Blockchain in Software Architecture 2: NFPs and design trade-offs

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Outline

- PITCH SESSION!
- What is Software Architecture?
  - Components, Connectors, Configuration
  - Non-Functional Properties (NFPs)
  - Models: Views and Viewpoints
  - NFP Analysis and Trade-offs
- Blockchain in Software Architecture
  - Blockchain as Component, Connector, Configuration
  - Blockchain Component Services
- Design and Trade-offs in Blockchain-based Applications
- Summary

What is Software Architecture?

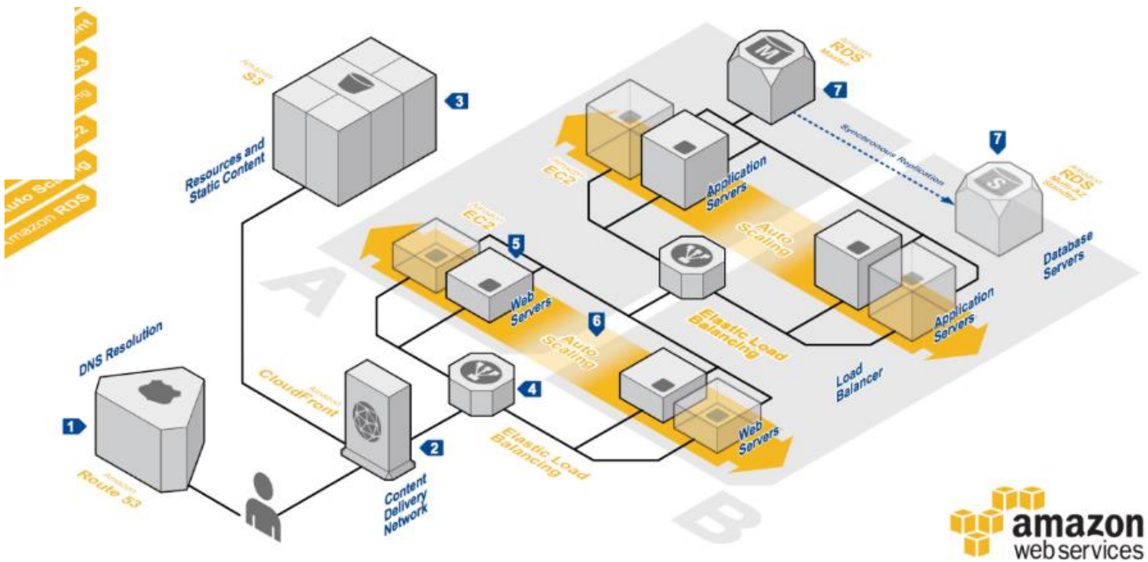
Every software system has a software architecture

- *"The set of structures needed to reason about the system, which comprises software elements, relations among them, and properties of both"*

- Diagrams/ Documentation
- Designing
  - (But not all design is architecture)
- Discipline/ Practice/ Profession
- Discovery (Research Area)
  - Starting in 1960s, increasing interest since 1990s

Software Architecture Elements

- A software system's architecture is typically not a uniform monolith
  - Component, Connector, and Configuration



Software Component

- Software components are the fundamental building blocks for software architecture
- A software component is an architectural entity that
  - Encapsulates a subset of the system's functionality and/or data
  - Restricts access to that subset via an explicitly defined interface
  - Has explicitly defined dependencies on its required execution context

- Components typically provide application-specific services

Software Connectors

- In complex systems interaction may become more important and challenging than the functionality of the individual components

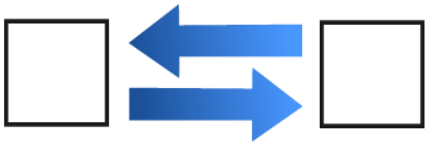
- Architectural building block tasked with effecting and regulating interactions among components

- Connectors typically provide application-independent interaction facilities
  - **Communication**: transfer data
  - **Coordination**: transfer control
  - **Facilitation**: enable and optimise component's interactions
  - **Conversion**: adjust the interactions between incompatible interfaces

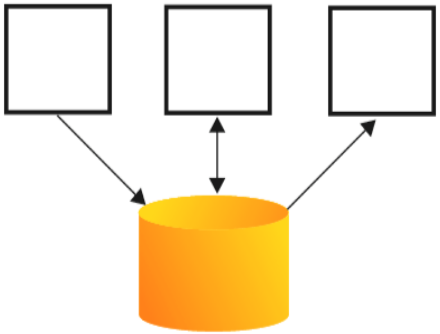
Example Software Connectors

File Transfer

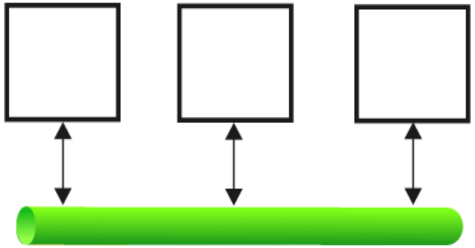
Stream



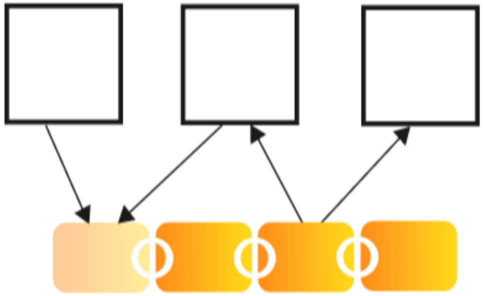
Remote Procedure Call



Shared Database



Message Bus



Blockchain

Architecture defines system structure

- Decomposition of system into components/modules/subsystems
- Architecture defines:
  - Component interfaces
    - What a component can do
  - Component responsibilities
    - Precisely what a component will do when you ask it
  - Component connections and dependencies
    - How components are related to each other through their interfaces

- Can we infer system properties from element properties?

Architecture specifies component communication

- Data passing mechanisms, e.g.:
  - Function call
  - Remote method invocation
  - Asynchronous message

- Control flow
  - Flow of messages between components
  - Sequential
  - Concurrent/parallel
  - Synchronization

Non-Functional Properties and Requirements

- There are two kinds of requirements:
  1. Functional Requirements (i.e. what are the inputs and outputs)
  2. Non-Functional Requirements (a.k.a. *Qualities*, or *-illities*)
     - e.g. “Performance” (latency, throughput, …)
     - e.g. “Security” (confidentiality, integrity, availability, privacy, …)
     - e.g. Usability, Reliability, Modifiability, …
     - Cost
     - Technical and business constraints

ISO/IEC 25010:2011 Quality Model

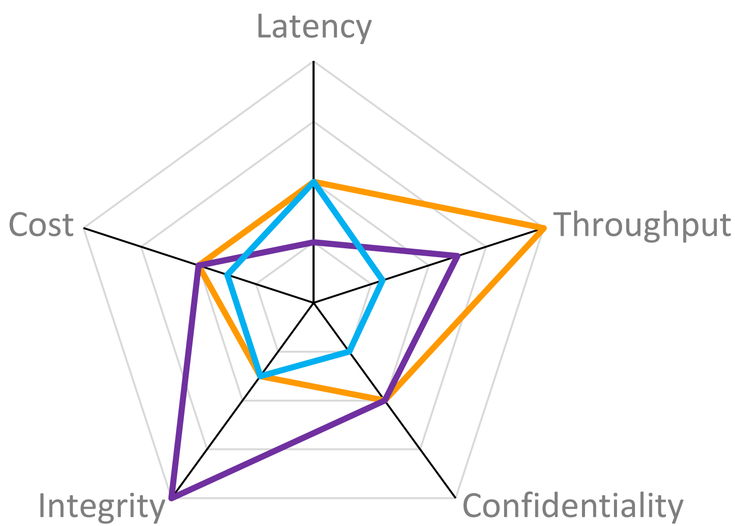
- **Functional suitability**
  - Functional correctness
  - Functional complete-ness
  - Functional appropriate-ness
- **Performance efficiency**
  - Capacity
  - Resource utilization
  - Time behavior
- **Compatib-ility**
  - Interop-erability
  - Co-existence
- **Usability**
  - Operability
  - User error protection
- **Reliability**
  - Availability
  - Recoverab-ility
  - Maturity
  - Fault tolerance
- **Security**
  - Integrity
  - Confidential-ity
  - Non-repudiation
  - Accountab-ility
  - Authent-icity
- **Maintain-ability**
  - Modularity
  - Reuseability
  - Modifiab-ility
  - Testability
  - Analyzab-ility
- **Portability**
  - Installability
  - Replace-ability
  - Adaptability

