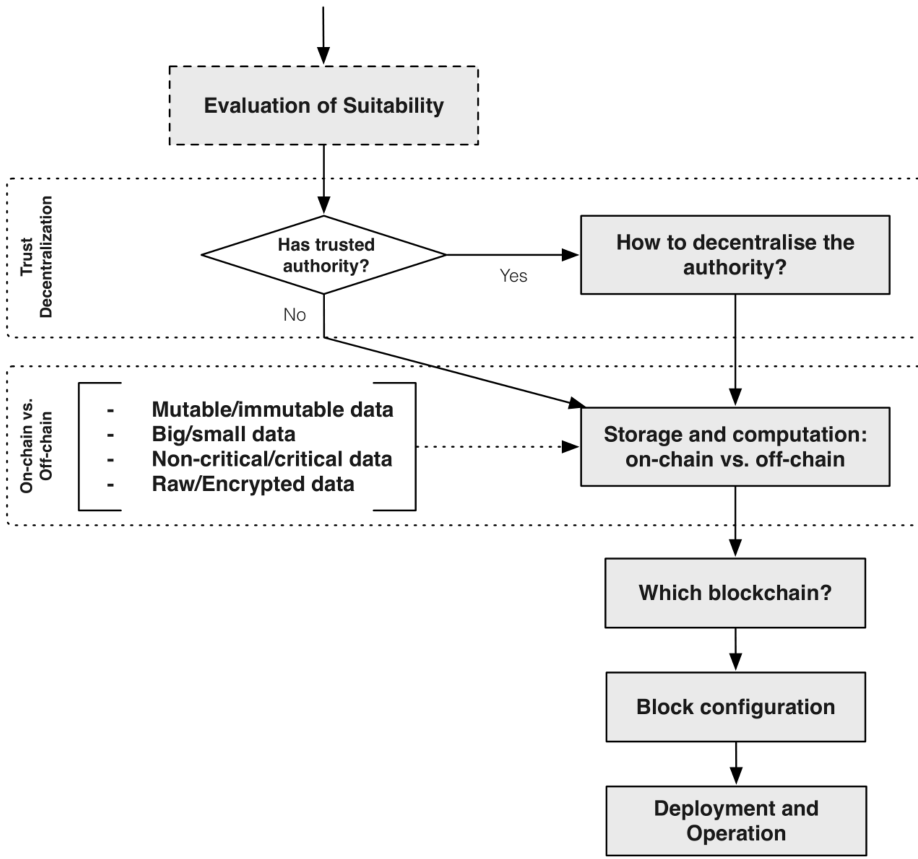


Non-Functional Trade-Offs

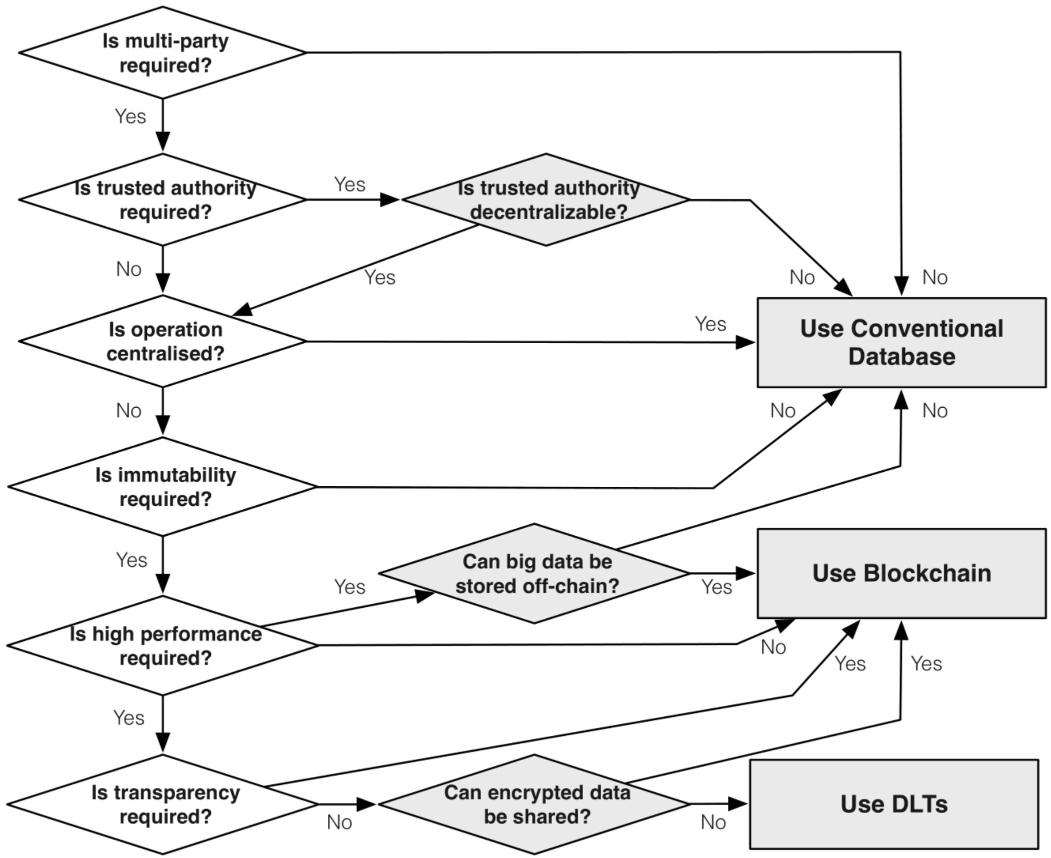
- Compared to conventional database & script engines, blockchains have:
  - (-) Confidentiality, Privacy
  - (+) Integrity, Non-repudiation
  - (+ read/ - write) Availability
  - (-) Modifiability
  - (-) Throughput / Scalability / Big Data
  - (+ read/ - write) Latency

Security: combination of CIA properties

Design process



Evaluation of Suitability




Designing and Developing Blockchain Applications:

Model-driven Engineering for Blockchain Applications

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Model-driven Engineering & Blockchain

- Model-driven engineering (MDE):
  - A methodology for using models at various levels of abstraction and for different purposes during software development
  - Low-level models: production code can be directly derived from the models
  - High-level models: means of communication between business owners and developers implementing a system
  - Intermediate levels can support model-based system analysis or system management tools
  - Any level: generate a code skeleton or early version of the code
  - Can cover static structures (like data models) or dynamic behavior (activity sequences)
- Advantages in the blockchain context:
  - Code generation can implement best practices and well-tested building blocks
    - Code can adhere to blockchain "standards" (like ERC-20, ERC-721, …)
  - Models can be independent of specific blockchain technologies or platforms
  - Models are often easier to understand than code – particularly useful in communicating with business partners about smart contracts
    - Facilitates building trust

MDE for data structures and tokens

- Approach:
  - Model data structure (variables, types) – not for fungible tokens
  - Model relationships to other types / tokens
  - Select features

