

Hyperledger

Öz, B., Hoops, F., Gebele, J., Gellersdörfer, U., & Matthes, F. (2024). "Blockchain-based Systems Engineering". Lecture Slides. TU Munich.

Chair of Software Engineering for Business Information Systems (sebis)
Department of Computer Science
School of Computation, Information and Technology (CIT)
Technical University of Munich (TUM)
www.matthes.in.tum.de

1. Beyond Public Blockchains
 - Recap
 - Motivation
 - Use Cases
2. The Hyperledger Project
 - Vision and Mission
3. Hyperledger Fabric
 - Architecture
 - Membership Service Provider
 - Application
 - Ordering Service
 - Peers
 - Chaincode
 - Order-Execution vs. Execution-Order
 - Limitations
 - Nodes and Roles
 - Transaction Flow
 - Channels
 - Ledger
 - Recent Developments in Hyperledger Fabric

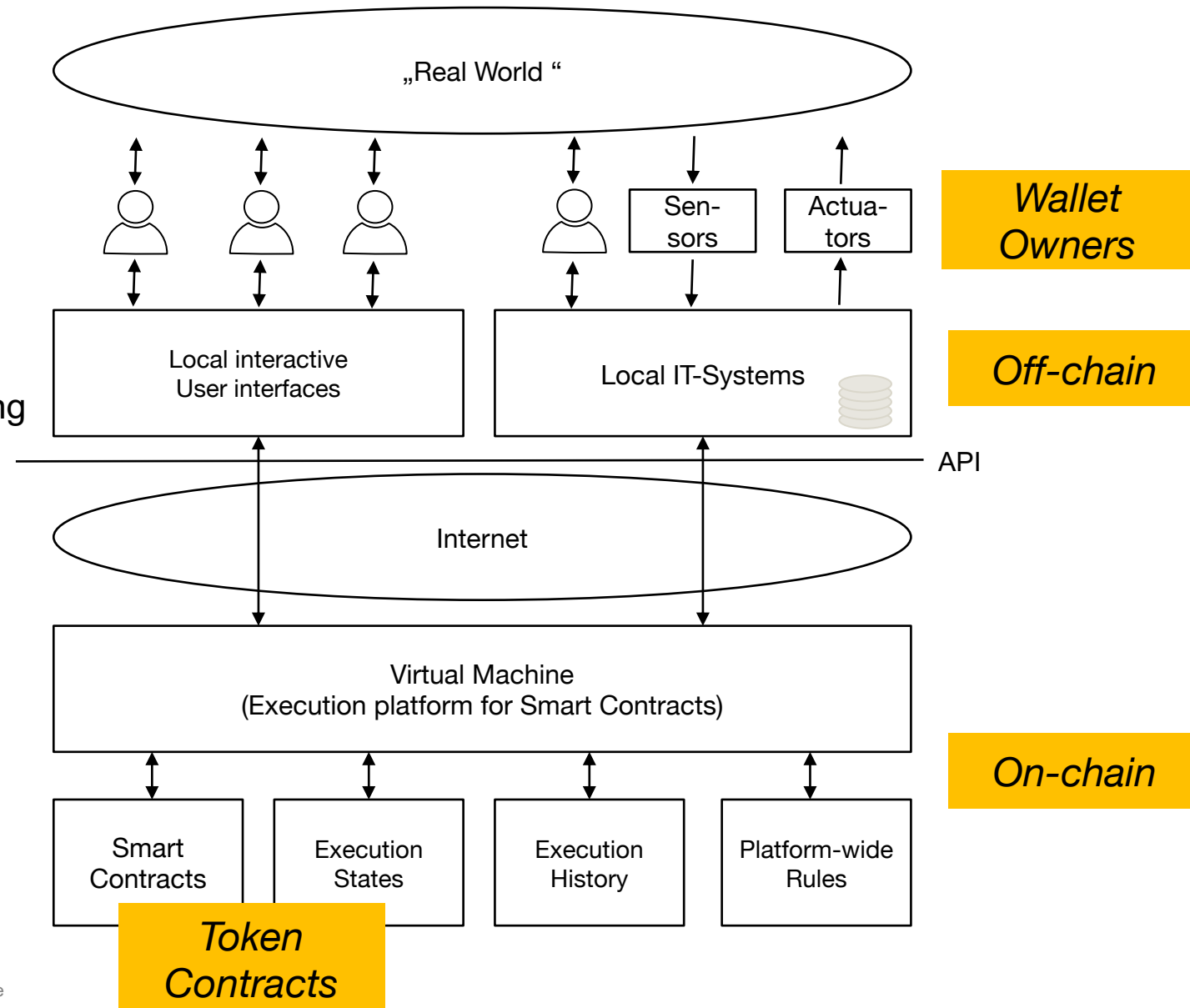
Reference Architecture for a Smart Contract Platform

Recap - Lecture 01



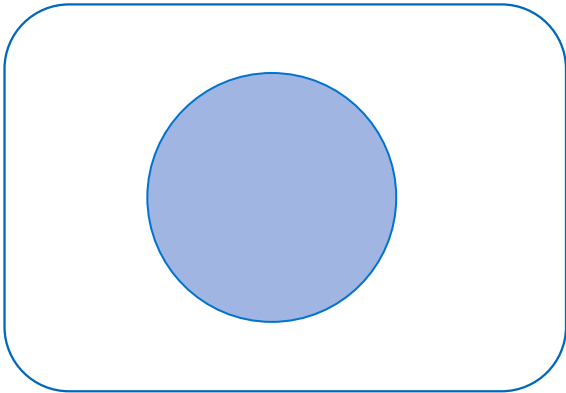
Example:

Safe transfusion medicine
Blood product supply chain involving
Clinics
Labs
Logistic companies
Blood donor centers