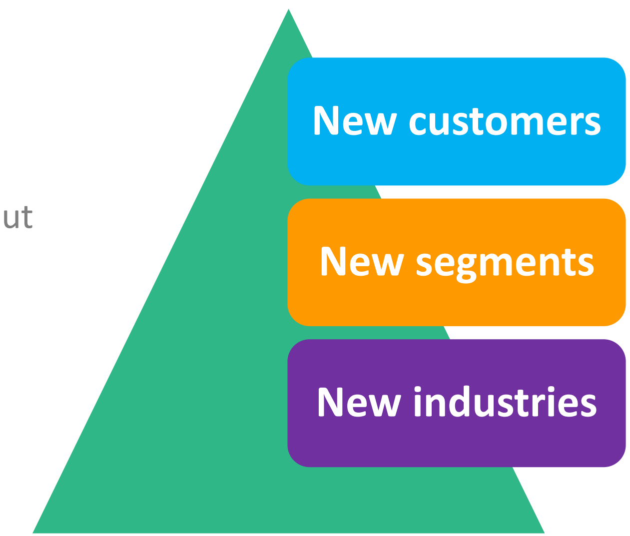
Why Non-Functional Properties Matter

Regulatory Requirements

System Performance

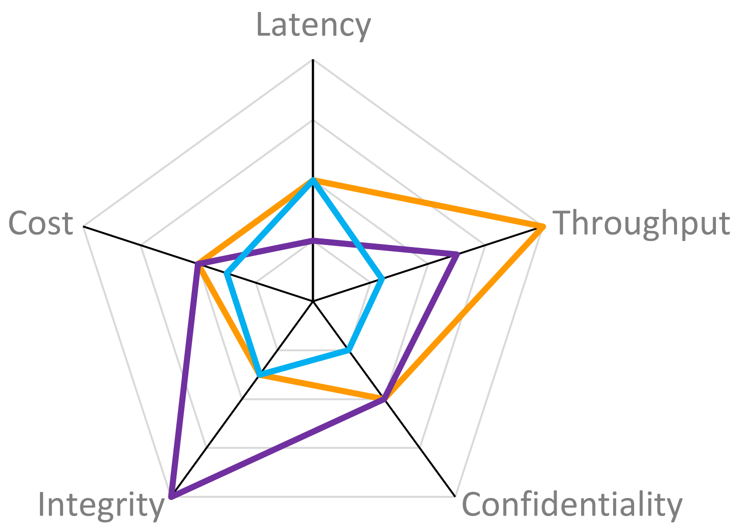
Market Opportunities

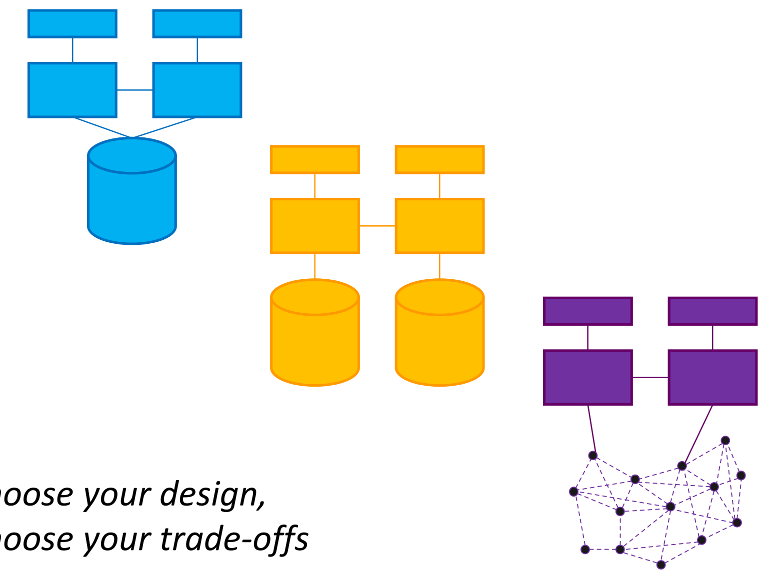




Software Architecture

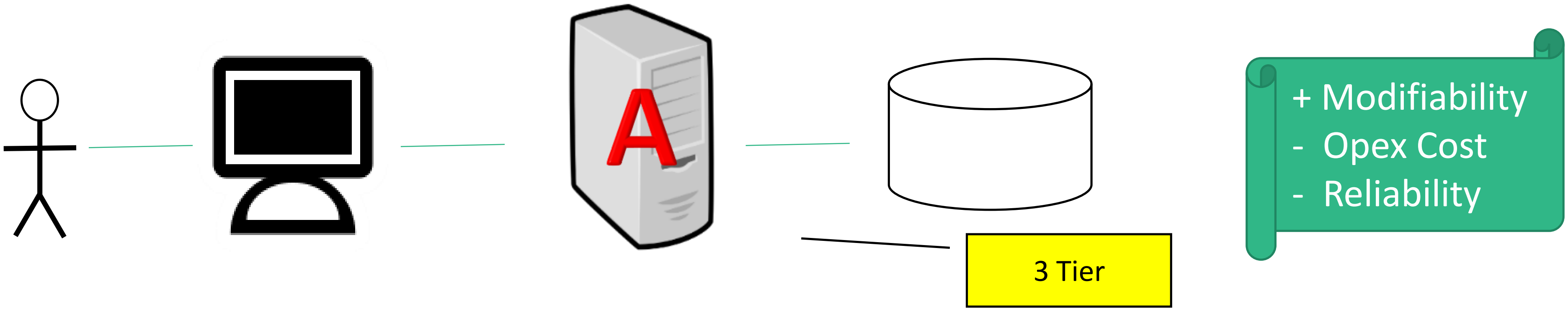
<u>Non-Functional Properties arise from Architectural Design Choices</u>



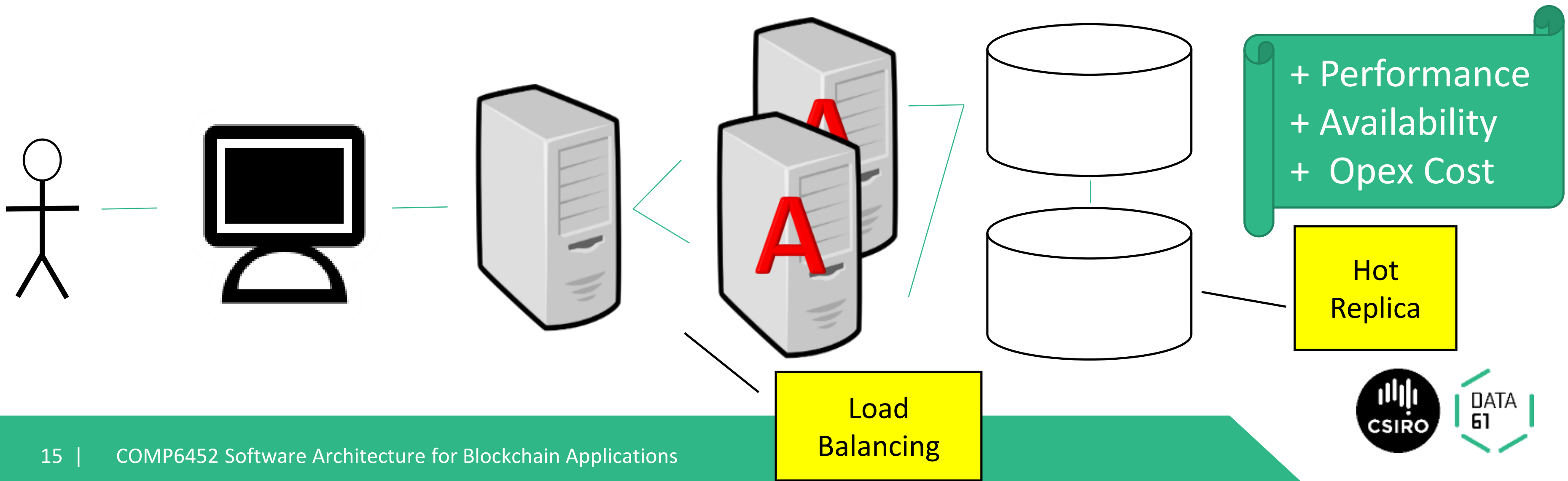


Choose your design,
Choose your trade-offs

For Example...



A
3 Tier
+ Modifiability
- Opex Cost
- Reliability



A
A
Load Balancing
Hot Replica
+ Performance
+ Availability
+ Opex Cost

Architecture is an Abstraction

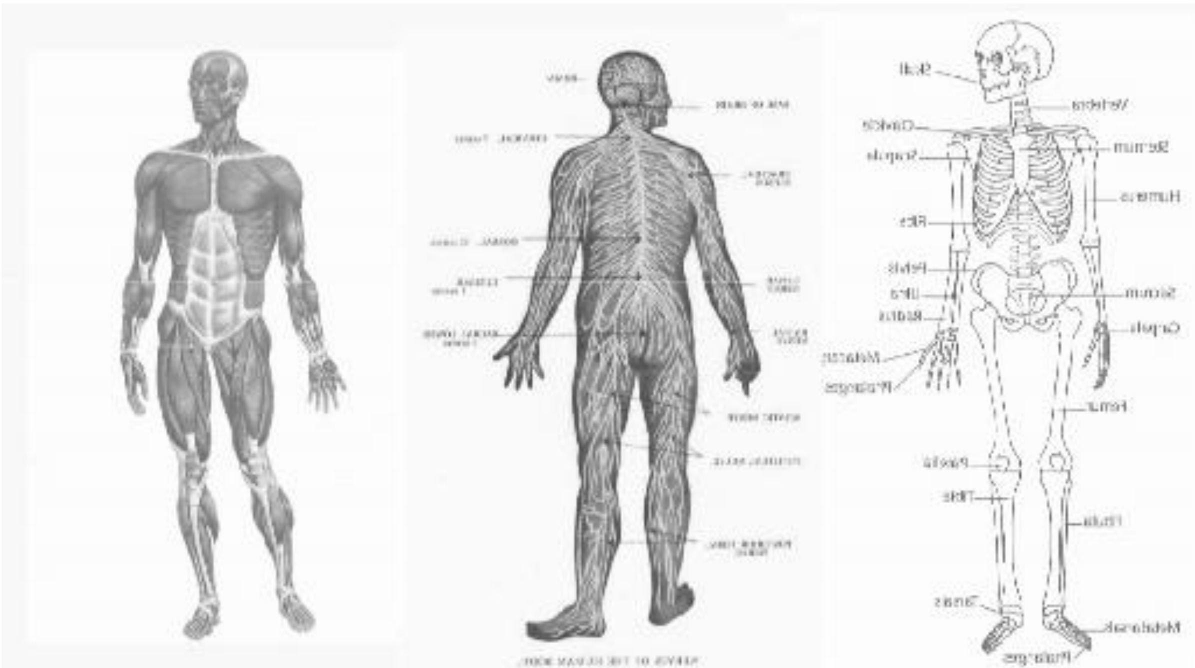
- Architecture provides an abstract view of a design
  - Hides complexity of design
  - May or may not be a direct mapping between architecture elements and software elements
    - e.g. “marketecture”

- “All models are wrong, but some models are useful”

  - Box

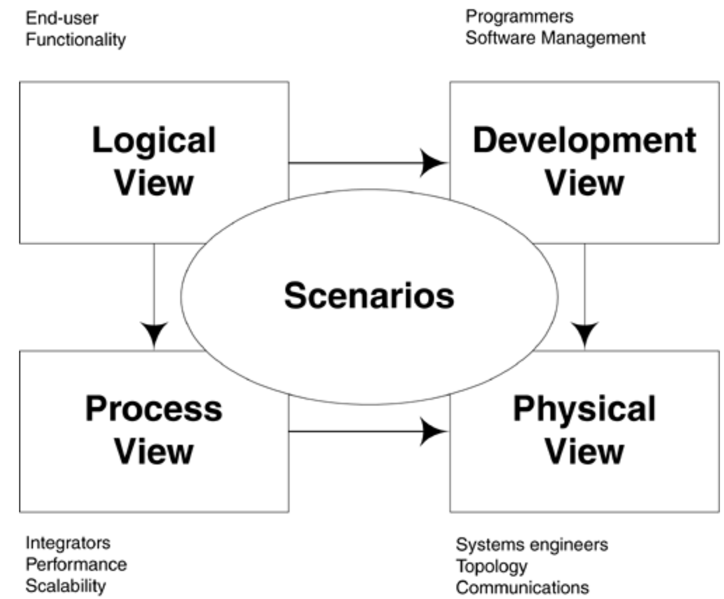
- Discussion: Why Abstraction?

Viewpoints and Views

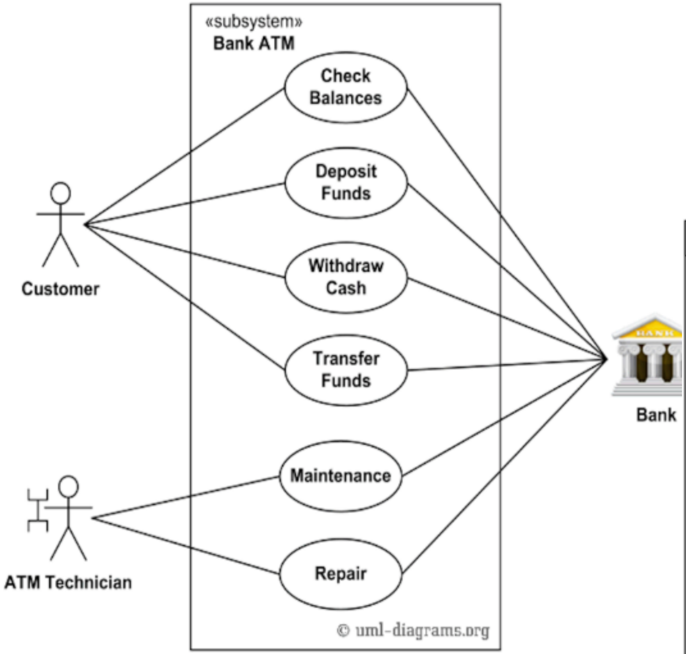


Krutchen's 4+1 View Model

- **Logical**: architecturally-significant elements and the relationships between them.
- **Process**: concurrency and communications elements
- **Physical**: how the major processes and components are mapped to applications hardware
- **Development**: internal organization of the software components as held in e.g. a configuration management tool
- **Use cases**: requirements for the architecture; related to more than one particular view

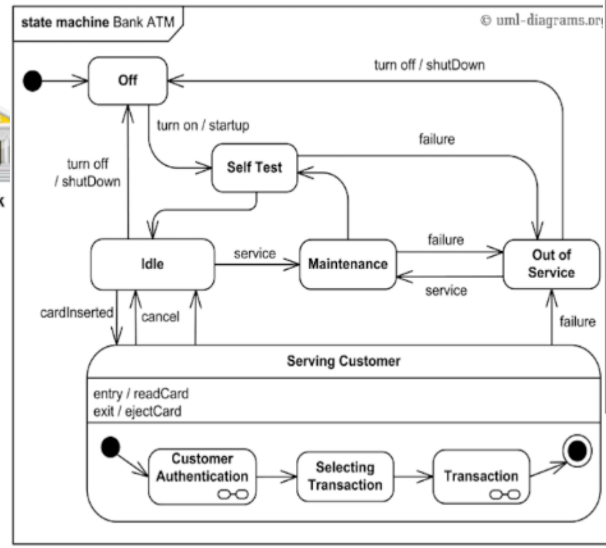


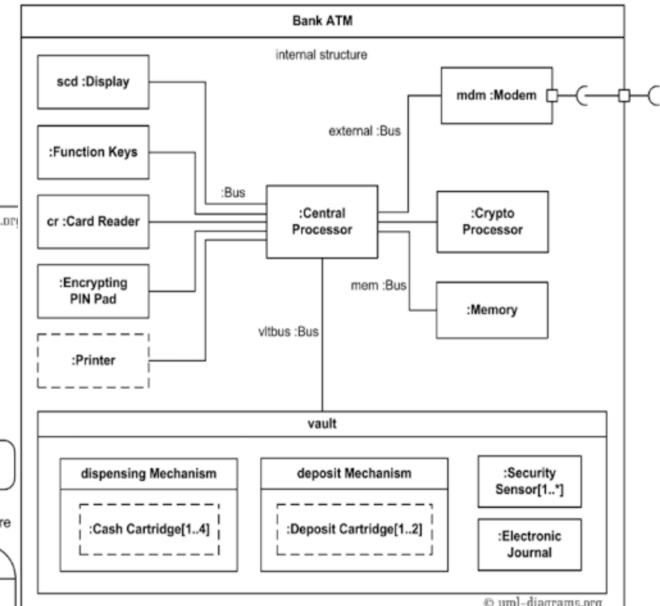
UML as Viewpoints and Views



UML Use Case

UML Statechart





UML Composite Structure

Architecture Analysis Methods

- Analysis is one of the important uses of models

- e.g. does this design support service availability?
  - (Quantitative) fault-tree statistical analysis
  - (Qualitative) failure scenarios

- e.g. What is the transaction latency in this design?
  - (Quantitative) Simulation-based prediction of latency distributions
  - (Quantitative) Formula-based calculation of average latency

- e.g. Will this design ensure confidentiality?
- e.g. Is this design easily modifiable?