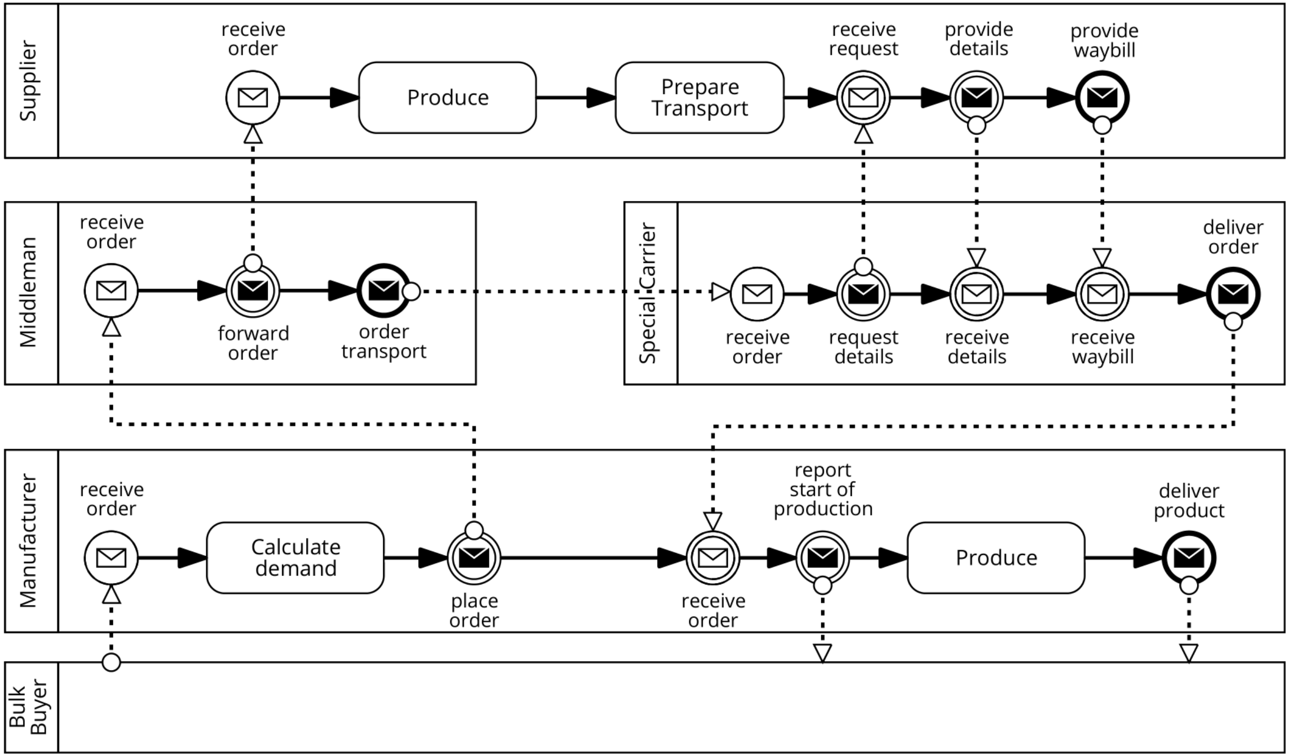
  → Code is generated – deploy or customize
- Feature examples:
  - Fungible tokens:
    - Can be minted? Burnt? By whom?
  - Non-fungible tokens
    - Include standard method(s) for sale
    - One contract for all tokens or one per token?
- Code generated is compliant with standards

  → interface syntax and semantics

MDE for Processes – Motivation

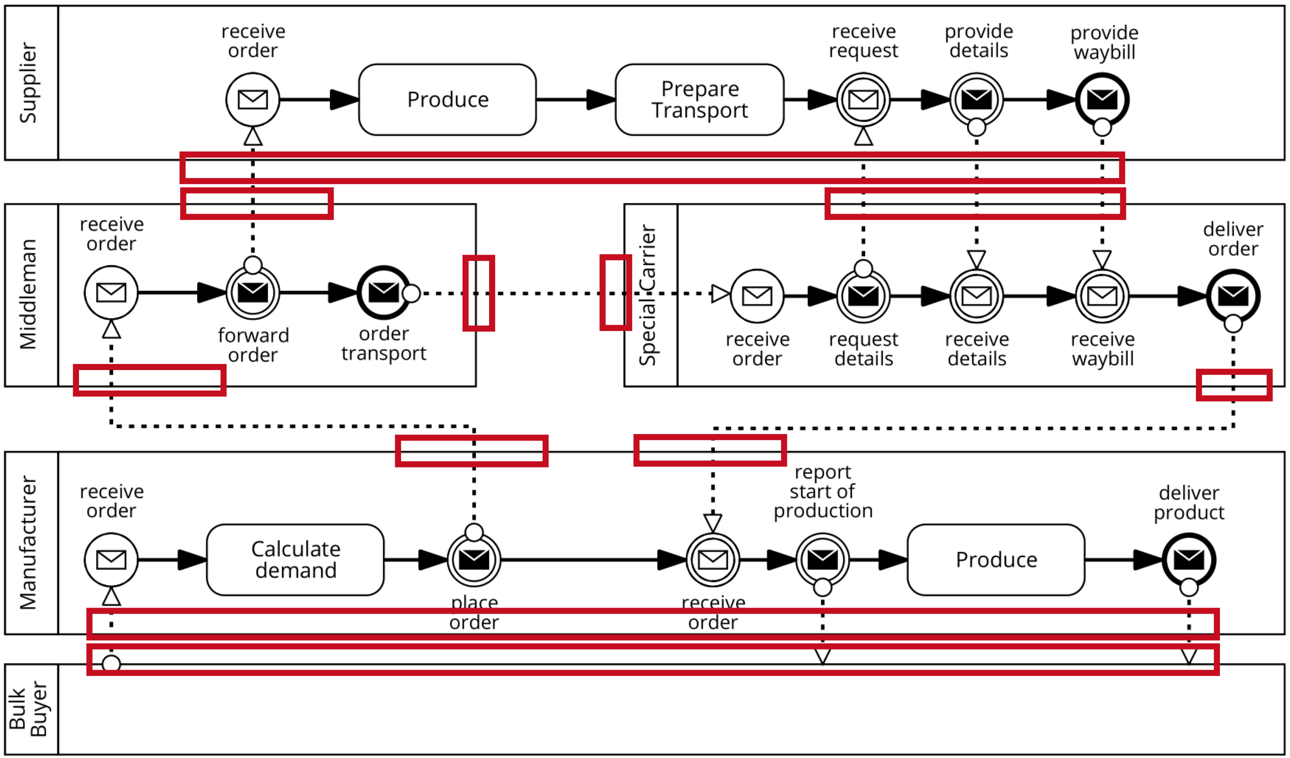
- Integration of business processes across organizations: a key driver of productivity gains
- Collaborative process execution
  - Doable when there is trust – supply chains can be tightly integrated
  - Problematic when involved organizations have a **lack of trust** in each other
    → if 3+ parties should collaborate, where to execute the process that ties them together?
  - Common situation in "coopetition"

Motivation: example



Issues:
- Knowing the status, tracking correct execution
- Handling payments
- Resolving conflicts

Motivation: example



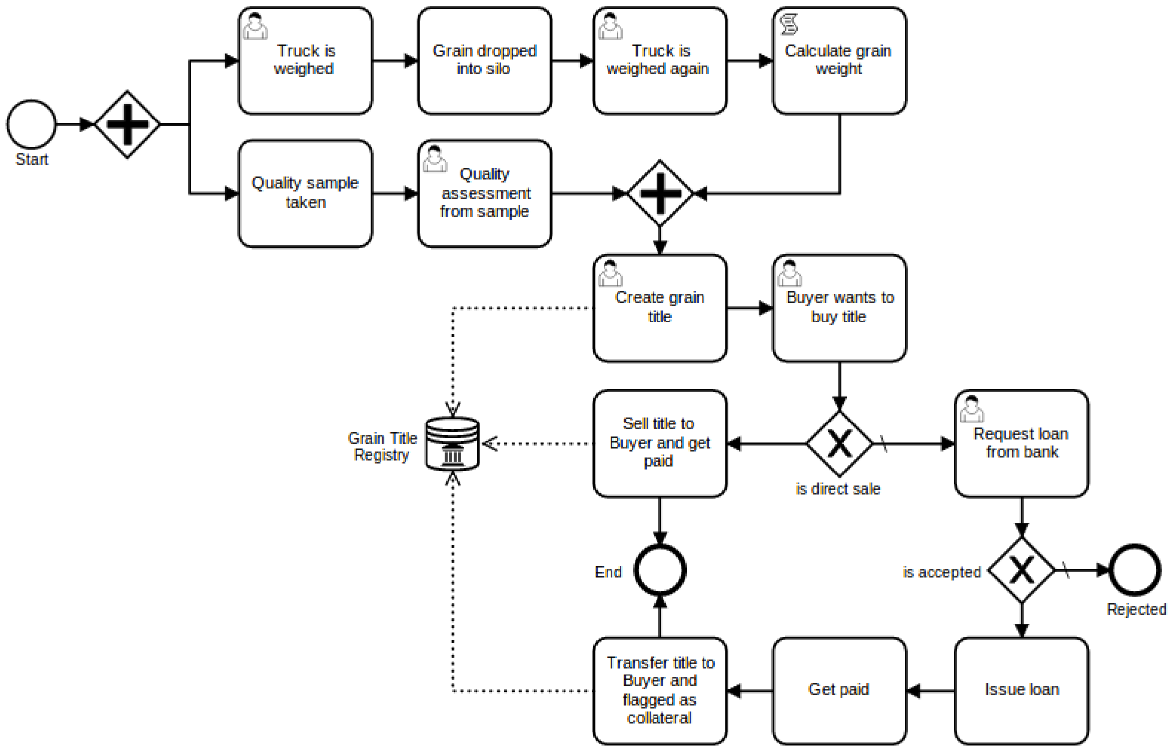
Service Interface

Issues:
- Knowing the status, tracking correct execution
- Handling payments
- Resolving conflicts