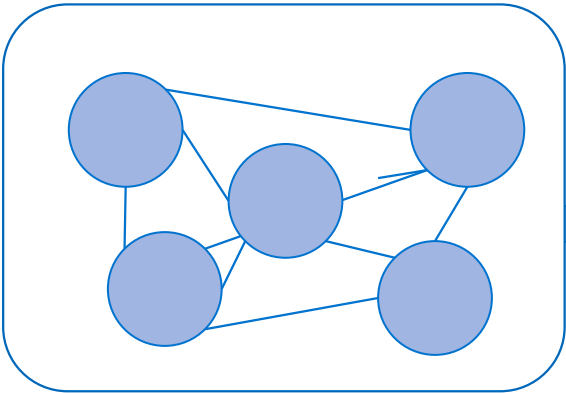


Comparison to Established Centralized Solutions

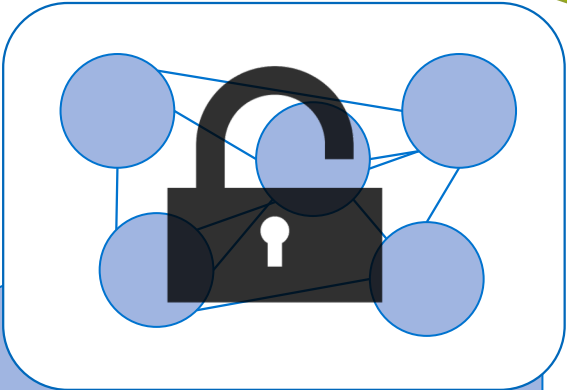
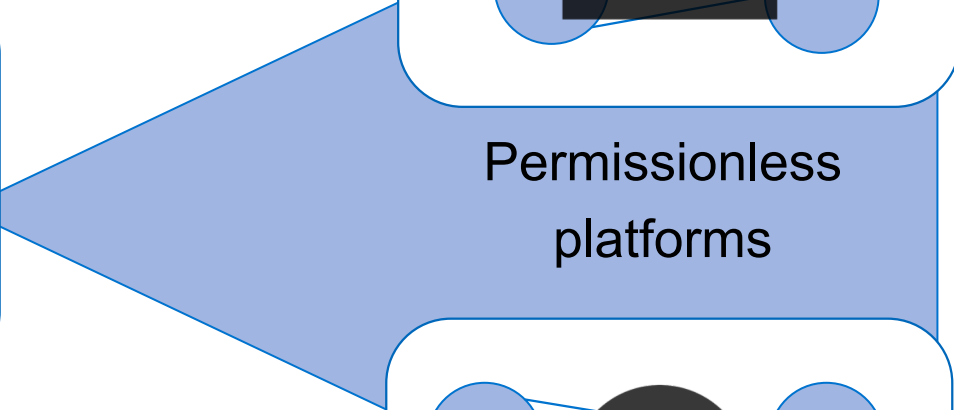
Recap - Lecture 01



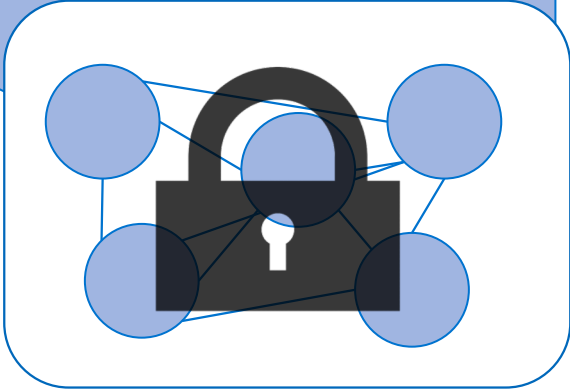
Centralized
platforms



Blockchain-based
platforms



Permissionless
platforms



Permissioned
platforms

Strengths

- Efficient
- Scalable
- Off-the-shelf (familiar) components

Weaknesses

- Requires **trust** in platform provider
 - Availability
 - Sufficient resources
 - Fair conditions (e.g. pricing)
 - No manipulations

Opportunities

- There are established non-technical measures to ensure trust, e.g. cooperatives, third-party (or state) supervision, Open Source licenses, etc.

Threats

- Emergence of **monopolies** and **cartels**, and the associated risks

Strengths

- Consensus of nodes on shared set of facts
- Traceability of the complete transaction history
- Optimized for cross-organization collaboration
- Decentralized and redundant
- (Transparency of all transaction details)
- Pseudonymity of the wallet owners
- Financial incentives for network growth

Weaknesses

- Lack of privacy
- Dependency on a crypto currency
- Energy consumption (Proof-of-Work)
- Limited transaction throughput
- Risk of centralization in the ecosystem
 - MetaMask, Mining Pools, etc.
- Complexity

Opportunities

- Innovation thrust for IT solutions in the global finance system
- Lowered entry barriers for IT-savvy players with limited financial resources
- Impetus to re-evaluate established business models and economic mechanisms

Threats

- Unregulated
- Conflicts with current legal standards and practices

Strengths

- Data protection (data and transactions)
- Authentication and authorization
- Scalability
- Familiar programming languages
- Familiar development environments and tools
- Established IT service providers
- Professional consulting and training services
- Interoperability with standard enterprise IT

Weaknesses

- "Low-level" data models
- Cumbersome process modelling
- Complex distributed software development
- Low maturity of development tools

Opportunities

- Compliance
- Extensive EU funding
- Domain-specific architectures and abstractions (data marketplaces, IoT, public administration)
- Blockchain as a (cloud) service
- National blockchains

Threats

- Unfamiliar organizational structure (cooperative, association, ...)
- Complex consortium agreement negotiations
- Complex governance (committees, voting rights)
- Limited availability and cost of IT experts
- Fragmentation of the market

The TradeLens Disaster

An Example of Failed Permissioned Blockchain Governance

- TradeLens was a digital platform that used blockchain technology to connect stakeholders and streamline processes in the shipping industry.
- The platform was created by IBM and Maersk with the intention of being a decentralized system.
- However, **due to Maersk's significant stake in the platform**, other shipping companies became concerned about potential bias and unfair treatment.
- This lack of trust led some competitors to refuse to use the platform, which hindered its adoption in the industry.
- As of November 2022, Maersk and IBM announced their decision to withdraw the TradeLens offerings and discontinue the platform.

TRADE
LENS



TradeLens was founded on a bold vision for global supply chain digitization as an open and neutral industry platform. This vision centered on the ability to enable true information sharing and collaboration across a highly fragmented industry globally.