- Different kinds of models allow different kinds of analyses

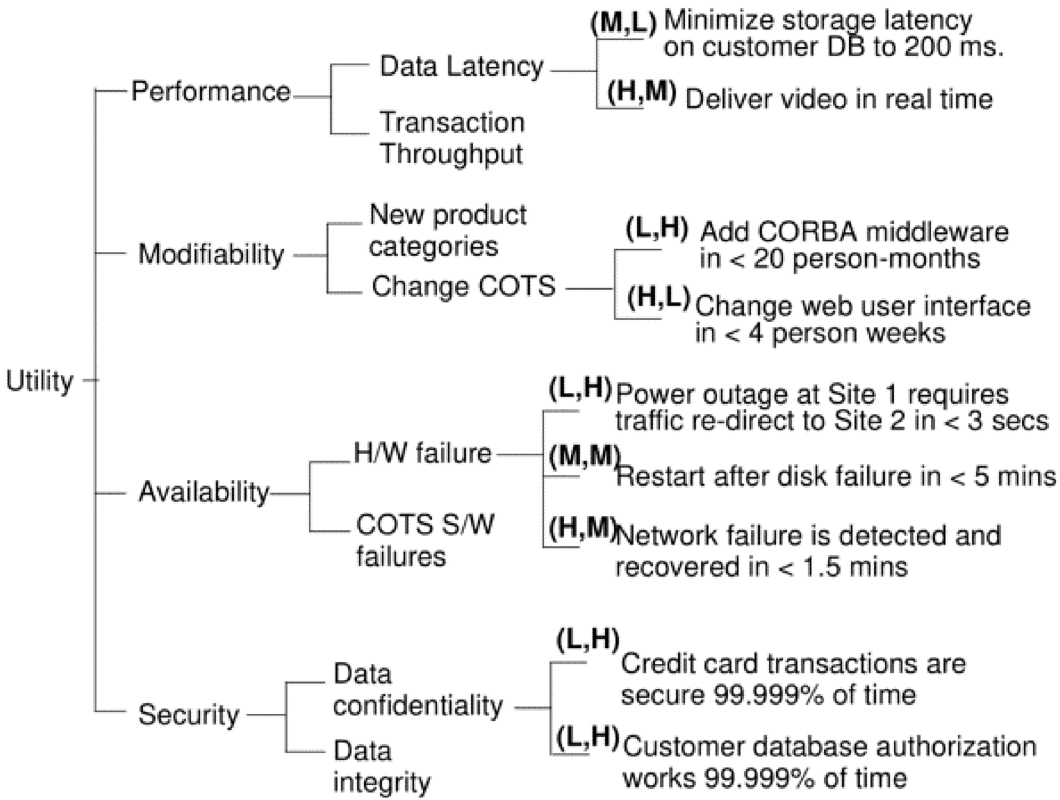
Design Trade-offs

- Often, improving one quality will hurt another one
  - e.g. Use a bigger server
    - faster, but more expensive
  - e.g. Use redundant servers
    - better availability (hot fail-over)? Or better performance (load balancing)? Worse write latency? more expensive
- What are the trade-offs? How should you choose?
- Specific methods exist to help
  - ATAM: Architecture Trade-off Analysis Method
  - Multi-criteria decision-making methods

ATAM

- Presentation
  1. Present ATAM
  2. Present Business Drivers (NFPs and other business goals)
  3. Present Architecture
- Investigation & Analysis
  4. Identify Architectural Approaches
  5. Generate Quality Attribute Utility Tree (& initial use case scenarios)
  6. Analyse Architectural Approaches
  7. Brainstorm & Prioritise Scenarios
  8. Analyse Architectural Approaches (using scenarios as test cases)
- Reporting
  9. Present Results (summary, risks, sensitivities/trade-offs, …)

ATAM Quality Attribute Utility Tree



(Importance, Risk to Achieve)

Example from “ATAM: Method for Architecture Evaluation” (Kazman et al., 2000)
https://resources.sei.cmu.edu/asset_files/TechnicalReport/2000_005_001_13706.pdf

ATAM Scenarios

Scenario: S12 (Detect and recover from HW failure of main switch.)

Attribute: Availability

Environment: normal operations

Stimulus: CPU failure

Response: 0.999999 availability of switch

Architectural decisions	Risk	Sensitivity	Tradeoff
Backup CPU(s)	R8	S2	
No backup Data Channel	R9	S3	T3
Watchdog		S4	
Heartbeat		S5	
Failover routing		S6	

Reasoning:

- ensures no common mode failure by using different hardware and operating system (see Risk 8)

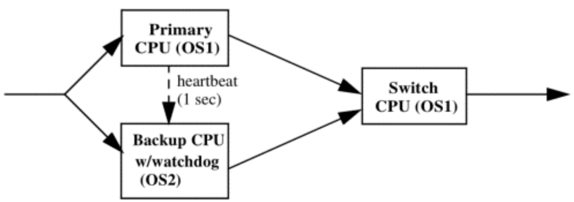
- worst-case rollover is accomplished in 4 seconds as computing state takes …

- guaranteed to detect failure with 2 seconds based on rates of heartbeat and watchdog …

- watchdog is simple and proven reliable

- availability requirement might be at risk due to lack of backup data channel … (see Risk 9)

Architecture diagram:



- Scenarios are commonly used in Software Architecture
  - In ATAM, links attributes, risks, trade-offs, & reasoning about architecture design
- Qualitative – identify and evaluate risks
- Methodical, but not exhaustive

Example from “ATAM: Method for Architecture Evaluation” (Kazman et al., 2000)
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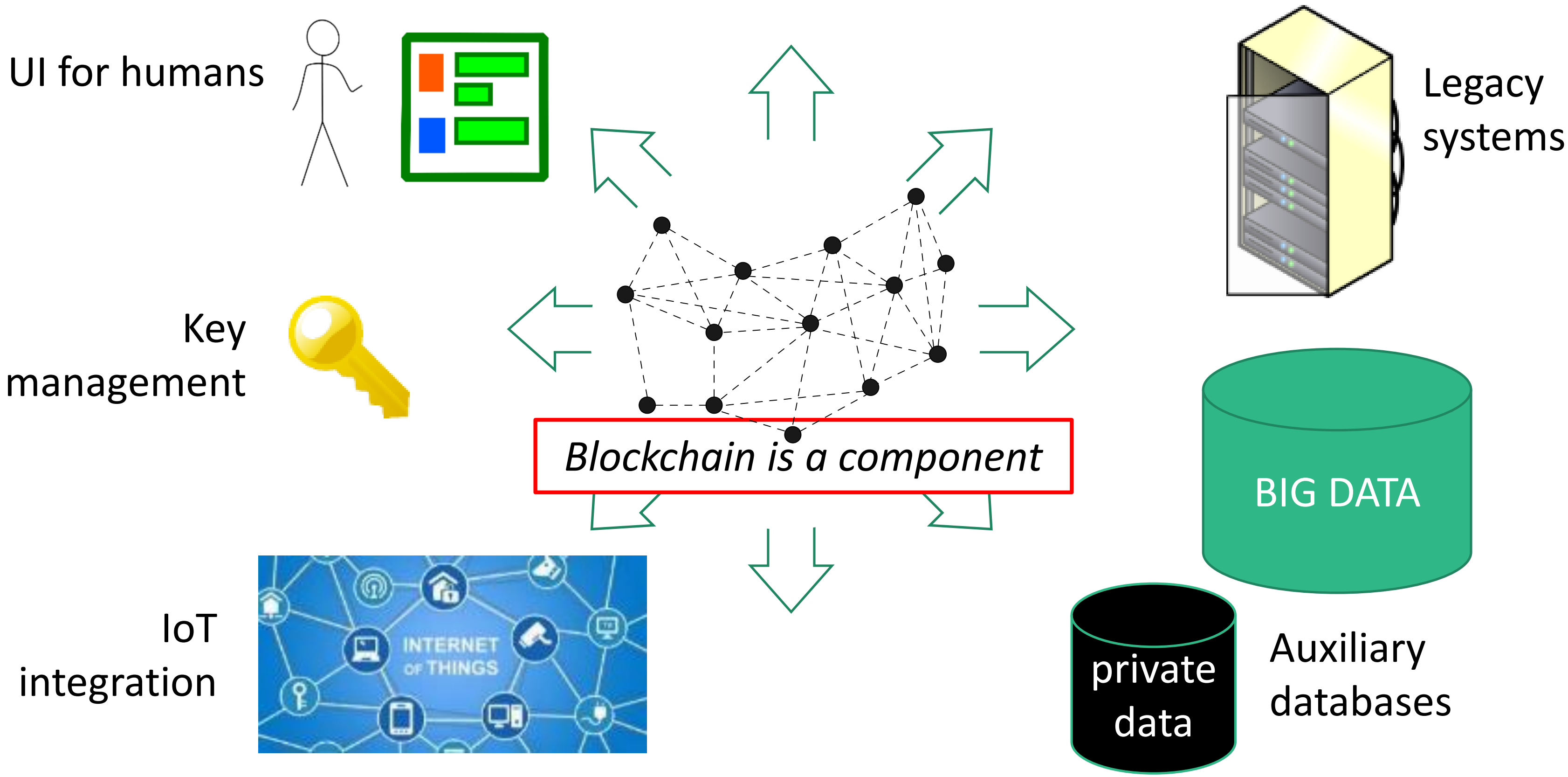
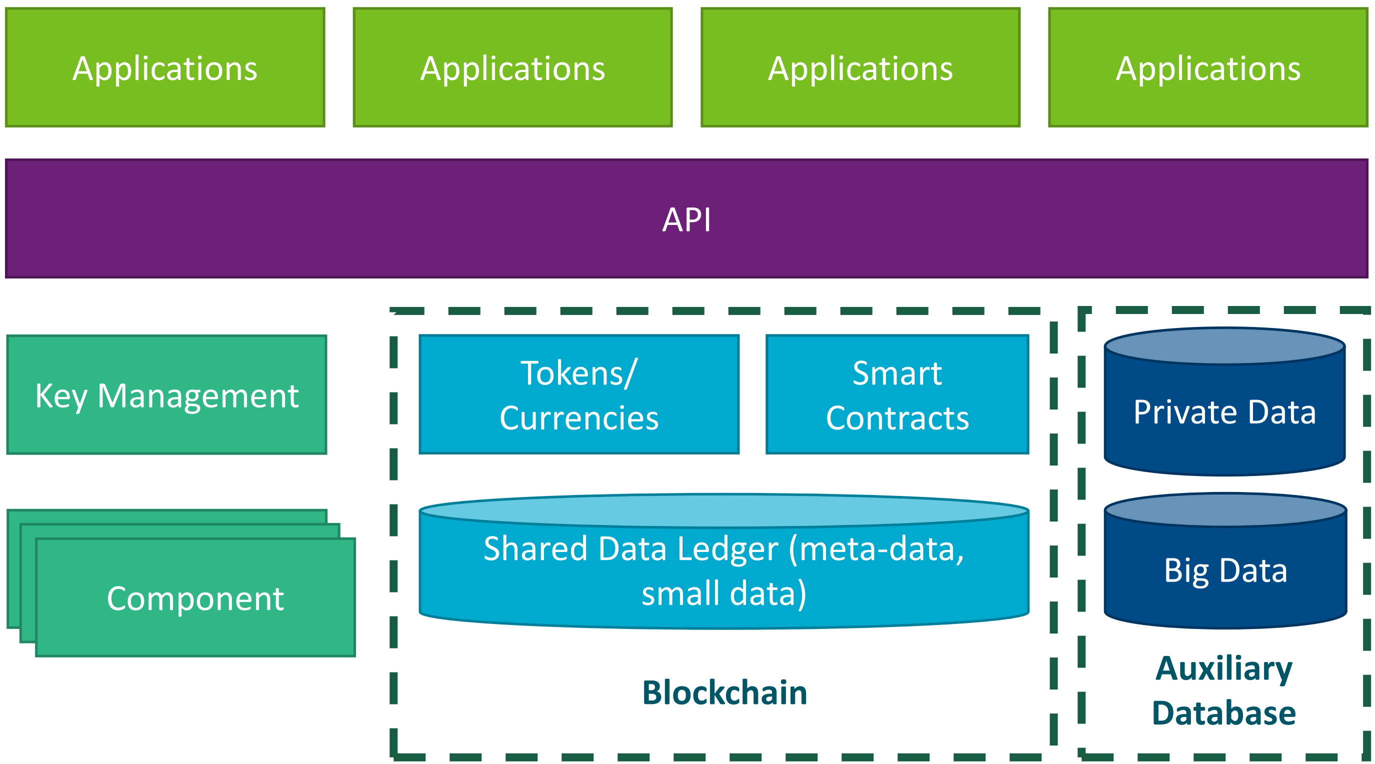
Blockchain in Software Architecture