Approach in a nutshell [2]

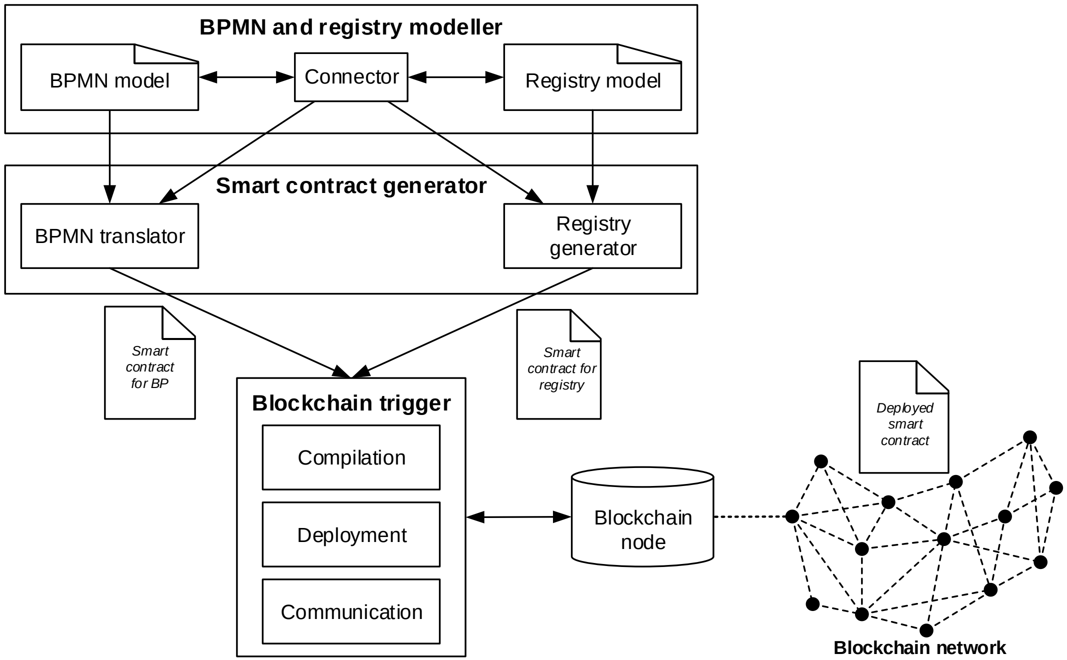
- Goal: implement collaborative business processes as smart contracts
  - Translate (enriched) BPMN to smart contract code
  - Triggers act as bridge between Enterprise world and blockchain
  - Smart contract provides:
    - Independent, global process monitoring
    - Conformance checking and process enforcement: only expected messages are accepted, only from the respective role
    - Automatic payments & escrow
    - Data transformation
    - Encryption
- Processes can make use of data / token contracts
  - Process activity to hand over title to a car / shipment / grain / ..., e.g., in exchange for fungible tokens

Combining process and data/token models

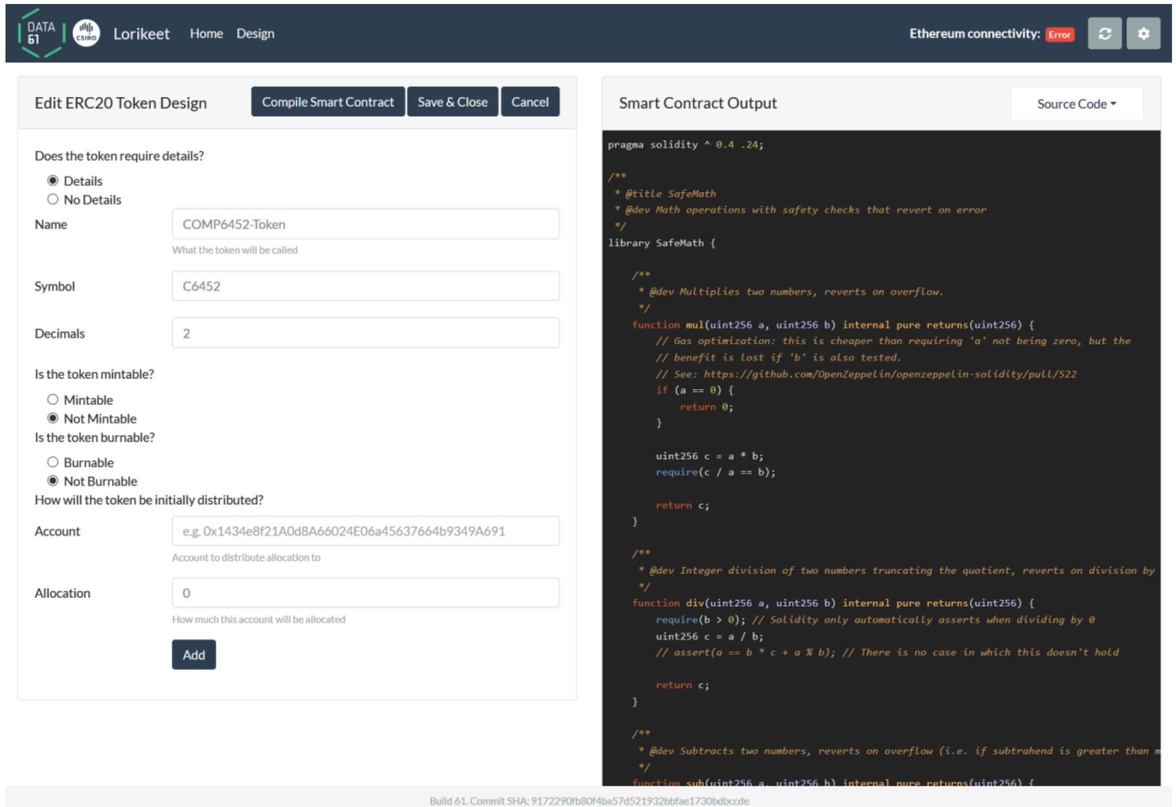


Data61 tool: Lorikeet [10]