Unfortunately, such a level of cooperation and support has not been possible to achieve at this point in time and A.P. Moller - Maersk (Maersk) and IBM have announced the discontinuation of the TradeLens platform.

We would like to express our sincere thanks for those that interacted with TradeLens since 2018. We are honored to have been part of your digitization journey.

Public blockchain:

The network has open read and write access for anyone who wants to participate.

Examples:

Ethereum, Monero, Bitcoin, Litecoin

vs

Private blockchain:

Read and write access to the network is limited to a certain set of entities. These networks are (so far) also always permissioned (see following slide). Therefore, private blockchains usually achieve a much higher throughput rate compared to public chains. Private blockchains are a very centralized approach to blockchains and use cases have yet to be found where such solutions are superior to conventional systems.

Examples:

Monax, MultiChain, C-Chain, Quorum

Permissionless blockchain:

The network is completely open for anyone who wants to participate in reaching consensus. Currently, a highly used Sybil control mechanism is Proof-of-Work (PoW). Network participants are usually financially incentivized by a native currency (e.g., Ether or Bitcoin).

Examples:

Ethereum, Monero, Bitcoin, Litecoin

vs

Permissioned/consortium blockchain:

Participation in the consensus mechanism is restricted to a certain set of entities. This allows the use of more centralized Sybil control mechanisms (e.g., Proof of Authority). Therefore, permissioned blockchains usually achieve a much higher throughput rate compared to permissionless chains.

Examples:

Ripple, Hyperledger Fabric

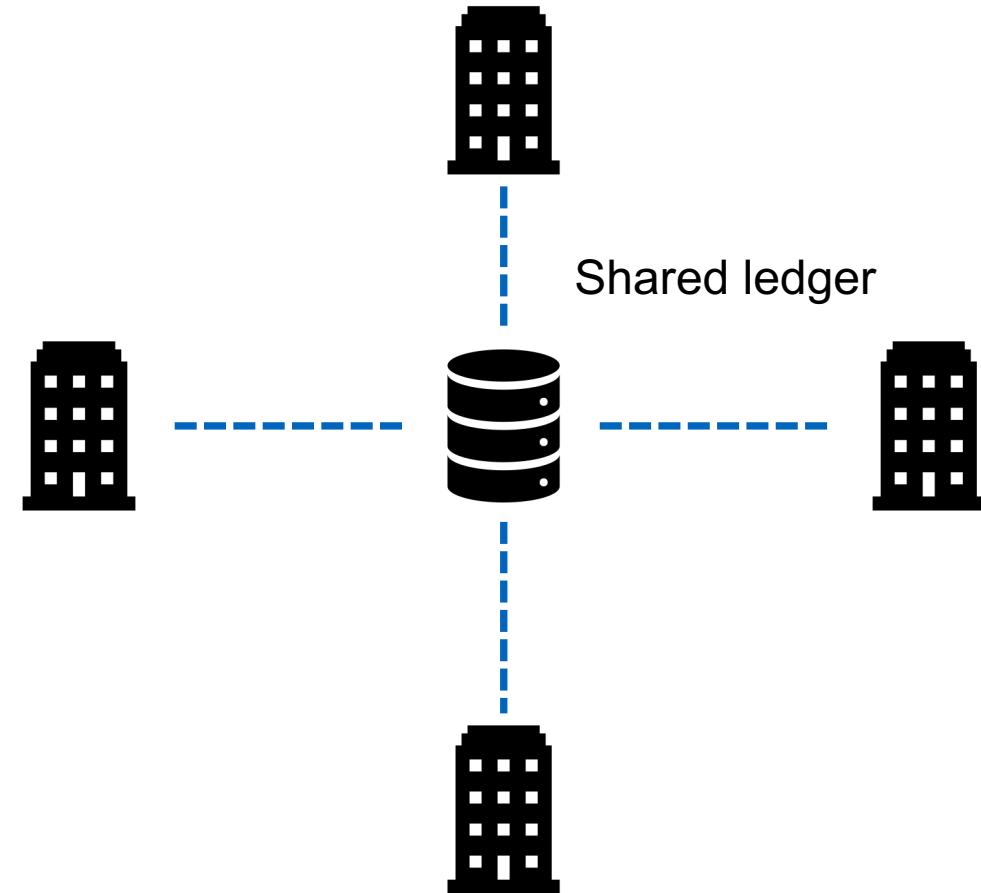
The problem:

Multiple parties that do not fully trust each other need to share information in a tamper proof and secure way.

Challenges:

Having a cost effective and secure data structure.

- Who owns and operates the ledger?
- Who pays for the shared data structure?
- What are allowed operations on the shared data structure?
- What is the process of adding new parties?
- How is consensus achieved?



Privacy

The network must be secured via authentication and authorization mechanisms. Only involved parties should be able to issue transactions and participate in the network.

Smart contracts

The platform should support the execution of business logic on which the participating parties have agreed on.

Trust

All transactions that are issued on the network must be verified and valid to a set of rules on which the participating parties agreed on.

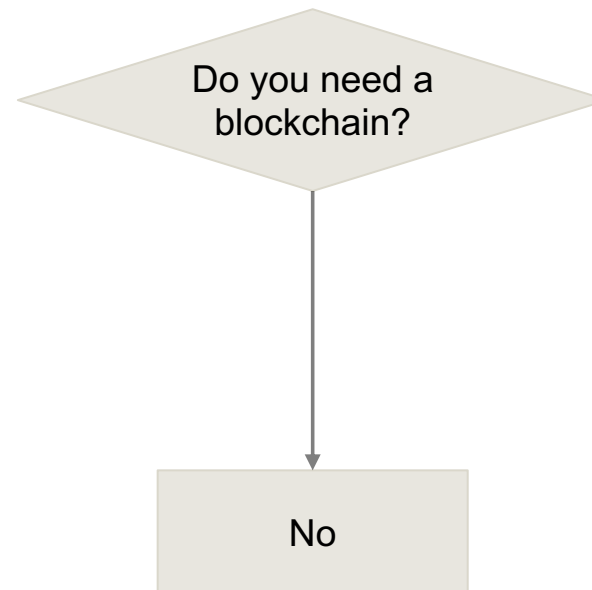
Single source of truth

An immutable ledger that keeps track of all transactions. Participating parties must be accountable for transactions they issue on the network.