Blockchains are Not Stand-Alone Systems



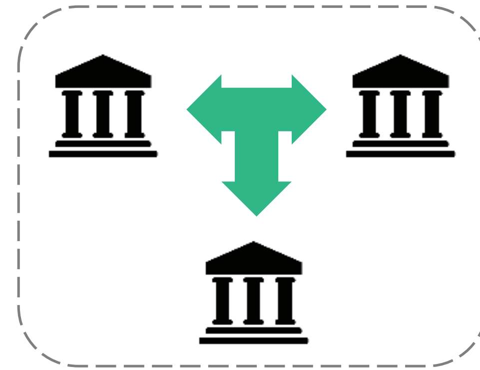
Blockchain in Larger Software System



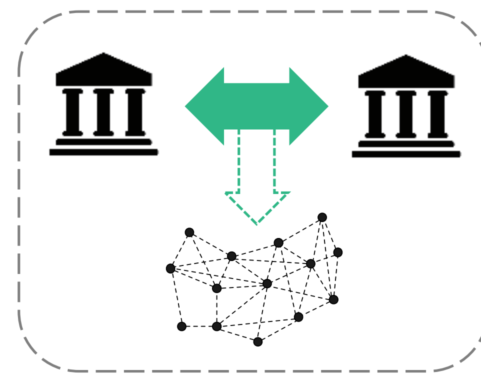
What Does a Blockchain Do?

- Functionally, blockchains are…
- A database (ledger)
  - Record of transactions
- A compute platform
  - “Smart contracts”
- Distributed, and no central owner

Centralised Trust using a Third-Party



Distributed Trust using a Blockchain



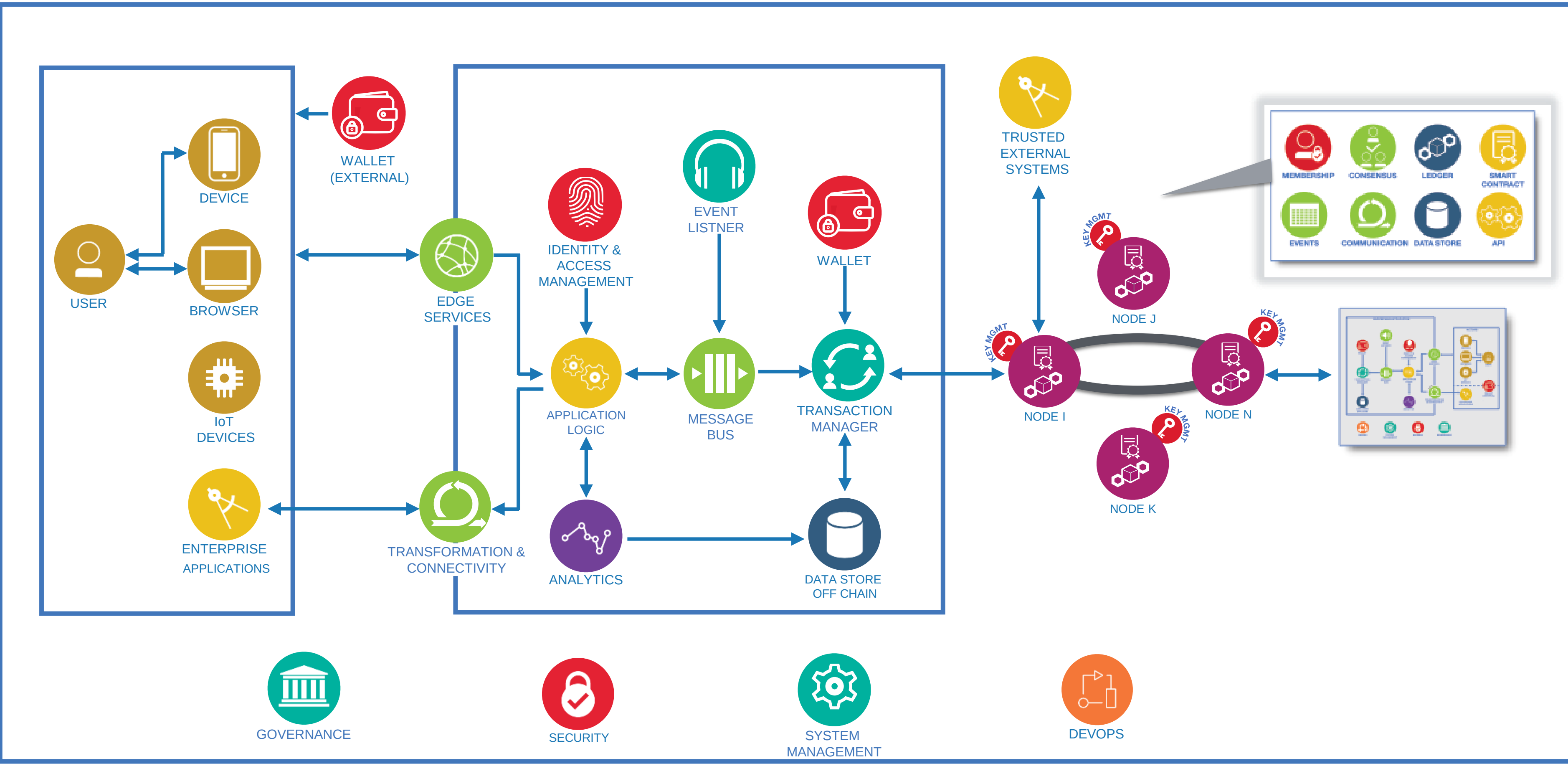
Blockchain as a Software Component

- Complex, network-based software component

- Providing services
  - Data storage
  - Computation services
  - Communication services
  - Asset management

- Features
  - Cryptographically-secure payment
  - Mining
  - Transaction Validation
  - Incentive mechanism
  - Permission management

An Example Blockchain Reference Architecture



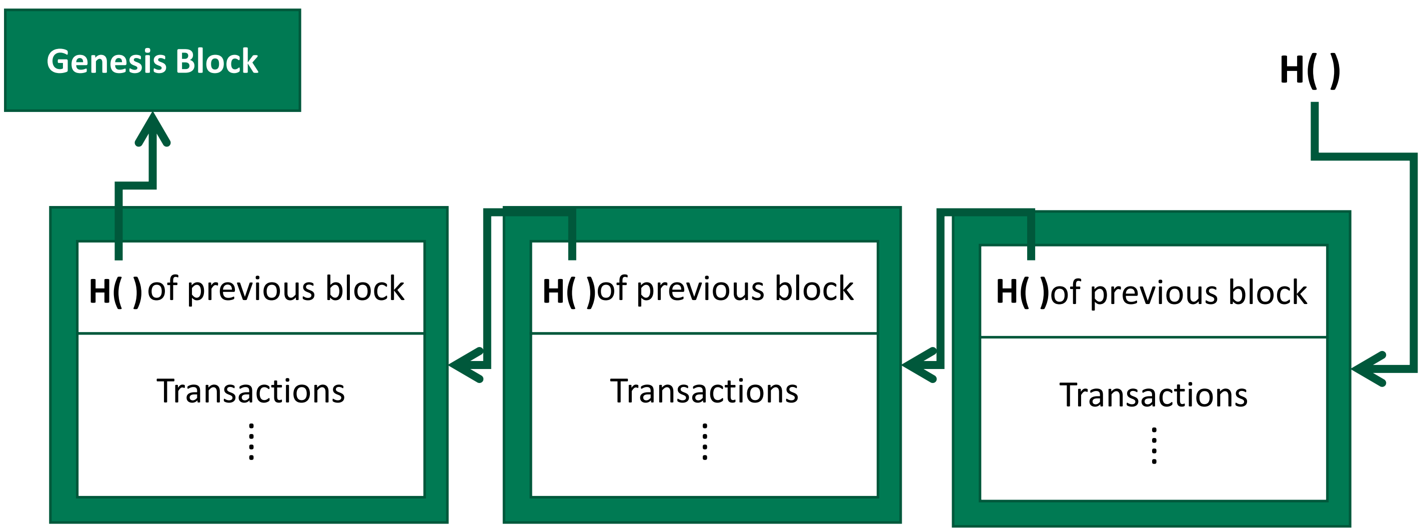
https://www.ibm.com/cloud/garage/architectures/blockchainArchitecture/reference-architecture

Blockchain Component Service Options

- **Data Storage**
- Computation Service
- Communication Service
- Asset Management

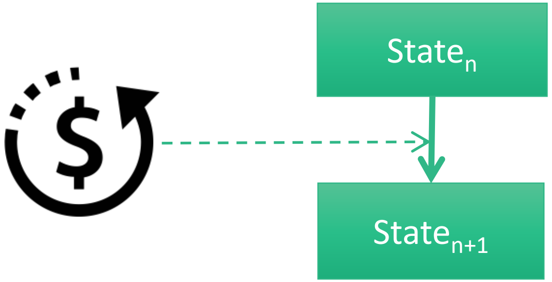
Blockchain as Storage Element

- Blockchain data structure
  - Linked list with hash pointers
- Tamper-proof
  - Computational constraints
  - Incentive scheme



Blockchain as Storage Element

- Transaction Integrity
  - Transactions represent authorized state transitions
  - Transactions can record data
  - Transaction can transfer control of digital assets among participants
    - Crypto-currencies
    - Smart contract-based digital assets
  - Public key cryptography and digital signature are used to identify accounts
    - Ensure integrity and authorization of transactions initiated on a blockchain