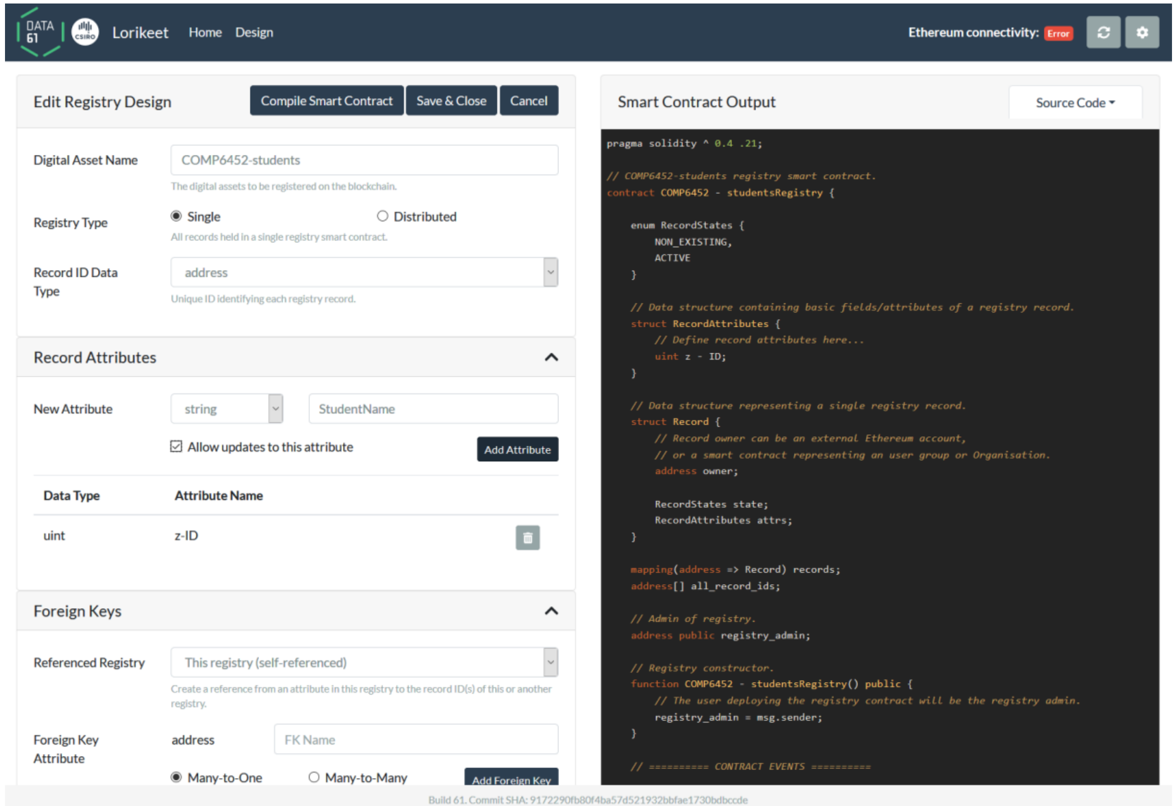
- Lorikeet: automatic generate smart contracts from BPMN models/registry data schema