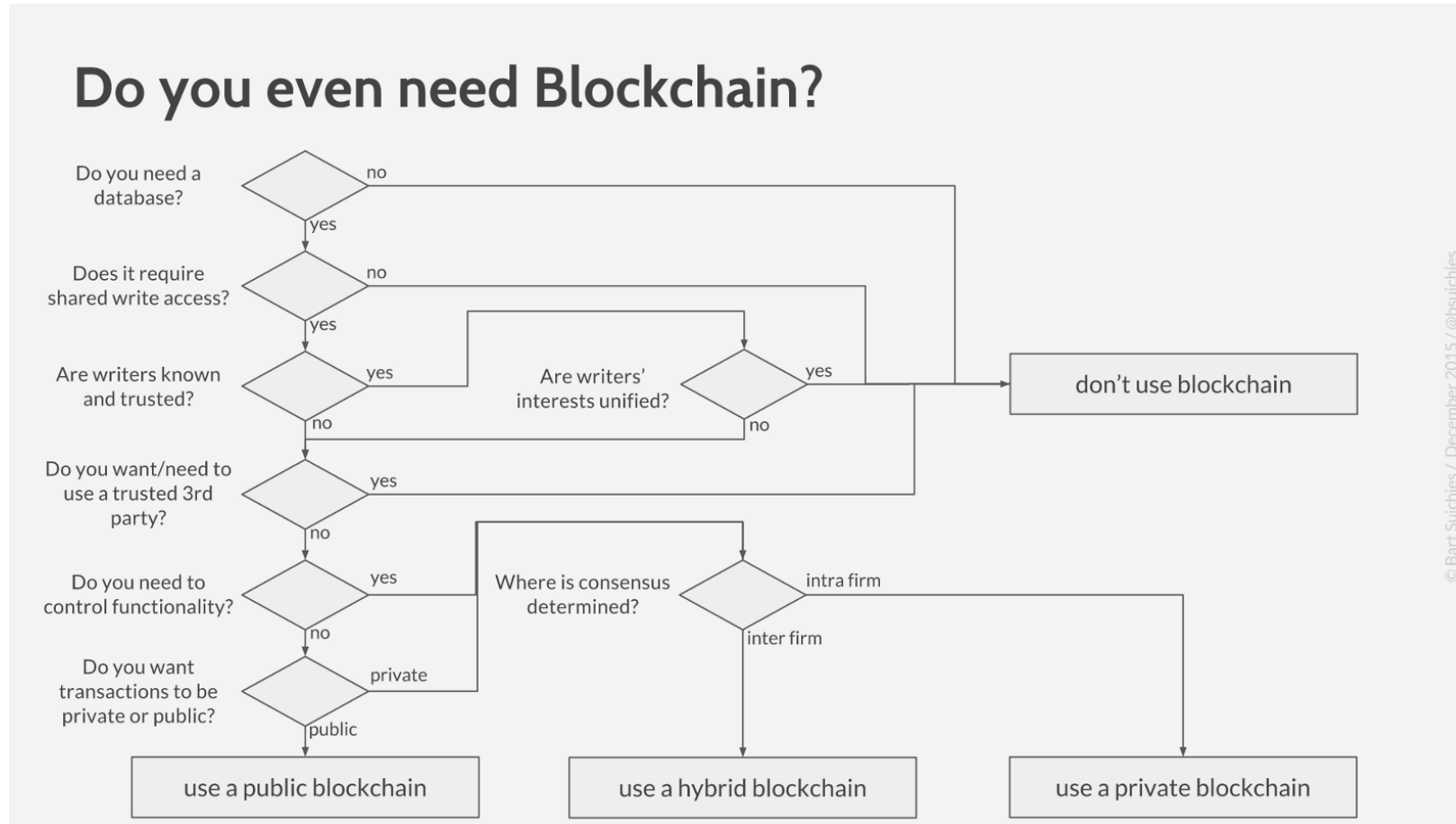
When to Use Blockchain

Blockchain is one of the most hyped technology trends nowadays and many enterprises are trying to leverage the technology. However, for finding a use case for a blockchain-based solution it is necessary to understand the technology and the use case well.