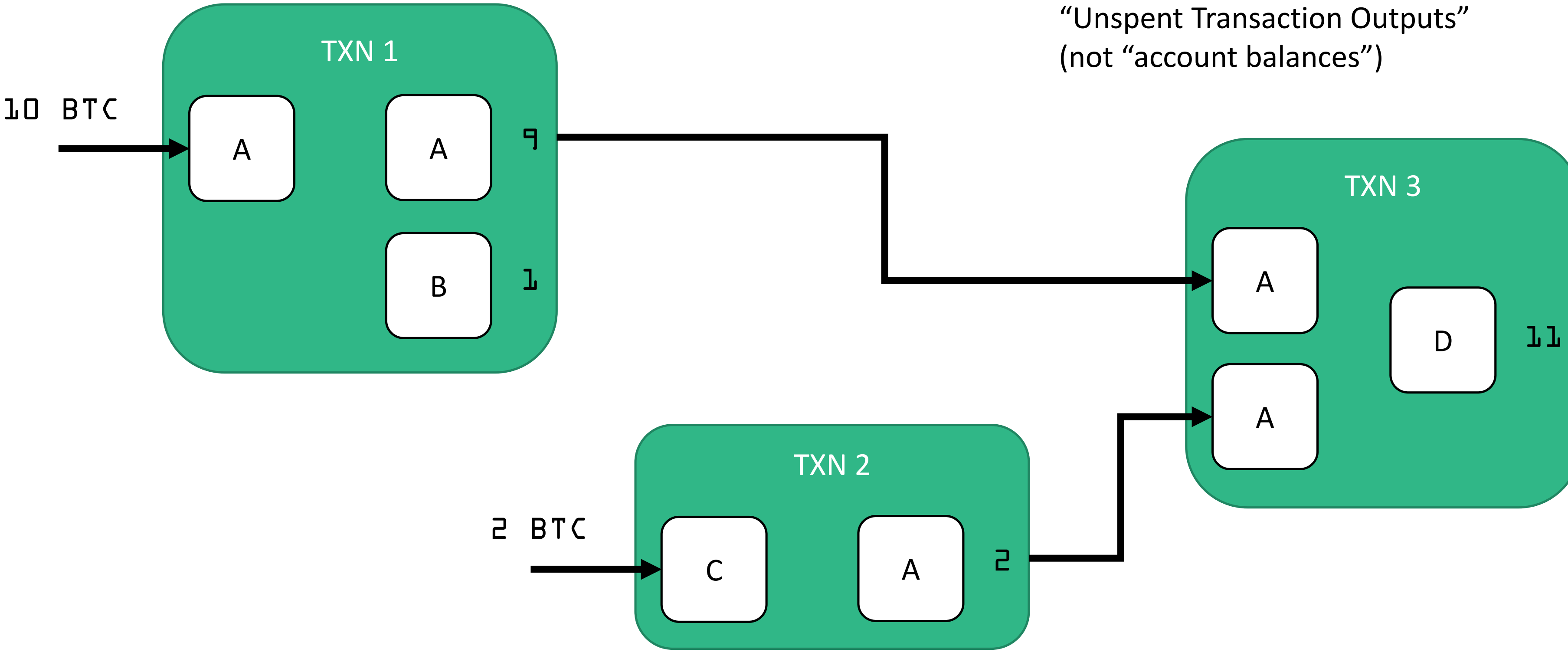


Representation of Digital Assets

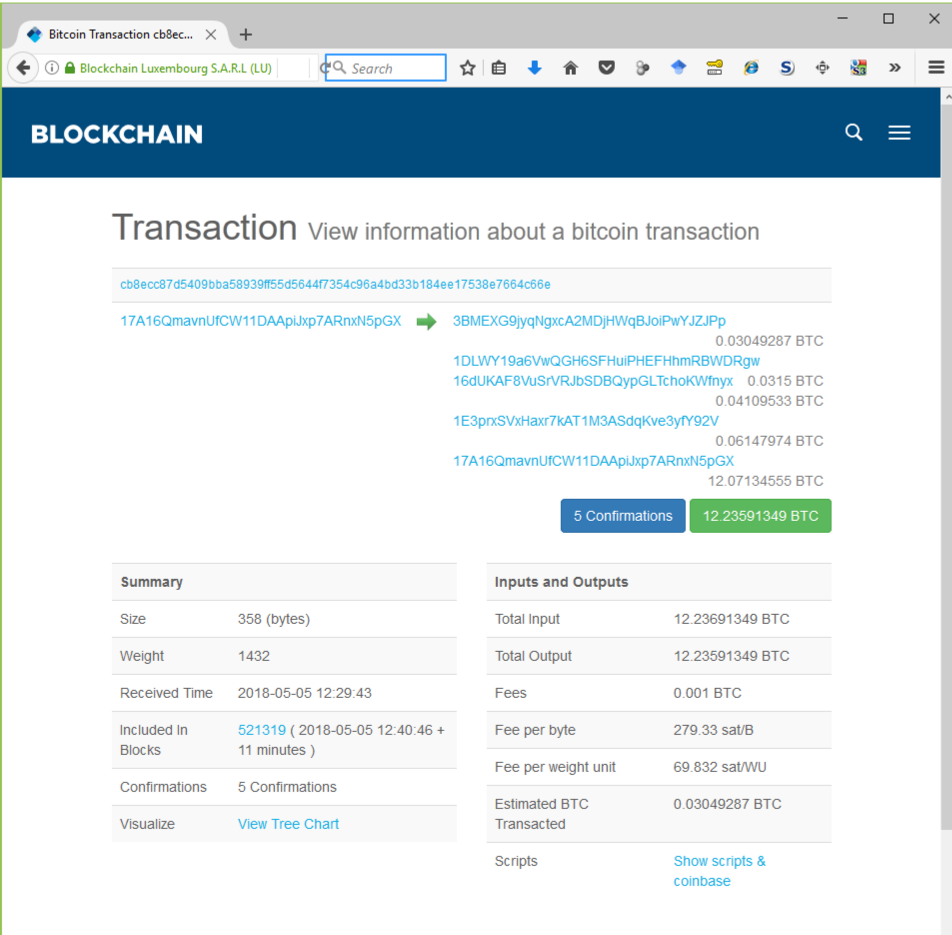
- Bitcoin Cryptocurrency
  - Collection of unspent transaction outputs (UTXO) from all previous transactions to that address
  - Tokens represented using conventions (e.g. tracking “color”)
- Ethereum
  - Cryptocurrency account balances in global system state
  - Tokens represented by smart contracts using storage

Bitcoin Holdings – UTXO

“Unspent Transaction Outputs”
(not “account balances”)



What Do Bitcoin Transactions/ Holdings Look Like?


Bitcoin Transaction cb8ec...

Blockchain Luxembourg S.A.R.L (LU)

BLOCKCHAIN

Transaction View information about a bitcoin transaction

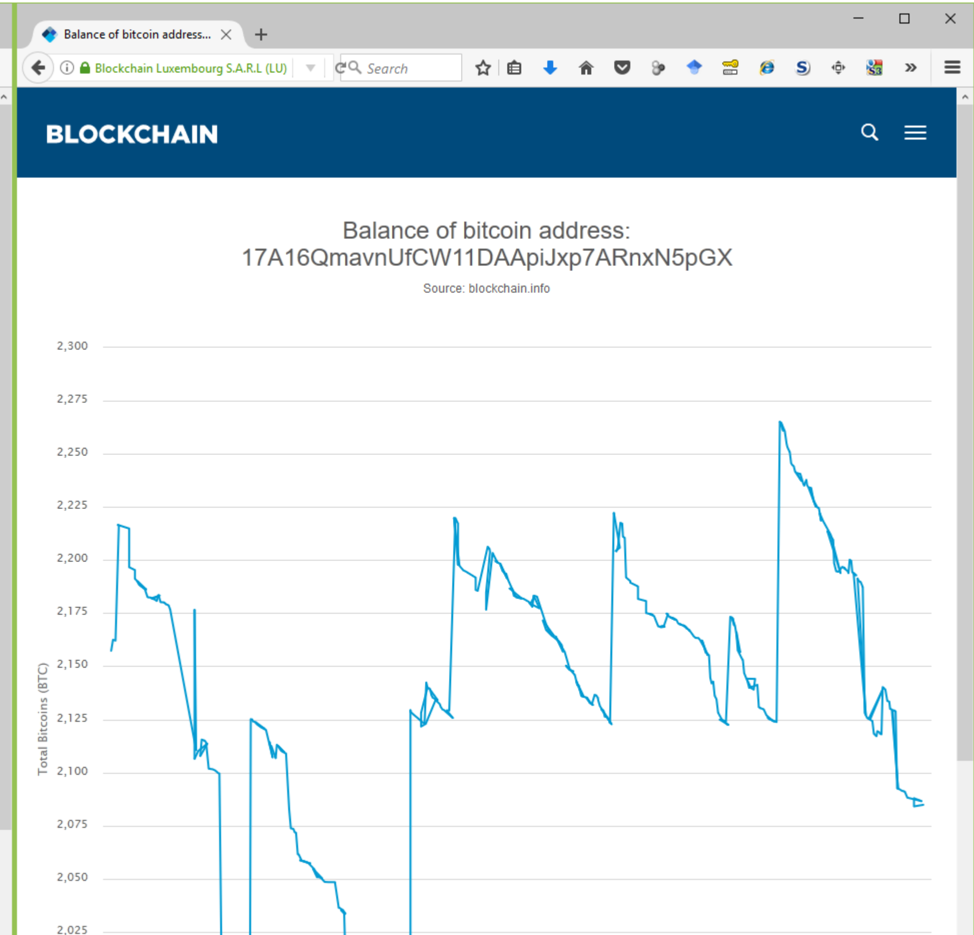
cb8ecc87d5409bba58939ff55d5644f7354c96a4bd33b184ee17538e7664c66e

17A16QmavnUfCW11DAApiJxp7ARnxN5pGX ➡ 3BMEXG9jyqNgxcA2MDjHWqBJoiPwYJZJPp 0.03049287 BTC
1DLWY19a6VwQGH6SFHuiPHEFHhmRBWDRgw
16dUKAF8VuSrVRJbSDBQypGLTchoKWfnyx 0.0315 BTC
0.04109533 BTC
1E3prxSVxHaxr7kAT1M3ASdqKve3yfY92V 0.06147974 BTC
17A16QmavnUfCW11DAApiJxp7ARnxN5pGX 12.07134555 BTC

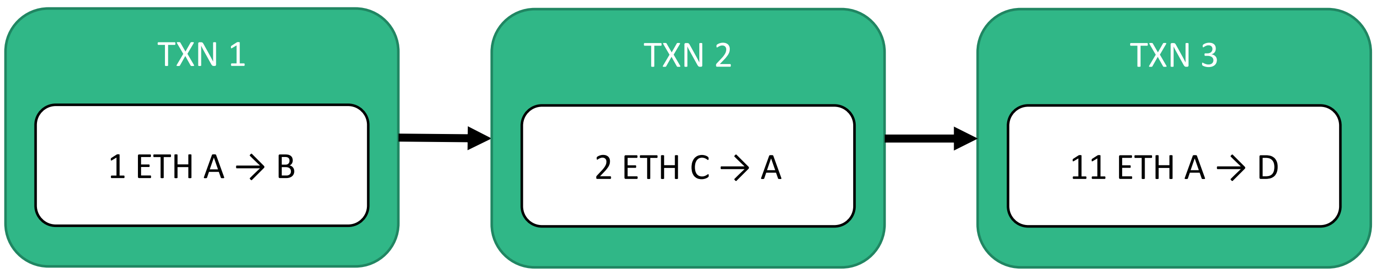
5 Confirmations | 12.23591349 BTC

Summary	
Size	358 (bytes)
Weight	1432
Received Time	2018-05-05 12:29:43
Included In Blocks	521319 (2018-05-05 12:40:46 + 11 minutes)
Confirmations	5 Confirmations
Visualize	View Tree Chart

Inputs and Outputs	
Total Input	12.23691349 BTC
Total Output	12.23591349 BTC
Fees	0.001 BTC
Fee per byte	279.33 sat/B
Fee per weight unit	69.832 sat/WU
Estimated BTC Transacted	0.03049287 BTC
Scripts	Show scripts & coinbase