Design time for fungible tokens

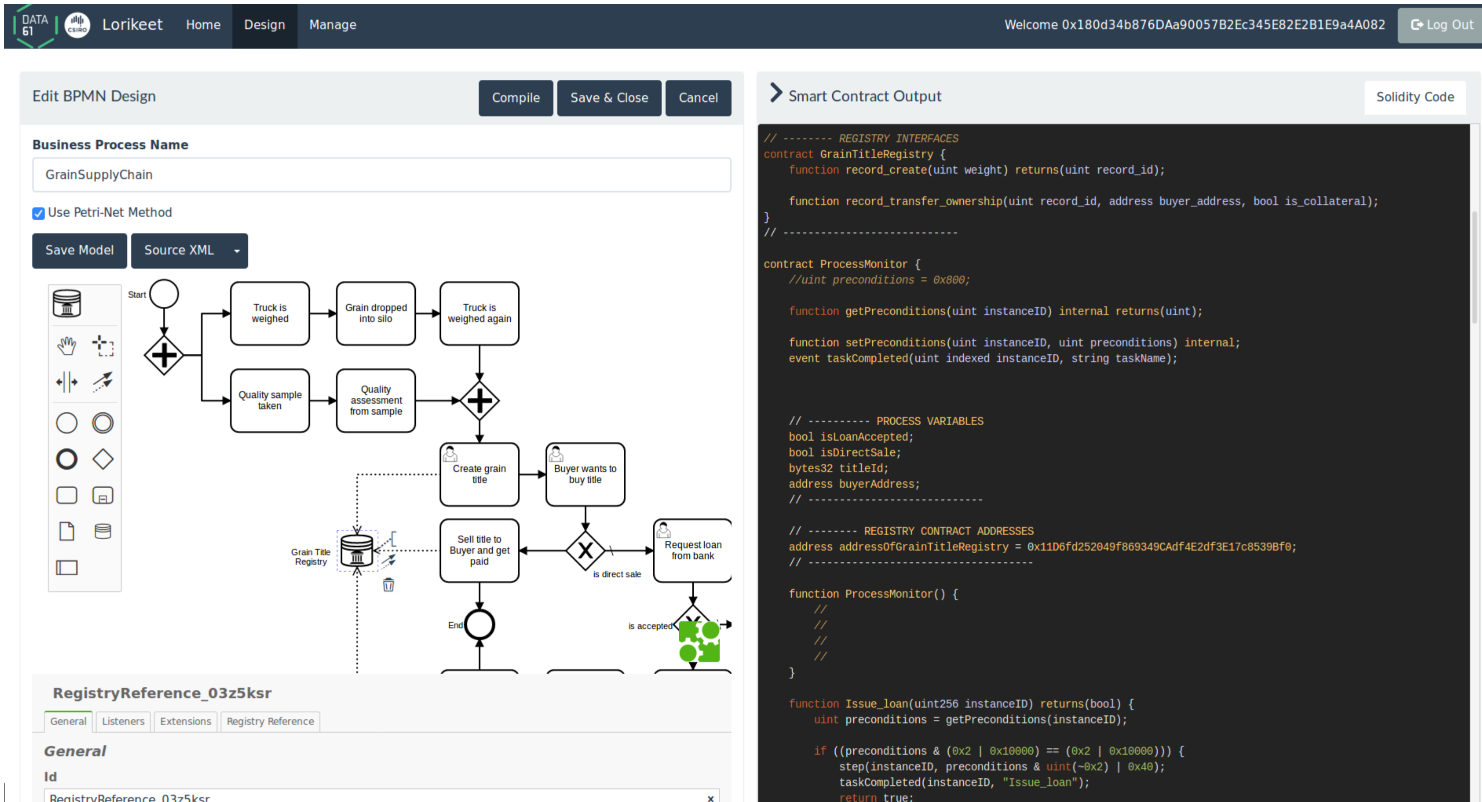


Design time for data models / non-fungible tokens

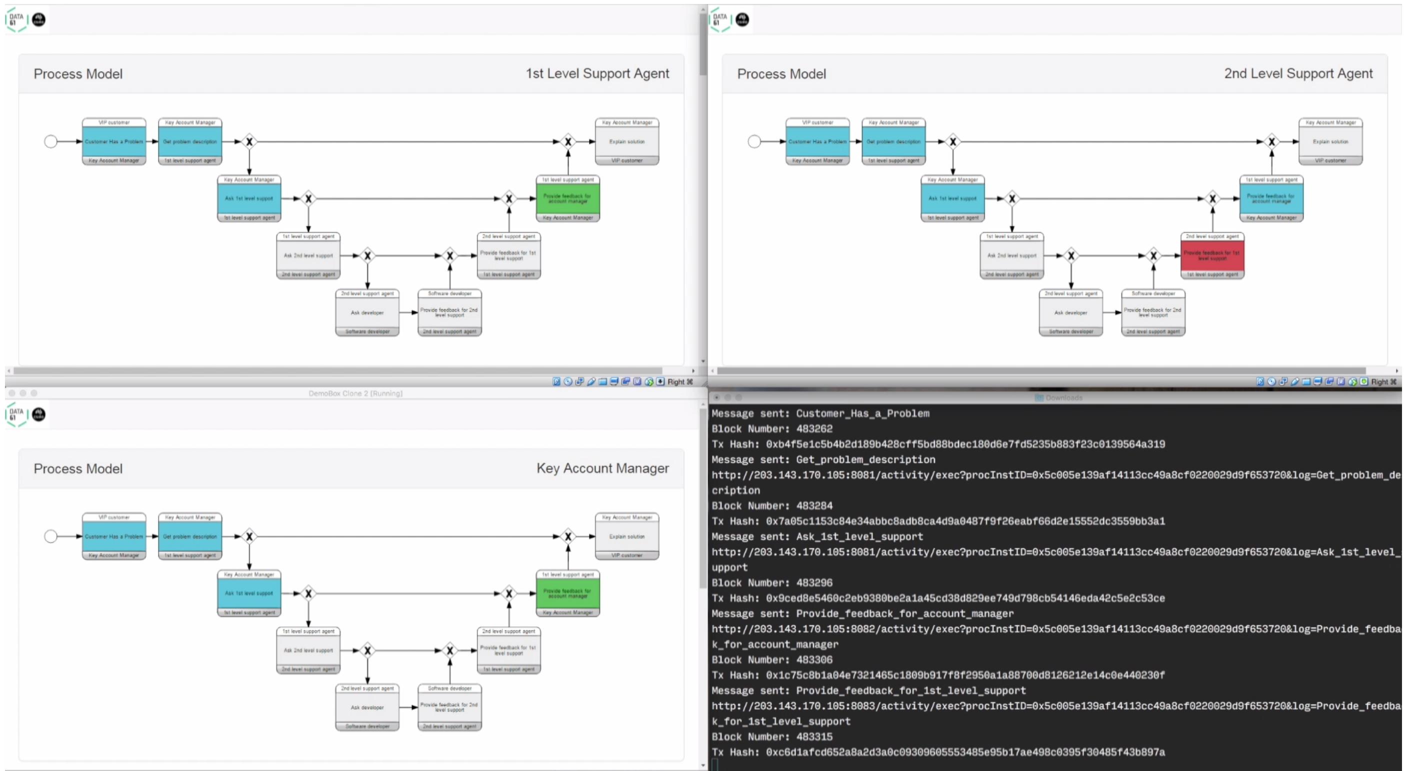


Design time for process models

Demo video: https://drive.google.com/file/d/1rpy-oHbDVkXa6u4Fn73wSX8rINn1sv3U/view



Runtime View of Process Instances



General remarks about developing blockchain applications

- Code is immutable!
- Consequences:
  - Follow **all** security best practices
  - Test heavily
  - Do code reviews
  - Build in features for updating as needed and acceptable for the user base
    - Governance for updates, e.g.: updates will become active only after 1 week / 1 month, …
  - Understand all (relevant) parts of the blockchain system – if you get it wrong, there is no safety net
  - Design includes potentially hard trade-offs between confidentiality and transparency, though patterns exist for resolving parts of those

Integrating Blockchain-based Applications with Services

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Related keynote paper:

Springer Link Search Me...

Australian Symposium on Service Research and Innovation
ASSRI 2018, ASSRI 2018: Service Research and Innovation pp 13-21
| Cite as

Blockchain and Services – Exploring the Links

Keynote Paper

Authors | Authors and affiliations

Ingo Weber

Conference paper
First Online: 06 October 2019

103
Downloads

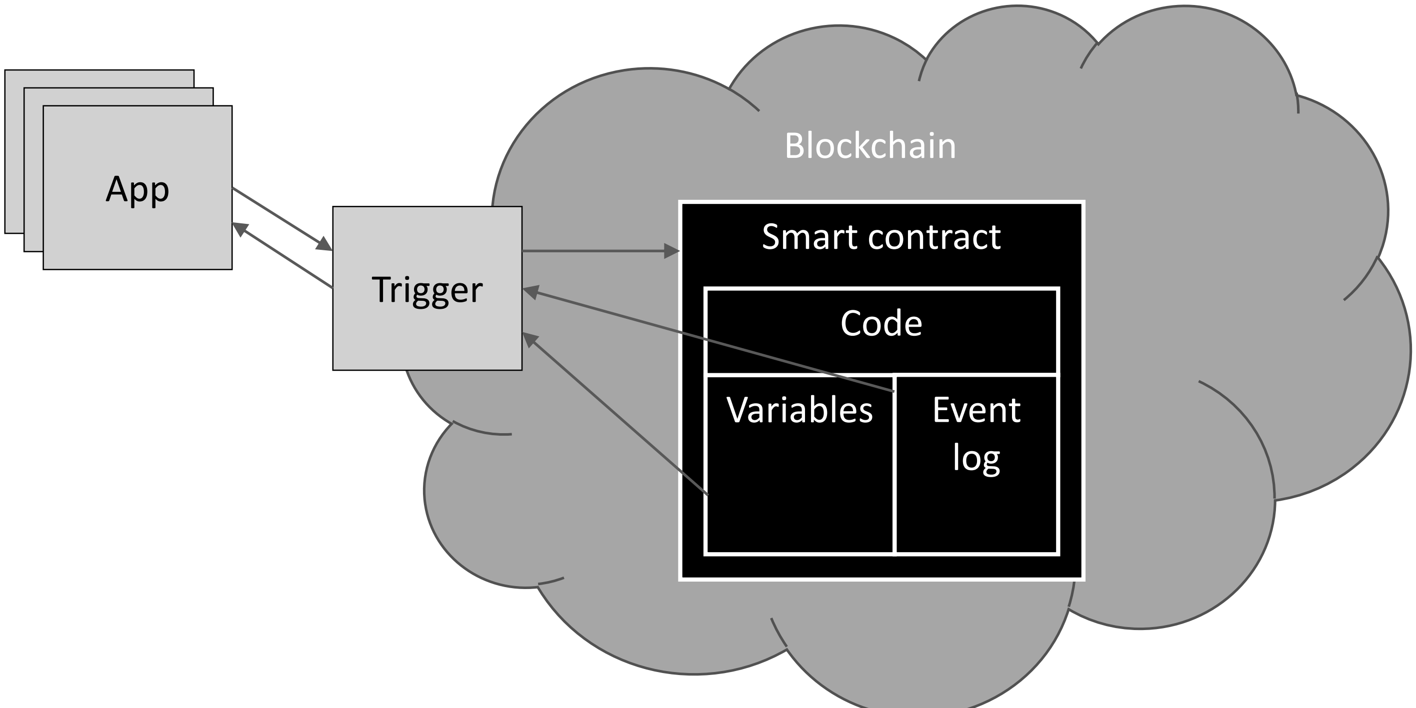
Part of the Lecture Notes in Business Information Processing book series (LNBIP, volume 367)

Ingo Weber. Blockchain and services - exploring the links: Keynote paper. In *ASSRI'18: Australian Symposium on Service Research and Innovation*, pages 13-21, October 2019. [9]