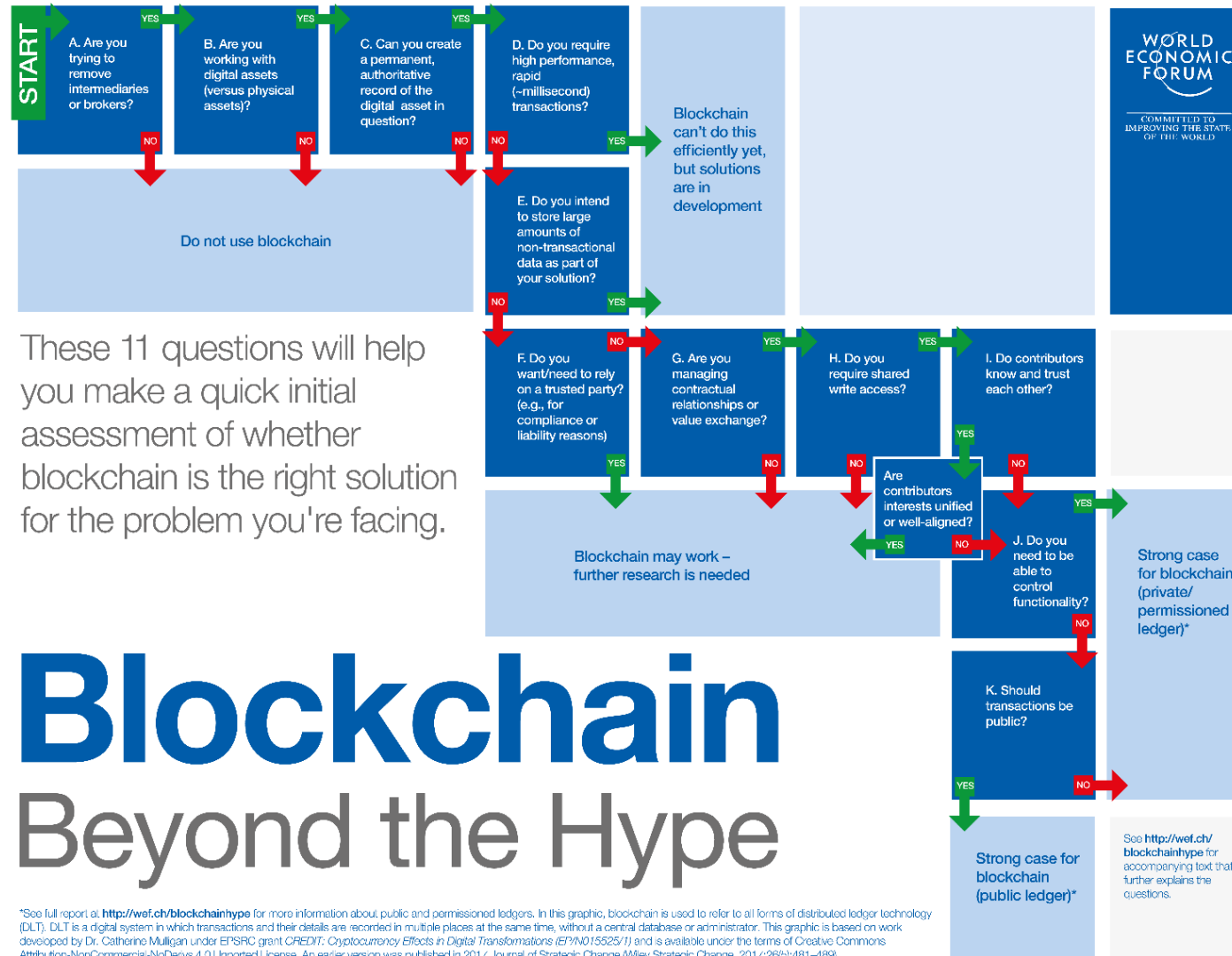
Therefore, several individuals and institutions came up with different models for making a decision whether a blockchain-based solution makes sense or not.



(Joke) Model by Dave Birch (<https://twitter.com/dgwbirch?lang=de>)



Source: <https://medium.com/@bsuichies/why-blockchain-must-die-in-2016-e992774c03b4>

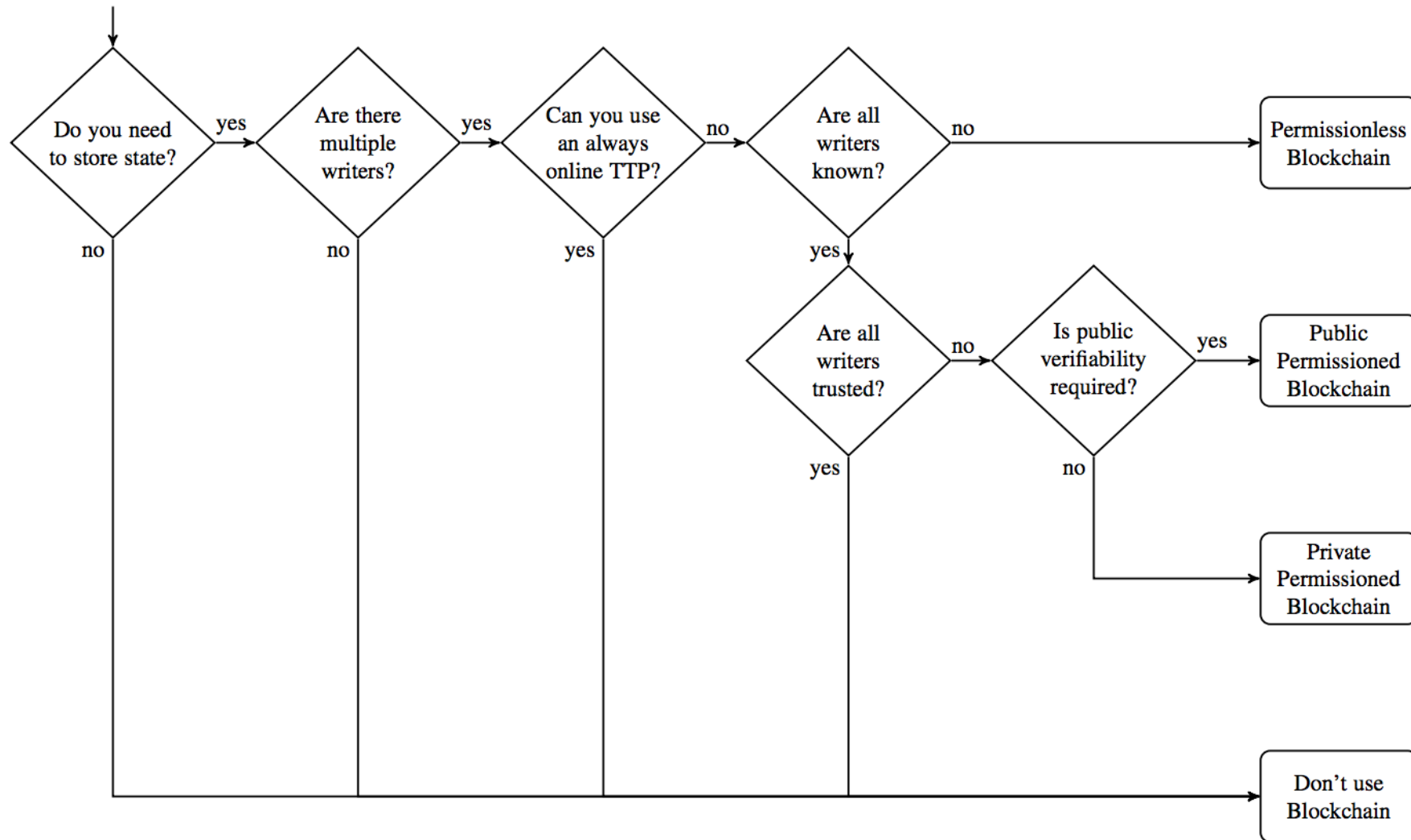


These 11 questions will help you make a quick initial assessment of whether blockchain is the right solution for the problem you're facing.