Ethereum Holdings – Accounts



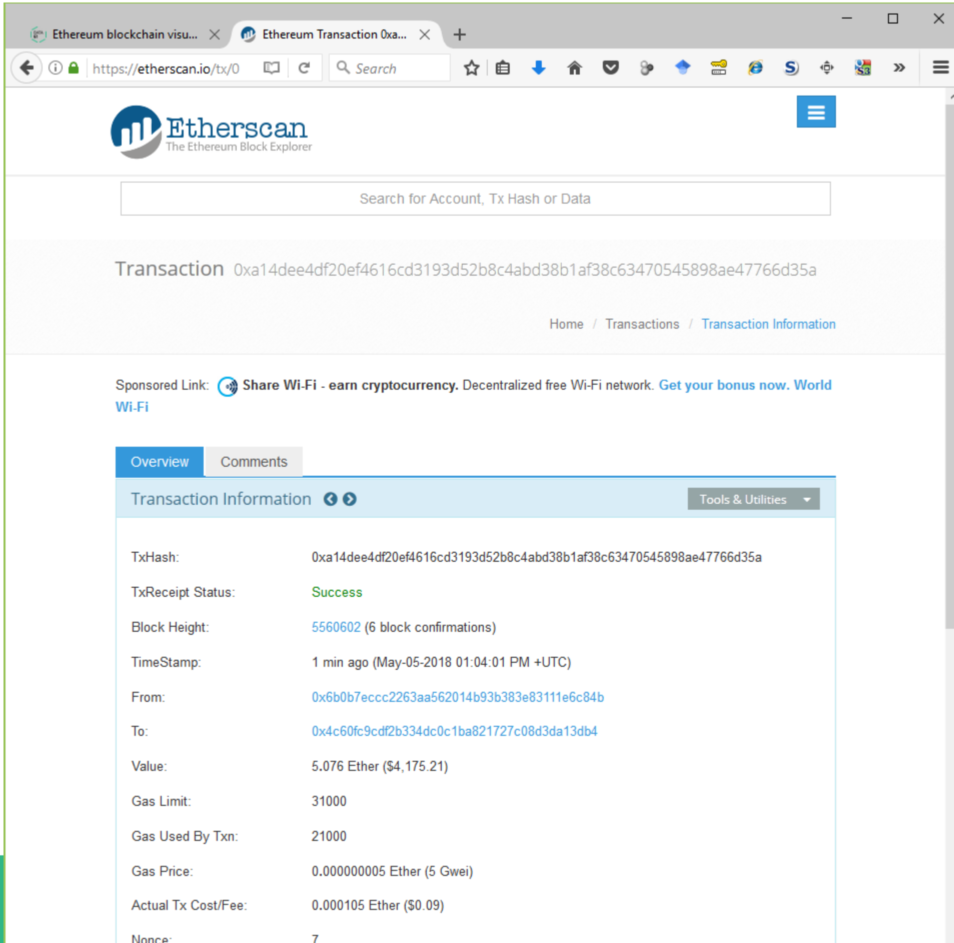
Address	Balance
A	10
B	1
C	4

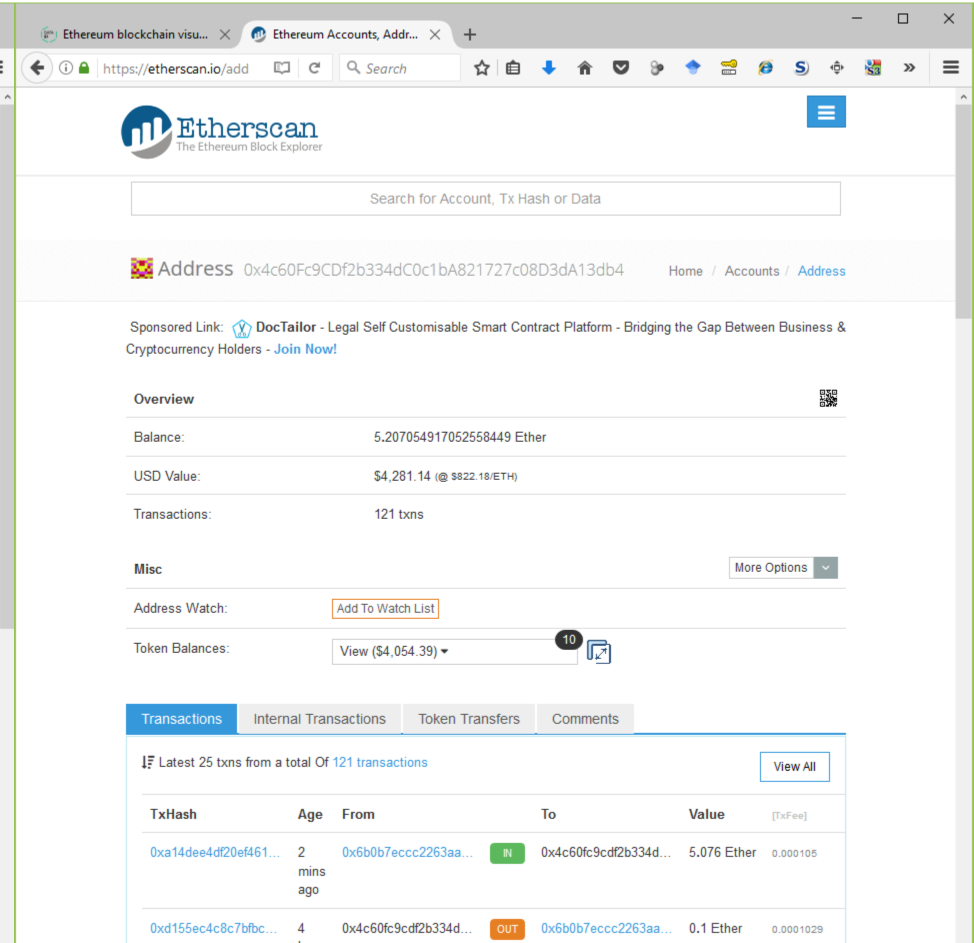
Address	Balance
A	9
B	2
C	4

Address	Balance
A	12
B	0
C	2

Address	Balance
A	1
B	0
C	4
D	11

What Do Ethereum Transactions/ Holdings Look Like?





Storing Arbitrary Data on Blockchain

- Two ways of storing data on blockchain
  - Adding data into transactions
    - Bitcoin
    - Ethereum
  - Adding data into contract storage
    - Smart contract on Ethereum
    - Smart contracts have an address, which is used to invoke the contract
    - Smart contract can only update its own storage
    - "Update" is only to the latest view of state (remember, append-only txns)

- Both ways store data through submitting transactions
  - Contain information of money transfer
  - Together with optional other data

Comparison with Other Data Storage

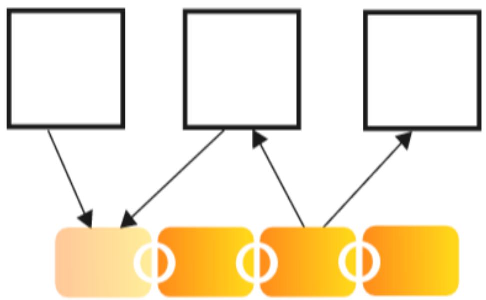
- Comparison with Shared Centralised Database
- Comparison with Cloud Storage
- Comparison with Peer-to-Peer Data Storage
- Comparison with Replicated State Machines

NFPs: Blockchain vs Conventional Technology

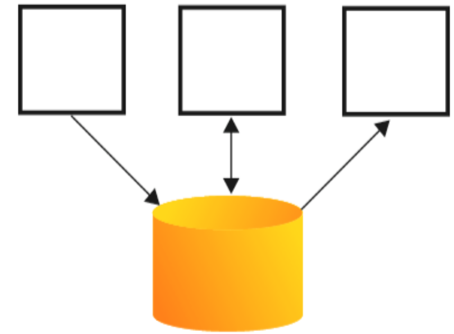
- Non-Functional Property Trade-offs
  - (+) Integrity, Non-repudiation
  - (-) Confidentiality, Privacy
  - (-) Modifiability
  - (-) Throughput/ Scalability/ Big Data
  - (+ read/ - write) Availability/ Latency

- Many “limitations” are only for older public blockchains
  - e.g. hugely inefficient (more electricity than Ireland?)
  - e.g. very low performance (1 hour latency? max 3 tps?)

Blockchain vs. Shared Centralised DB



- Transactions are Append-Only
  - Mimic "CRUD" only as a view of the blockchain (transaction log)
- Consensus by majority of peers agree on transactions
  - Usually no master, no trusted nodes



- Create, Read, Update, Delete
  - Log present, but only for admins
- Distributed Transactions (2 Phase Commit, Paxos)
  - Usually a master node, usually only a few trusted nodes

Blockchain vs. Cloud

Blockchain	Cloud
No trusted single party	Cloud provider is trusted
Users can monitor or participate themselves as nodes that store the blockchain	Cloud provider store user data and provide access to the data
Data integrity is guaranteed (probabilistically)	Data integrity and access availability may not be guaranteed
No defined SLAs (service-level agreement) provided by public blockchain	Clearly defined SLAs

Blockchain vs. Peer-to-Peer Data Storage

- Peer-to-peer Data Storage allow users to access data that is stored in other computers connected to the same peer-to-peer network
- BitTorrent, IPFS (InterPlanetary File System)

Blockchain	Peer-to-Peer Data Storage
Very high availability • All nodes have the same shared copy of the blockchain data	Low availability for unpopular data
Not suitable for storing large data	Only store or distribute content the user wants to store or distribute
Strong data integrity	Hash pointer, checksum

Blockchain vs. Replicated State Machines

	Blockchain	Replicated State Machines
Fault Tolerance	Use distribution to not depend on any single entity	• Replicate state at multiple servers • Coordinate service requests from clients
Consensus	Ensure only one among multiple conflicting proposed transaction is included	Decide upon receiving update requests from components • Ensure only one client acquires a lock
Voting	large portion of the community to agree to achieve consensus	A quorum of voters with weighted votes
Communication	Transactions are replicated and persisted after it is included	• Transmitting state update data among components • Information is replicated
Facilitation	Blocks and transactions are totally ordered	Requests are ordered

Blockchain Component Service Options

- Data Storage
- **Computation Service**
- Communication Service
- Asset Management

Data and Computational Platform

- **Blockchain 1.0** – Cryptocurrency
- **Blockchain 2.0** – Cryptoeconomic State Machine
  - Smart contract: Event-driven program (with state) that runs on a blockchain
    - Can realize more complex business logic
      - *More than simple currency/token-based value transfer*
    - Can represent digital assets on the ledger
  - Computational results stored on the public ledger

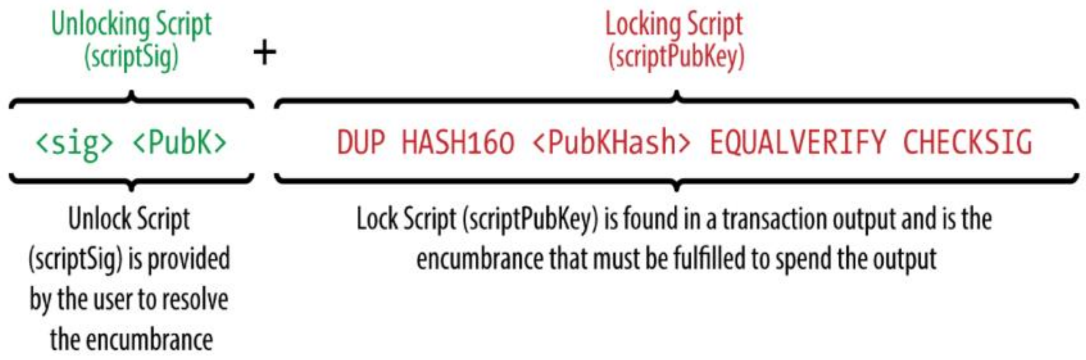
HYPERLEDGER

ETHEREUM

corda

Limited Computational Power of 1st Generation

- Native smart contracts on Bitcoin do not support complex control flow definition



- External services allow end users to build self-executing contracts on Bitcoin
  - Executed by external Oracle
  - Integrity of execution is not guaranteed

Turing-Complete 2nd Generation

- Ethereum is a general computational platform
  - Turing-complete programming language
  - In principle, as expressive as every other general purpose programming language (via Church-Turing thesis)
  - In practice, limitations on computational complexity
    - Gas limit

- Hyperledger Fabric, R3 Corda allow Java, etc
  - Can limit computation to nodes for parties of interest
  - Be careful to make your smart contracts deterministic

3rd Generation? Sub-Turing-Complete Again

- A middle way – a somewhat expressive language, but still allowing automated formal verification