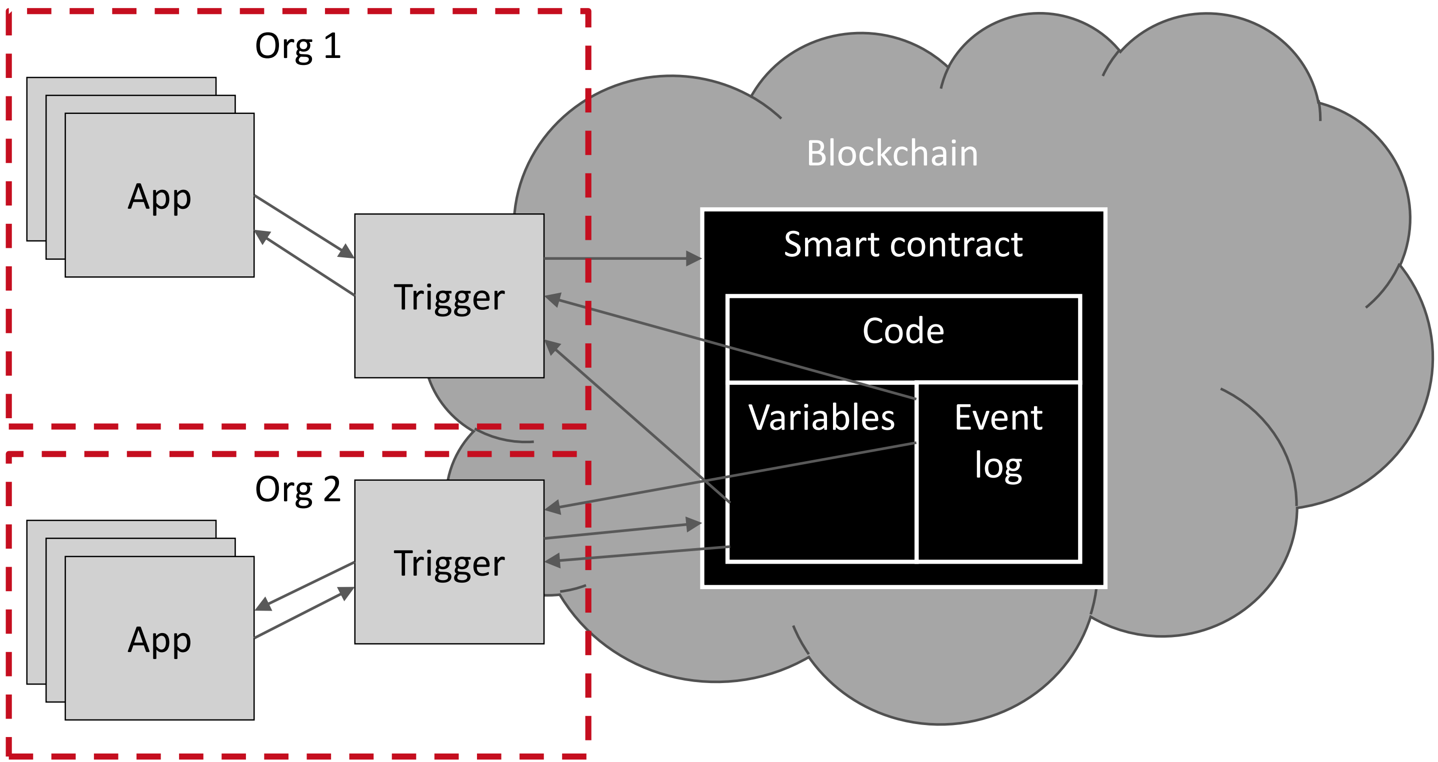
Blockchain is a closed-world system

- To interact with smart contracts on blockchain, need to:
  - Write: create and broadcast a blockchain transaction (BCTX) for each method call
  - Read: monitor smart contract variable values and/or event logs to see updates
- The outside world speaks Services
  - REST / SOAP-WSDL / JSON RPC
- How to bridge between the two worlds?
  - Recurring problem
  - Our solution: a *Trigger* component as bridge

Trigger as bridge between blockchain and services



Decentralization



Blockchain-as-a-Service

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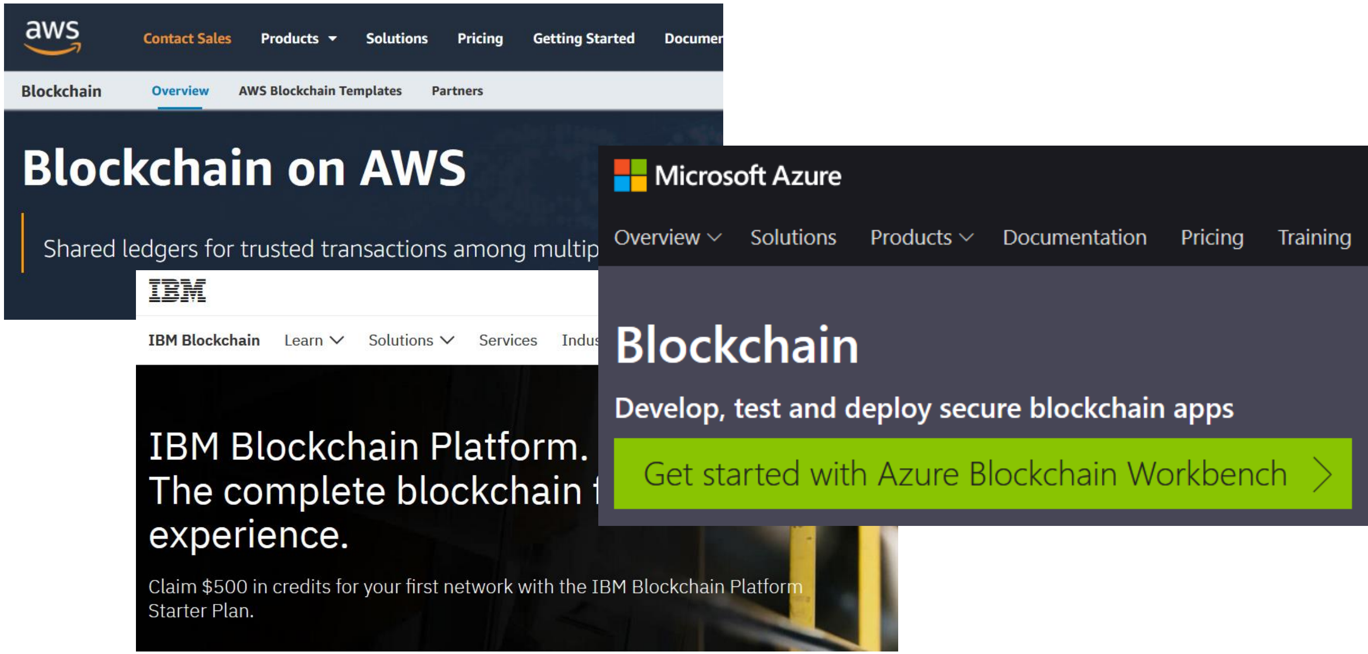
Motivation

- Blockchain is a relatively new technology with steep learning curve
  - Gartner survey: “23 percent of [relevant surveyed] CIOs said that blockchain requires the most new skills to implement of any technology area, while 18 percent said that blockchain skills are the most difficult to find.”
- aaS offers can bootstrap that learning phase to a degree
  - Pre-made templates
  - Management tools
    - IDEs
    - Monitoring tools
    - ...

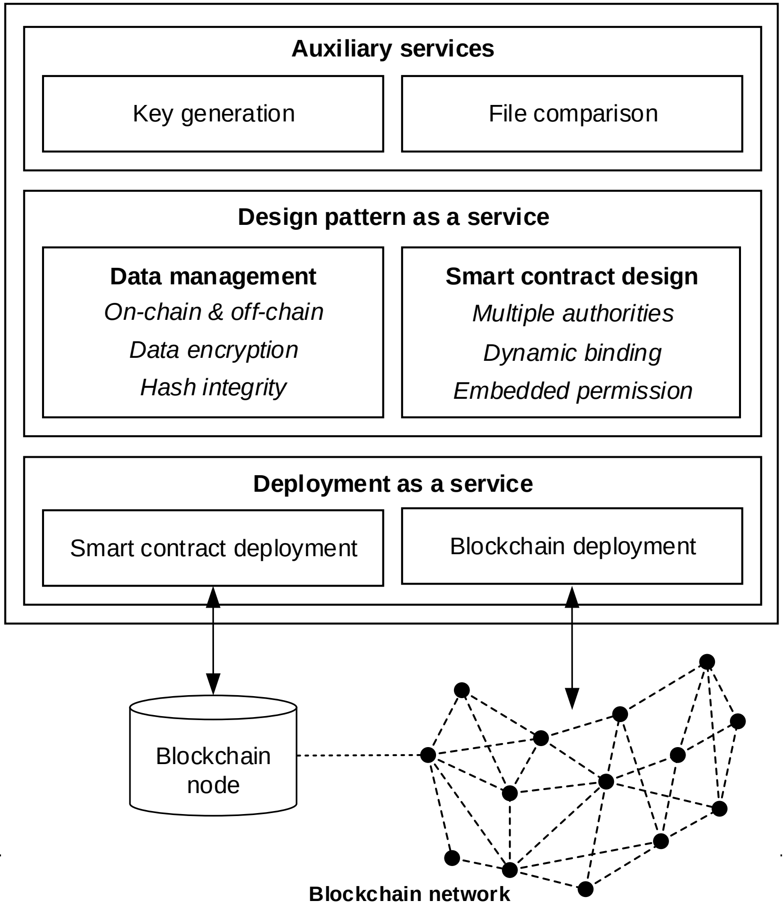
Commercial Offers



- But: what if all nodes are using the same provider?
  - Decentralization?