Blockchain Beyond the Hype

*See full report at <http://wef.ch/blockchainhype> for more information about public and permissioned ledgers. In this graphic, blockchain is used to refer to all forms of distributed ledger technology (DLT). DLT is a digital system in which transactions and their details are recorded in multiple places at the same time, without a central database or administrator. This graphic is based on work developed by Dr. Catherine Mulligan under EPSRC grant CREDIT: Cryptocurrency Effects in Digital Transformations (EP/N015525/1) and is available under the terms of Creative Commons Attribution-NonCommercial-NoDerivs 4.0 Unported License. An earlier version was published in 2017 Journal of Strategic Change (Wiley Strategic Change, 2017(26(6)):481–489).

Model by Karl Wüst and Arthur Gervais



1. Beyond Public Blockchains

- Recap
- Motivation
- Use Cases

2. The Hyperledger Project

- Vision and Mission

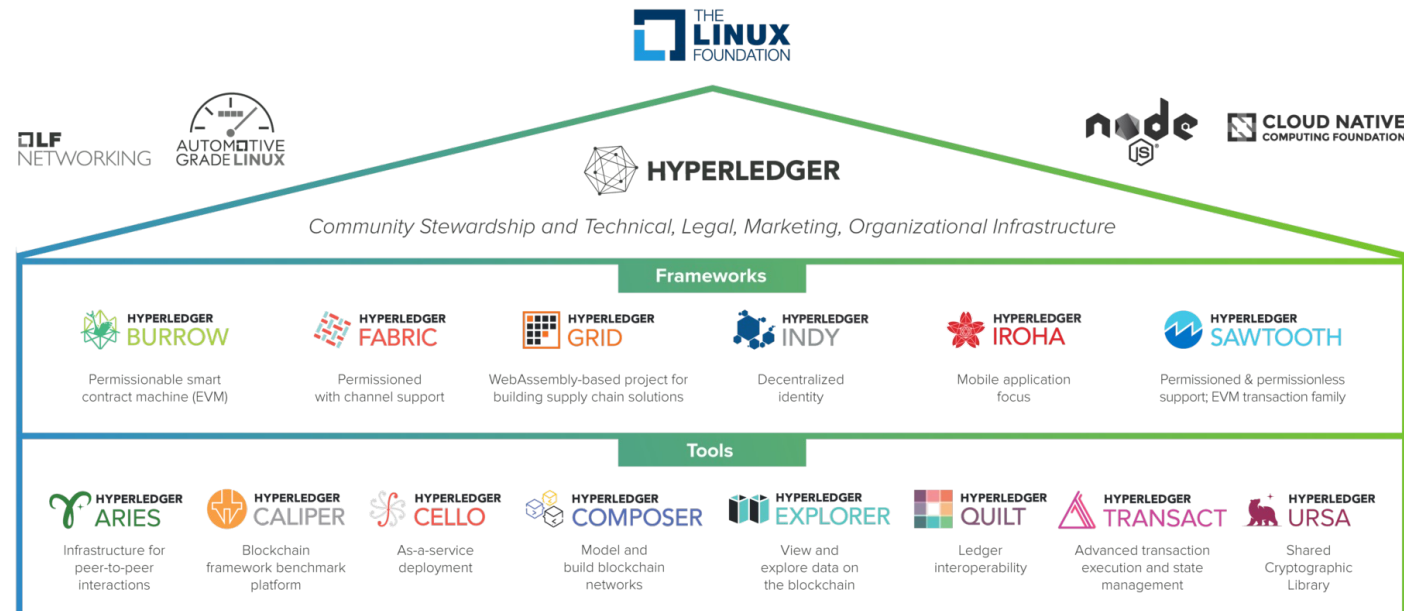
3. Hyperledger Fabric

- Architecture
- Membership Service Provider
- Application
- Ordering Service
- Peers
- Chaincode
- Order-Execution vs. Execution-Order
- Limitations
- Nodes and Roles
- Transaction Flow
- Channels
- Ledger
- Recent Developments in Hyperledger Fabric

Hyperledger as a Consortium DLT project



Hyperledger is an umbrella project hosted by the Linux foundation, initiated in 2015. The goal is to create open-source software that enables institutions to set up a shared and trustless ledger databases for collaboration. The most prominent project is Fabric, which can be used to set up a permissioned blockchain infrastructure with the capability of executing smart contracts. Fabric was originally initiated by IBM and Digital Asset.





“[Building] a global, cross-industry community of communities advancing business blockchain technologies.”¹

The vision behind Hyperledger is that there won't and can't be a one-fits-all blockchain solution. This is because of the various different use cases and requirements on the network and consensus. Based on their vision statement, the Hyperledger foundations predicts a future where multiple different public and private blockchain solutions co-exist. Each of them tailored to specific use cases.

“In this environment, Hyperledger serves as a trusted source of innovative, quality-driven open-source software development, creating modular components and platforms. Hyperledger is incubating and promoting enterprise-grade, open-source business blockchain technologies, on top of which anyone can set up apps to meet their business needs.”¹