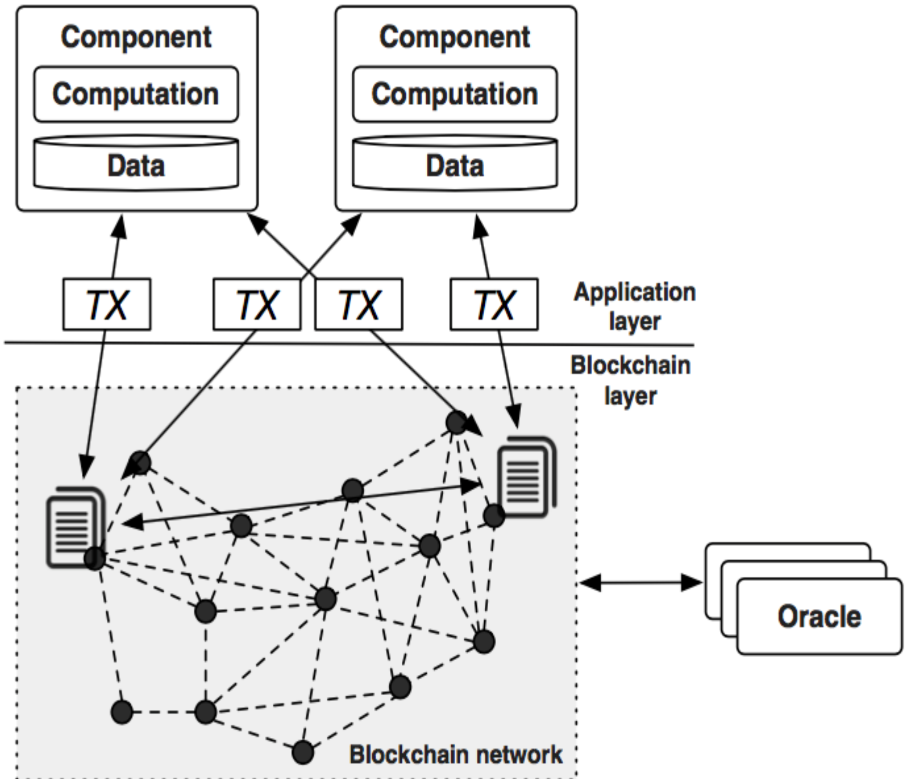
- e.g. Kadena's Pact language
  - Lists, datatypes
  - Functional: Conditionals, Fold, Map, Filter, …
    - But not arbitrary recursion
  - Automatic verification using model checkers (Z3)

- e.g. DAML (Digital Asset)
  - Functional, non-Turing complete
  - Focus on workflow for exchange of rights & obligations
  - Tool support for formal verification

Blockchain Component Service Options

- Data Storage
- Computation Service
- **Communication Service**
- Asset Management

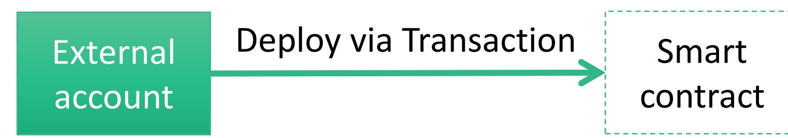
Data Communication



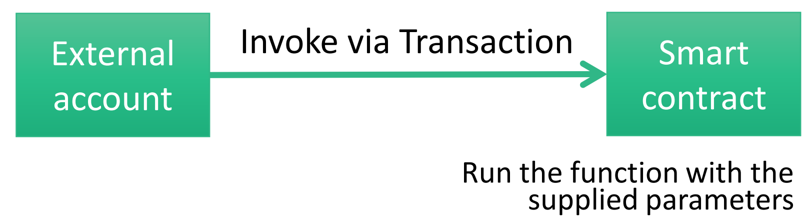
- Components at application layer use blockchain as a mediator to transfer data
  - Sending data to blockchain using transactions
  - Query blockchain to retrieve data
- Blockchain provides data API
  - Access historical transactions
  - Filter historical transactions
- Local component monitoring update from new blocks
  - Relevant data in a local database

Computation Communication 1/2

- Components use blockchain to coordinate computation
  - Submitting transactions to smart contracts to invoke their function
  - Using oracle to sign transactions depending on external state
- Typical control flow
  - Initiated from externally owned accounts
  - Transferred among contract accounts



- Contract termination
  - Cannot respond to transactions
  - Contract code remains on the blockchain
    - Permanently stored
    - In the creation transaction



Computation Communication 2/2

- Oracle facilitates component coordination with external state
  - Some direct support for oracles
  - Others use oracles as external services
    - Interacting with blockchain through normal transactions

- Validation of transactions depends on external state
  - Platform-supported oracle can validate and sign transaction
    - Block transaction progress until the oracle completes
  - Oracle can be an external service injecting data into blockchain
    - Other smart contracts use that data to validate transaction
    - Delay is between the external state changes and time when those are recorded into blockchain

- Automated vs. human

Blockchain Component Service Options

- Data Storage
- Computation Service
- Communication Service
- **Asset Management**

Asset Management and Control Mechanism

- Native token of the 1st generation of blockchain
  - Cryptocurrency is the native asset
  - Identity of the cryptocurrency or associated data can represent other assets
    - Track claims of title over physical assets
    - Transactions record the transfer of title from one user to another
  - Limited due to small size of arbitrary data
    - Bitcoin overlay network: colored coin
      - Taint a subset of Bitcoin to represent and manage real-world assets
      - Few attributes can be recorded and few conditions can be checked within blockchain

- Smart contract of the 2nd generation of blockchain
  - Enable more expressive data structure
  - Flexibility for tokenizing a wider variety of assets

Tokens as Digital Assets

- What is a Token?
  - Like plastic discs/boarding pass/ticket/ in the physical world
  - Digital asset on the blockchain – current “owner” etc can be checked by looking at ledger

- A token represents a bundle of rights and obligations
  - Can represent digital assets or physical assets
    - Fungible: interchangeable, like cryptocurrencies, gasoline
    - Non-fungible: Unique and cannot be interchanged, like cryptokitties, artwork and land
  - Transferrable (or not); Reusable (or not); Exclusive (or not); …

- Tokens for “ownership” of assets?
  - “Property” is a collection of rights
  - Can the blockchain legally bind ownership or change of ownership?
    - You could self-impose contractual conditions on token and underlying property, to try to ensure the blockchain record is consistent with legal ownership
    - But, contracts might not survive bankruptcy; and Courts can order change of ownership without the blockchain

Digital Assets and Blockchains: Symbiosis

- The blockchain ensures digital assets are not replicated
  - For digital information, you can make identical copies
  - For money and other assets, don't make identical copies!
  - The global public ledger means everyone can check

- Digital assets (esp. cryptocurrency for public blockchains) ensure the blockchain is operated
  - Provide incentives for nodes to operate the blockchain
    - Mining reward claimed under a convention, by the node that creates a block
    - Transaction fees – offered by the transacting party to the node which includes the transaction in a block

Token Standards on Ethereum

- ERC20 for fungible tokens
- ERC841 for non-fungible tokens

```
// ----------------------------------------------------------------------------
// ERC Token Standard #20 Interface
// https://github.com/ethereum/EIPs/blob/master/EIPS/eip-20.md
// ----------------------------------------------------------------------------
contract ERC20Interface {
    function totalSupply() public view returns (uint);
    function balanceOf(address tokenOwner) public view returns (uint balance);
    function allowance(address tokenOwner, address spender) public view returns (uint remaining);
    function transfer(address to, uint tokens) public returns (bool success);
    function approve(address spender, uint tokens) public returns (bool success);
    function transferFrom(address from, address to, uint tokens) public returns (bool success);

    event Transfer(address indexed from, address indexed to, uint tokens);
    event Approval(address indexed tokenOwner, address indexed spender, uint tokens);
}
```

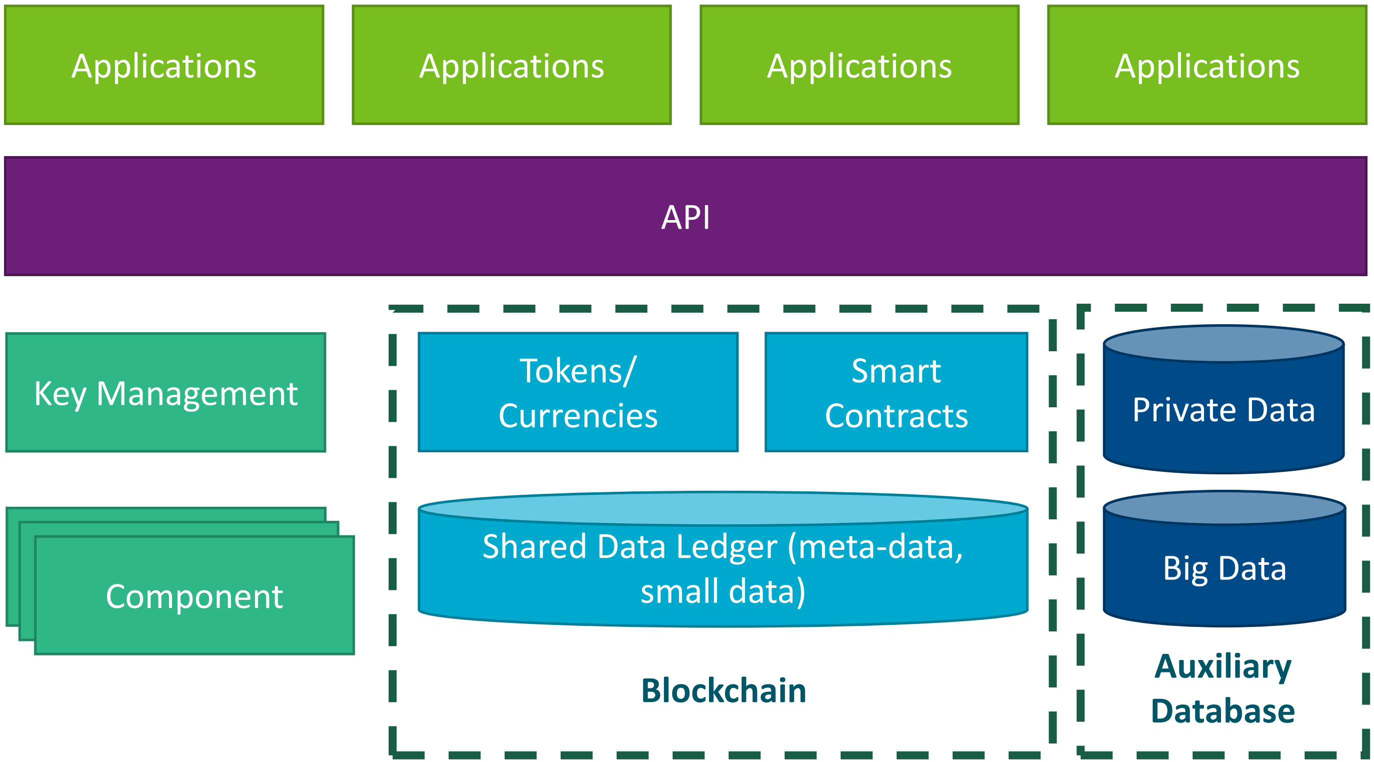
Design and Trade-offs in Blockchain Applications

Use Blockchain for What It's Good For

- Trustworthy and efficient ways to work together
  - Focus on spaces between individuals, organisations
    - Data integrity for information sharing
    - Neutral ground for process coordination
  - Logically centralises information
  - Administratively decentralises control

- Digital Assets and Tokens
  - Authorised by issuer, transferrable between cryptographic IDs
  - Representing physical assets, digital assets, services, rights, …
  - Be careful about legal title for property: blockchain is not magic

Recall: Blockchain in Larger Software System



How to use blockchains in a design?