Unified approach: uBaaS [8]

- Deployment as a service
  - Includes a blockchain deployment service and a smart contract deployment service
  - Platform agnostic to avoid lock-in to specific cloud platforms
- Design patterns as a service
  - Common data management services and smart contract design services
  - Based on a design pattern to better leverage the unique properties of blockchain (i.e. immutability and data integrity, transparency) and address the limitations (i.e. privacy and scalability)



Service-orientation vs. Smart Contracts

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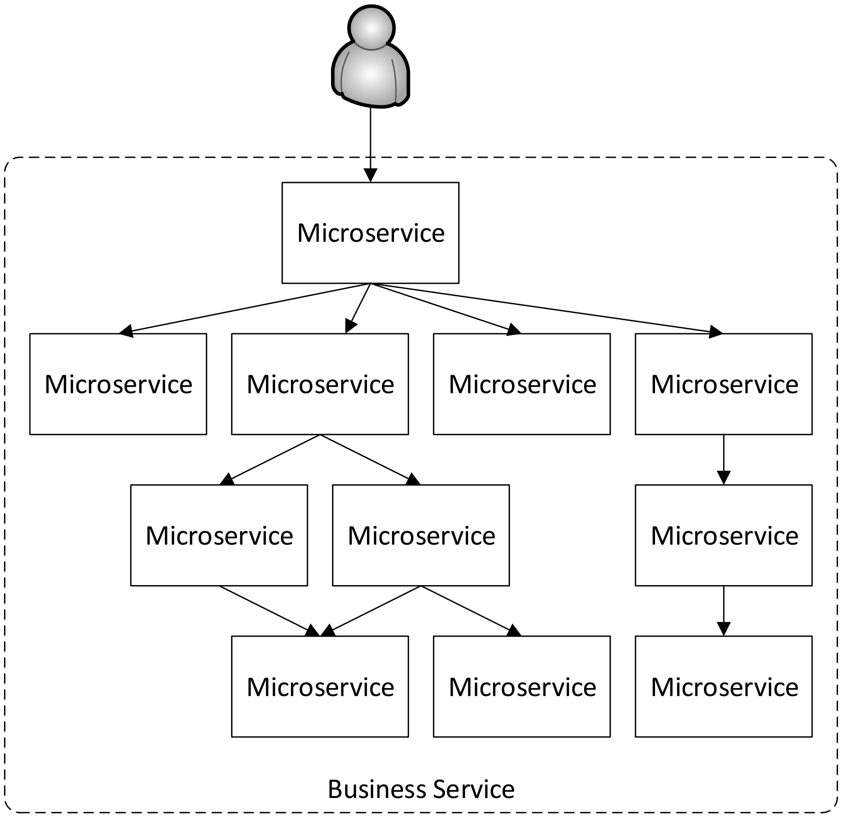
Microservice Architecture



- Each user request is satisfied by some sequence of services
- Most services are not externally available
- Each service communicates with other services through service interfaces
- Service depth may be 70, e.g., LinkedIn

Smart Contracts as Services?

- Analogy:
  - Smart contract code ≈ Java Class
  - Deployed smart contract ≈ Java Object, but with some properties
    - Defined interface
    - Standard way to invoke
    - Callable by anyone (who can send transactions to the blockchain)

  → Similar to Web service!

- Some design principles can apply

Service-Orientation Design Principles

- × **Standardized Service Contract:** the public interfaces of a services make use of contract design standards. (Contract: WSDL in WS*)
- ✓ **Service Loose Coupling:** to impose low burdens on service consumers (coupling ~ degree of dependency)
- × **Service Abstraction:** “to hide as much of the underlying details of a service as possible”
- ~ **Service Reusability:** services contain agnostic logic and “can be positioned as reusable enterprise resources”
- ✓ **Service Autonomy:** to provide reliable and consistent results, a service has to have strong control over its underlying environment
- × **Service Statelessness:** services should be “designed to remain stateful only when required.”
- × **Service Discoverability:** “services are supplemented with communicative meta data by which they can be effectively discovered and interpreted.”
- ~ **Service Composability:** “services are effective composition participants, regardless of the size and complexity of the composition.”
- × **Fundamental requirement – interoperability of services:** “...stating that services must be interoperable is just about as evident as stating that services must exist.”

Based on SOA Principles of Service Design, Thomas Erl, Prentice Hall, 2007, http://serviceorientation.com/serviceorientation.
Summary: I. Weber, Semantic Methods for Execution-level Business Process Modeling. Springer LNBIP Vol. 40, 2009.

Microservice Principles

- ✓ Small, focused functionality
- ✓ Split of responsibility
- ~ Full-stack & independently updatable without downtime
- × Stateless

- While some design principles for Microservice Architectures apply, others do not
  - Updates *can* be independent
  - But reliance on the *inability* of anyone to update without agreement / governance is one source of trust in a smart contract


Selected Applications & Adoption

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Selected Blockchain Projects

- Australian Securities Exchange:
  - Settlement of trades to be sped up from 2-3 days to minutes, freeing up billions of $$
  - In industry engagement, revision based on feedback and testing ongoing
  - Go-live of the blockchain system planned for 2021 / 2022

Picture source: modum.io

- Modum.io:
  - Ensure drugs do not exceed a temperature threshold
    - Tamper-proof IoT device & blockchain storage of data
  - Otherwise: use refrigeration trucks, 4-8x pricier

- Lygon.io
  - Joint initiative by Australian Banks
  - Platform for blockchain-based bank guarantees for commercial property leases
    - “Before Lygon, issuing a paper bank guarantee took up to a month. Today, Lygon achieves same-day issuance.”
  - Digital bearer instrument

Programmable Money [16]: core idea

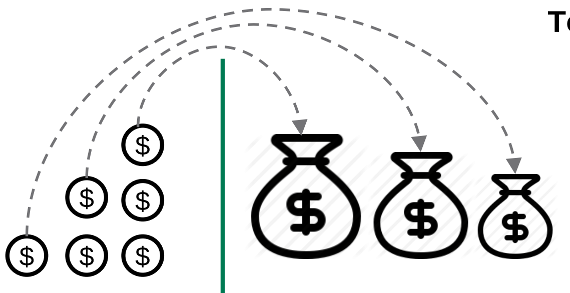
- Conditional payments: the transfer money only when predefined rules hold.
  - Examples: welfare payments, employee expenses, insurance payouts, ...
- Traditionally: conditions are checked (manually) in reimbursement or pre-approval/audit processes
  - Violation of policies: no reimbursement (or similar)

- Programmable money: next-generation conditional payments, on decentralized ledger / blockchain.
- In our programmable money project: programmed policies are not attached to accounts, but instead to money itself!
  - Policies here specify under which conditions money may be spent
  - When you try to spend money, the **money itself checks** automatically if a payment adheres to the policies
    → no uncertainty whether you will get reimbursed (and other benefits)

Programmable Money (“making money smart”)

Use case: National Disability Insurance Scheme (NDIS)

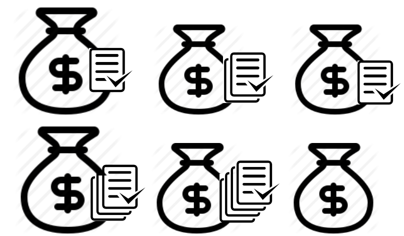
Tokens and Contracts



Tokens represent value of AUD for NDIS purchases.

Pouches represent different quantities of tokens.

Policy contracts stipulate rules and enforcements (e.g. ownership, eligible services, nominations, etc).

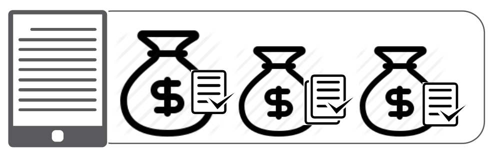


Smart tokens are formed when policy contracts are attached to pouches. Contracts can be destroyed when no longer required (e.g. after payment).

Provider Registry Contract

Providers are registered on a large policy contract.