1. Beyond Public Blockchains

- Recap
- Motivation
- Use Cases

2. The Hyperledger Project

- Vision and Mission

3. Hyperledger Fabric

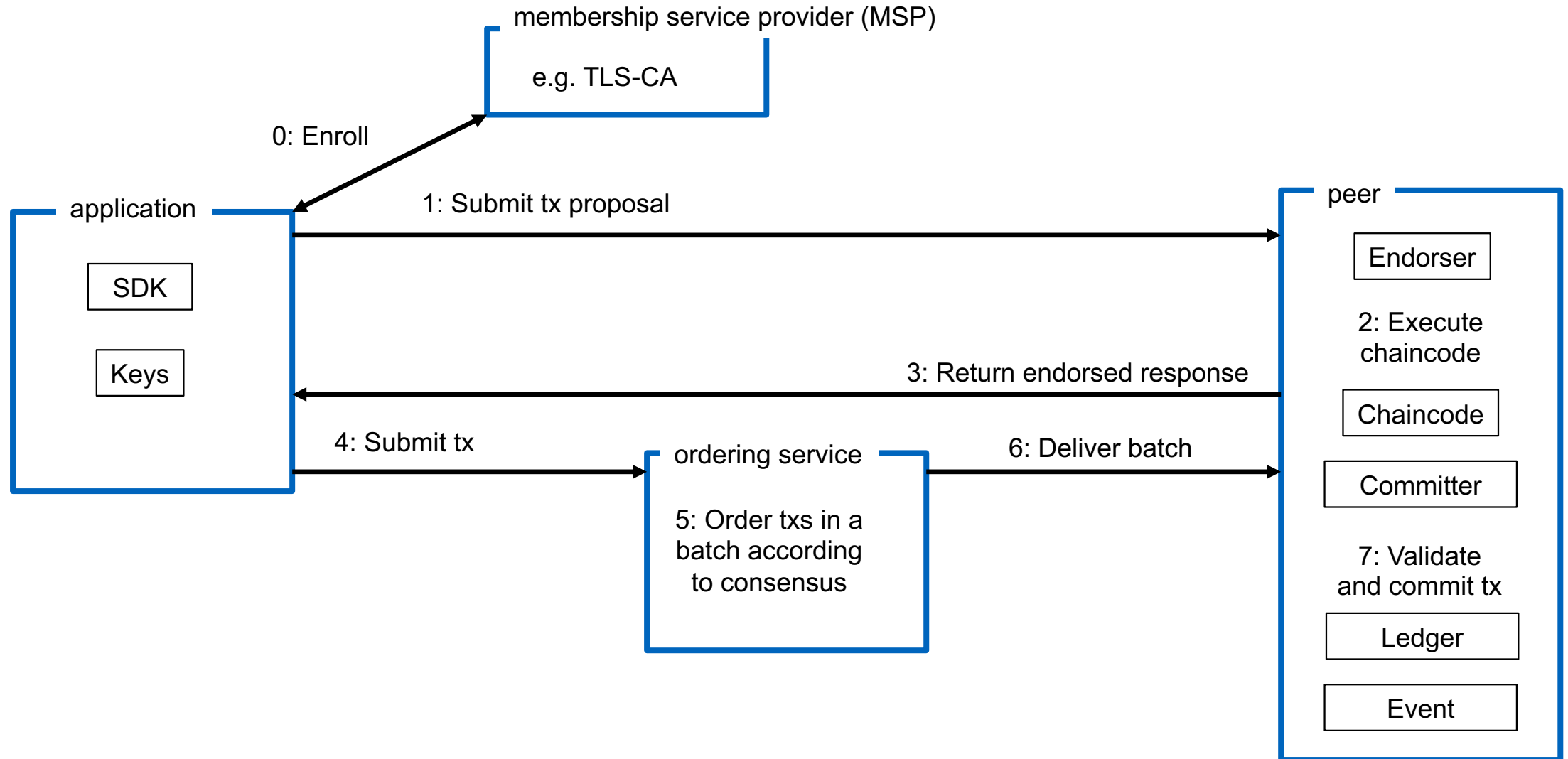
- Architecture
- Membership Service Provider
- Application
- Ordering Service
- Peers
- Chaincode
- Order-Execution vs. Execution-Order
- Limitations
- Nodes and Roles
- Transaction Flow
- Channels
- Ledger
- Recent Developments in Hyperledger Fabric

Fabric is currently considered as the most sophisticated and used framework in the Hyperledger ecosystem. The current version 2.2.5 is considered stable and ready for productive use. Fabric is highly modular and built with a focus on flexibility and scalability.

Features:

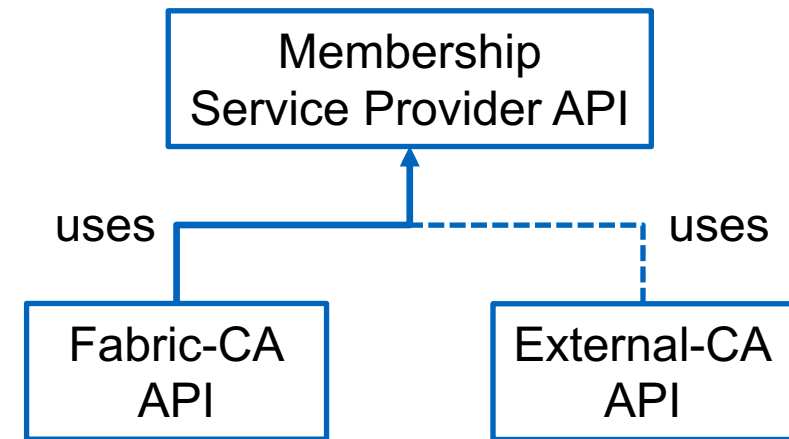
- **Permissioned network:** Fabric is designed as platform to set up permissioned blockchain networks. The framework uses a “Membership Service Provider” (MSP) to enroll new nodes into the network.
- **Channels and multi-ledger:** A core feature of Fabric are so-called channels to establish connections between peers. Each member of a channel maintains a copy of the channel’s specific ledger. Like in other blockchain networks, the ledger contains a sequenced list of all state transitions (transactions).
- **Chaincode:** Fabric allows network operators (system chaincode) and developers (application chaincode) to define certain business logic for a whole channel or for particular transactions.