- Later lectures covering topics in design process, blockchain design patterns, etc
- Some themes
  - Choice and configuration of blockchain
    - Private (Consortium) vs. Public
    - Single logical chain vs. network of distributed ledgers
  - Use programming design patterns for smart contracts
  - Combine on-chain with off-chain components
    - Hashed content on-chain (content off-chain)
    - Signed or encrypted content on-chain (keys off-chain)
    - “State channels” judges on-chain (computation & comms off-chain)
- Today, some illustrative examples

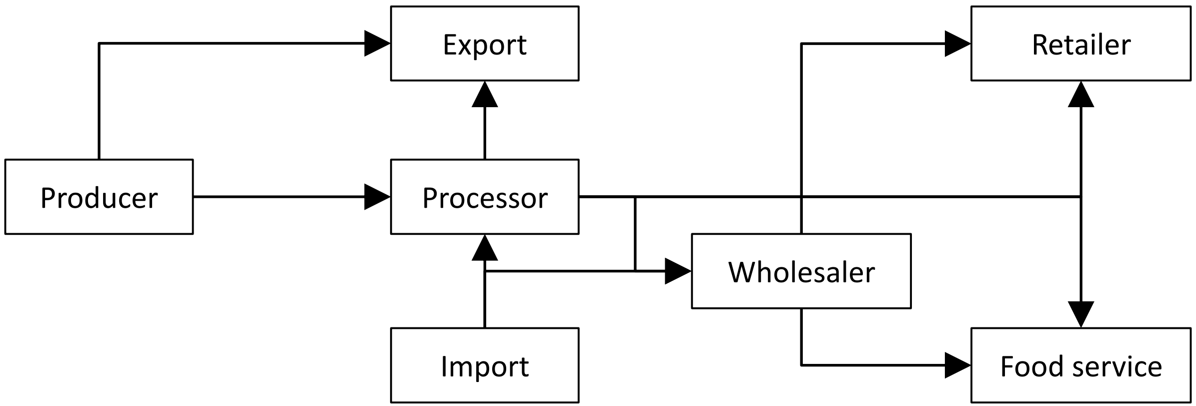
3 Examples from Data61/Treasury Reports

- http://www.data61.csiro.au/blockchain
- *Risks and Opportunities for Systems Using Blockchain and Smart Contracts*
- What are technical risks & opportunities for use cases?

Potential Use Cases

- Financial Services
  - Digital currency
  - (International) payments
  - Reconciliation
  - Settlement
  - Markets
  - Trade finance
- Government Services
  - Registry & Identity
  - Grants & Social Security
  - Quota management
  - Taxation
- Enterprise and Industry
  - Supply chain
  - IoT
  - Metered access
  - Digital rights & IP
  - Data management
  - Attestation
  - Inter-divisional accounting
  - Corporate Affairs
- Three Illustrative Cases Selected
  1. Agricultural supply chain
  2. Open data registry
  3. Remittance payments

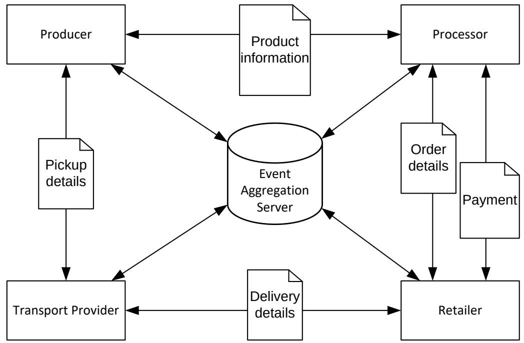
Agricultural Supply Chain – Use Case



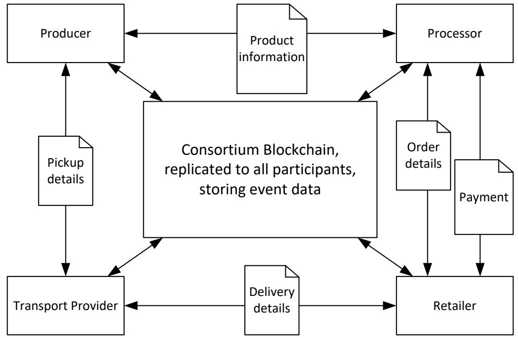
Interoperability
Latency
Integrity
Confidentiality
Scalability

Agricultural Supply Chain – Designs

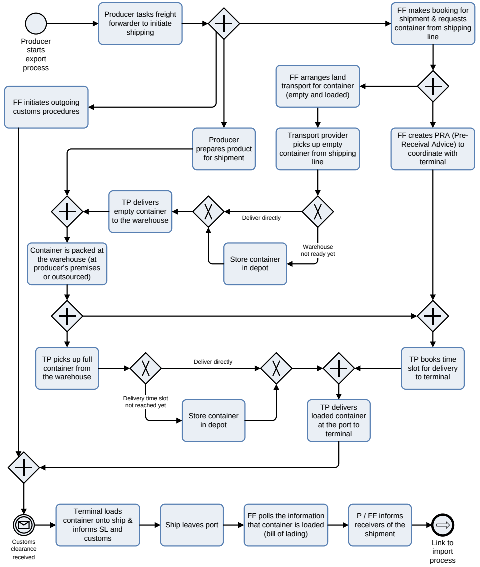
<u>1. Conventional</u>
Point-to-point messaging and event aggregation server



<u>2. Event Tracking on Blockchain</u>
Point-to-point messaging and event aggregation on blockchain



<u>3. Supply chain process coordination on blockchain as smart contracts</u>

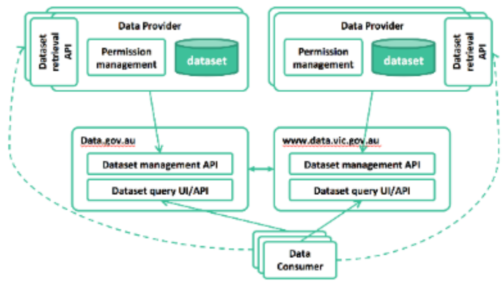


Open Data Registries – Use Case

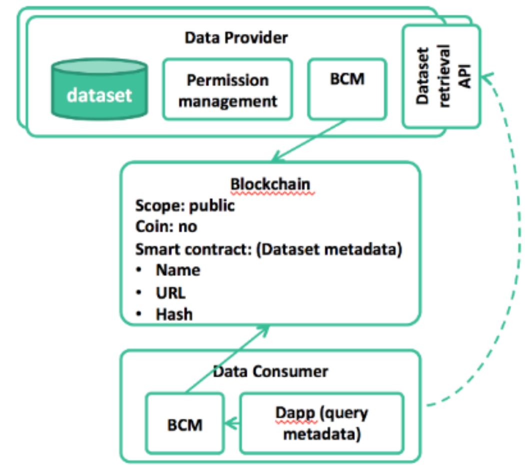
Integrity
Availability
Read Latency
Interoperability
Barriers to access

Open Data Registries – Designs

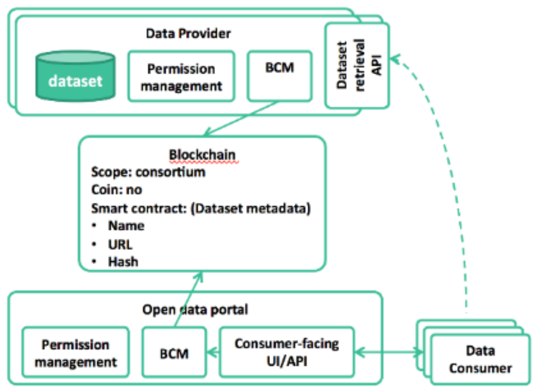
1. Conventional
Registry operated by single agency



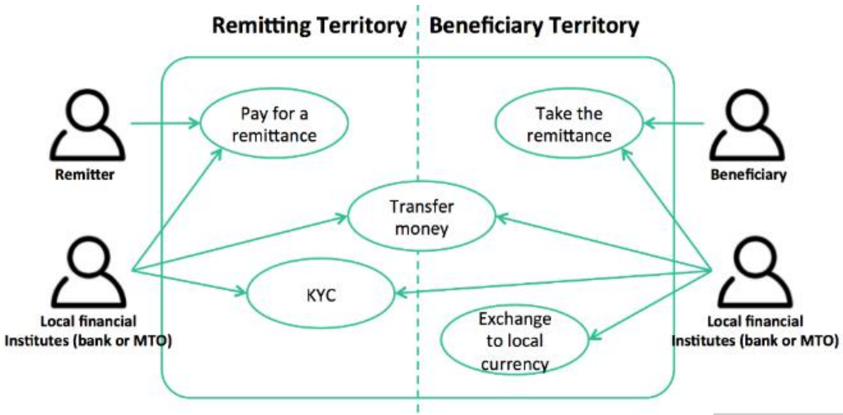
3. Registry on public blockchain
Agency only controls entries included on official index



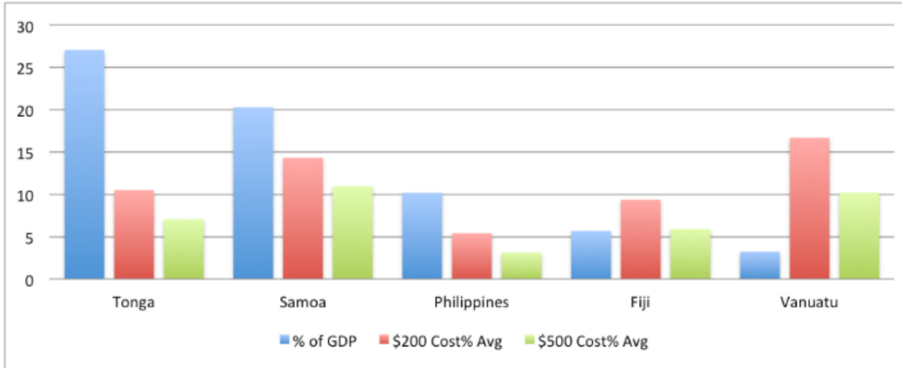
2. Consortium across data providers
Public access still controlled through a portal



Remittance Payments – Use Case

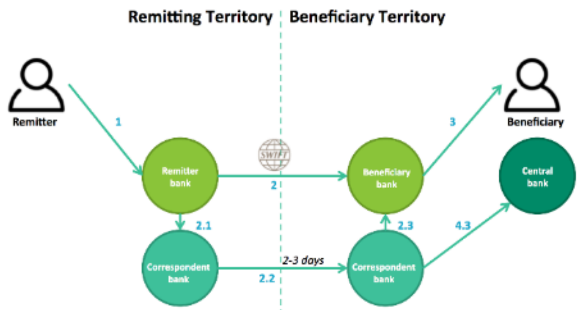


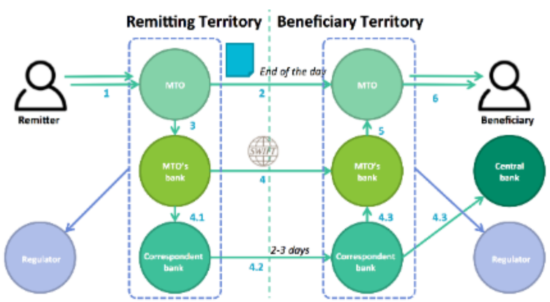
Write Latency
Cost
Cost transparency
Controlled confidentiality
Low barriers to entry



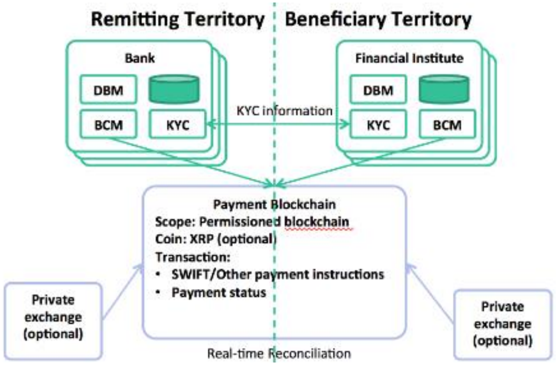
Remittance Payments – Designs

1. Conventional
Through bank or MTO

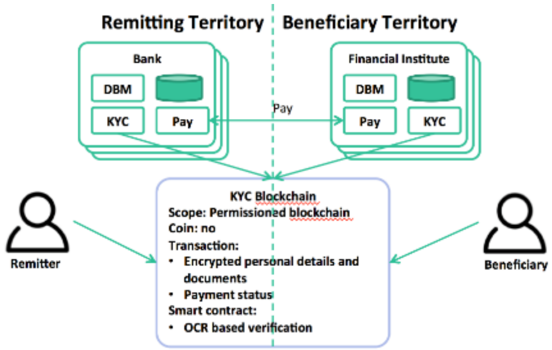




2. Payment through blockchain



3. KYC through blockchain



Summary

Summary

- What is Software Architecture?
  - Architectural design choices impact Non-Functional Properties (NFPs)
  - Use Architectural Models (Views and Viewpoints)
    - To communicate and analyse systems
  - Analyse NFPs and consider NFP Trade-offs

- Blockchain in Software Architecture
  - Blockchain as Component, Connector, Configuration
  - Blockchain Component Services
    - Data Storage
    - Computation Service
    - Communication Service
    - Asset Management

- Design and Trade-offs in Blockchain-based Applications

THANK YOU

www.data61.csiro.au