Participant plans

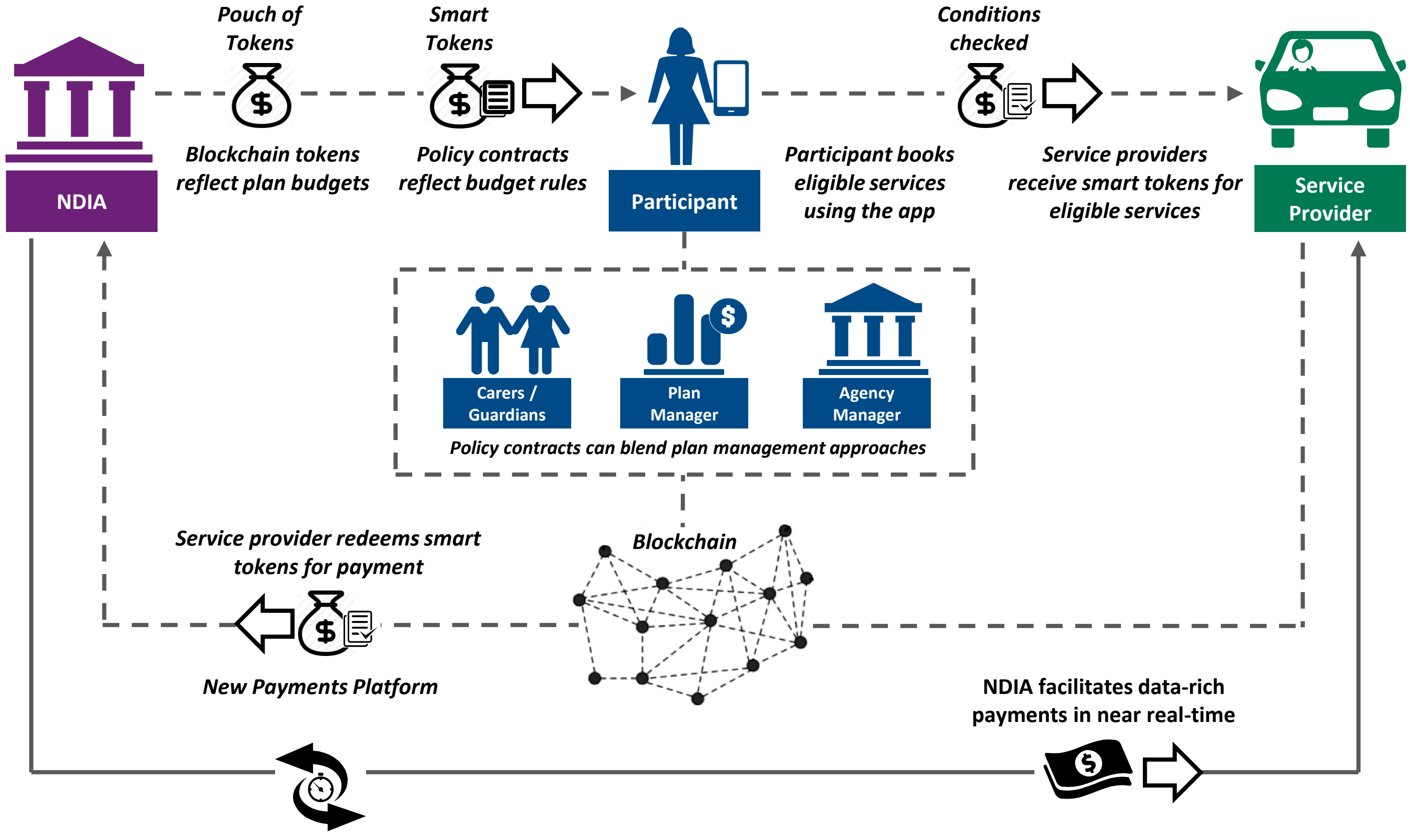


Participant plans have pouches of smart tokens for different budgets, which can be spent on services from providers.

Service Agreement Contracts

Service agreements provisionally attach tokens to providers and enable payments as services are delivered.

Programmable Money: our NDIS proof of concept



Programmable Money: further notes

- Many more details contained in the keynote paper

  Ingo Weber and Mark Staples. *Programmable money: Next-generation conditional payments using blockchain - keynote paper*. In CLOSER'21: International Conference on Cloud Computing and Services Science, April 2021.

- Including lessons learnt and some open questions, for programmable money and development of blockchain apps in general. Examples:
  - How to present the policies in a way that the users can understand them?
  - How to horizontally scale components that create and submit transactions on behalf of a single party?

Selected blockchain adoption examples

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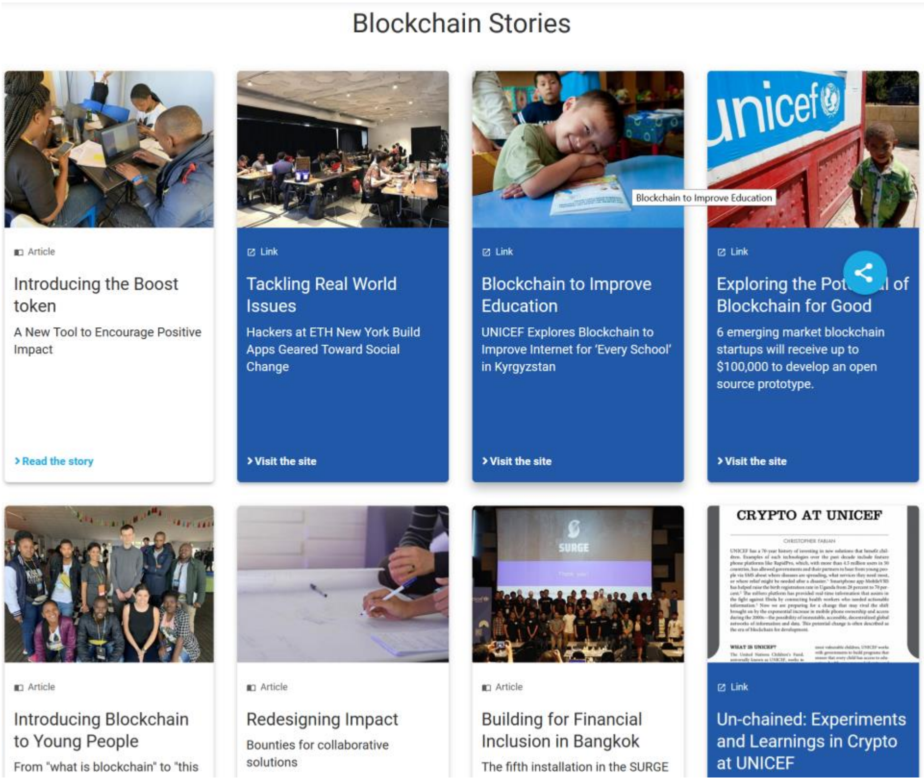

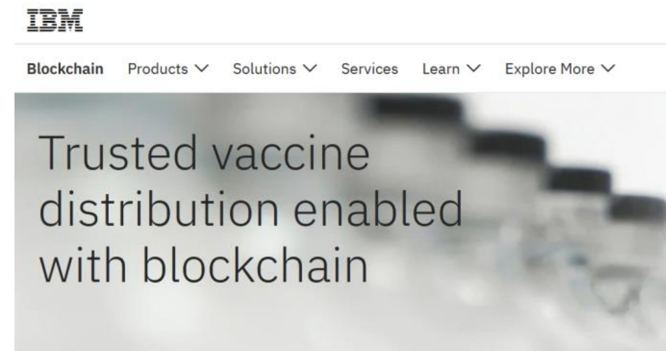

https://www.unicef.org/innovation/blockchain

Summary

- Blockchain basics and terminology
- Designing and developing blockchain applications
  - Architecture & design
  - Model-driven engineering
- Blockchain and Services:
  - Integrating Blockchain-based Applications with Services
  - Blockchain-as-a-Service
  - Service-orientation vs. Smart Contracts
- Programmable money
- Blockchain adoption

Blockchain Application Design and Development, and the Case of Programmable Money

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CLOSER'21 Keynote

Prof. Dr. Ingo Weber | April 2021

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