Architecture and Responsibilities

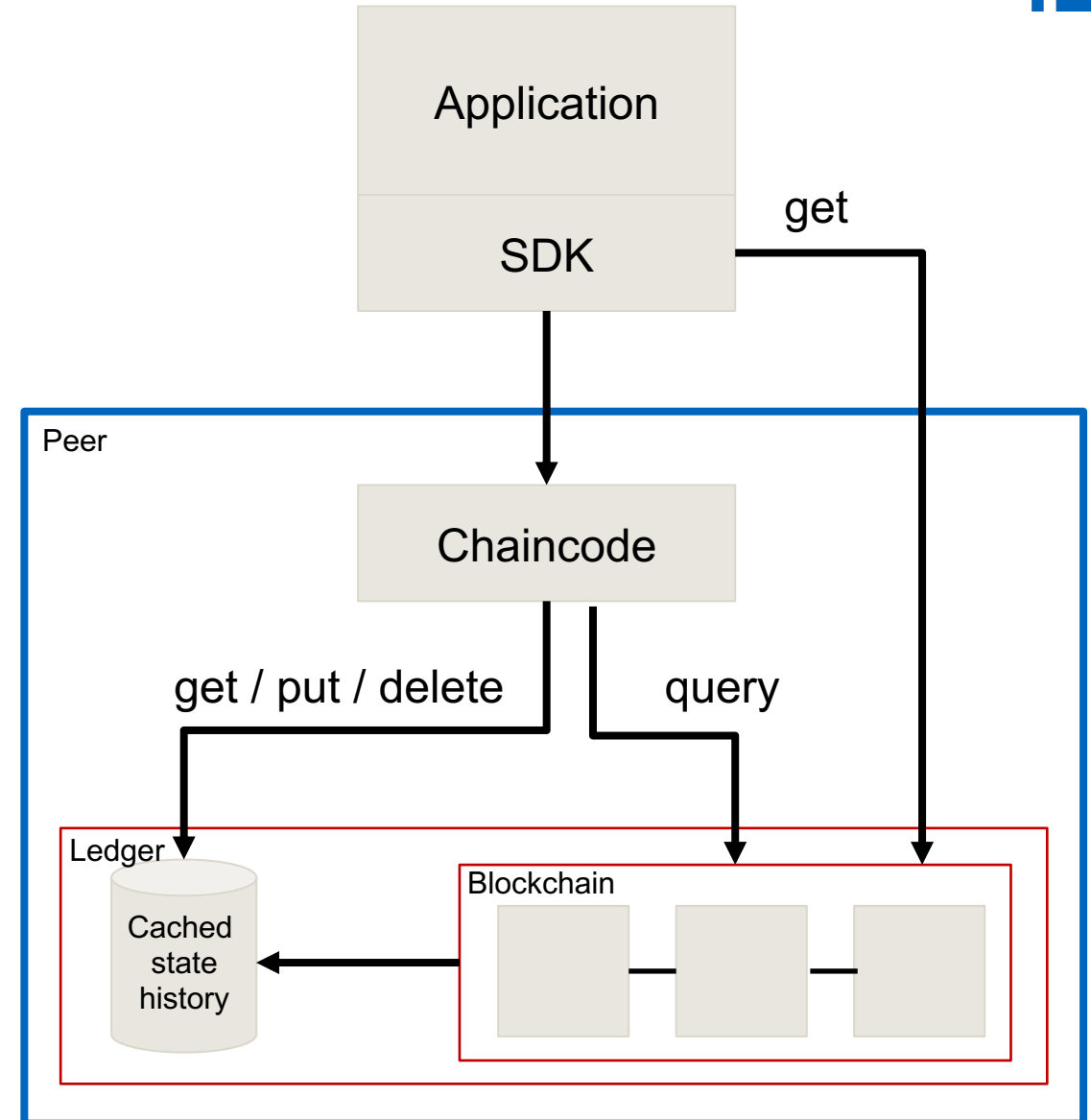


Membership Service Provider (MSP)

- The membership service provider has a pluggable interface that supports a range of credential architectures. A common external certificate authority (CA) is TLS-CA (https certificates).
- Fabric implements its own CA which is called Fabric-CA and used by default.
- The MSP is responsible for only letting authorized clients join the network. It governs the identity for applications, users, peers and the ordering service.
- Takes care of the the access control in the whole network. It ensures that only authorized clients can join certain channels and execute chaincode.



- Currently, applications are programs (written primarily in JavaScript, Java, or Go), that invoke calls on smart contracts.
- Applications are very similar to DApps in the Ethereum ecosystem. They usually handle the UI and enable an end user to use the blockchain.
- Applications submit transactions to the network and invoke chaincode calls.
- Communicate directly with peers



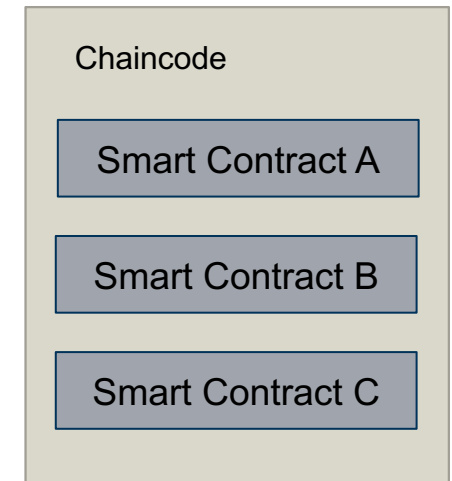
- The ordering service consists of one or more ordering nodes. The nodes do not store any chaincode, nor do they hold the ledger.
- The ordering service enforces the network policy and takes care of the authentication and authorization of the peers.
- Applications must submit transactions to an ordering service node. The node then collects transactions and orders them sequentially. The transactions are then put into a new block and delivered to all peers of a specific channel.
- The blocks are then broadcasted to the peers that hold the chaincode and the ledger. Before the transactions are committed, the peers validate it.
- Consensus is reached when the endorsement of a transaction is accepted, the ordering was successful and the execution was valid and committed.

- A peer is comparable to full-node in Ethereum or Bitcoin. It maintains the state of the ledger and executes transactions.
- Multiple roles for peers exist:
 - **Committing peer**
Maintains the state of the blockchain and commits transactions. It verifies endorsements and validate the results of a transaction.
 - **Endorsing peer**
An endorsing peer is always also a committing peer. The difference is that an endorsing peer additionally takes transaction proposals and executes them to create endorsements.
- The number of peers in a network is not limited and depends on the operating consortium.
- Chaincode supports the emission of **events**, e.g. when a certain transaction happened. Peers are responsible for handling and delivering such events to subscribers (applications), publish / subscribe architecture pattern.

Hyperledger Fabric uses the terms "smart contracts" and "chaincode". While smart contracts refer to the transaction logic of a business object, whereas a chaincode is a **technical container of a group of related smart contracts** for installation and instantiation.

Basically, chaincode is a program written in JavaScript or Java that is installed on a node. A chaincode program allows to write business logic that changes the state of the ledger.

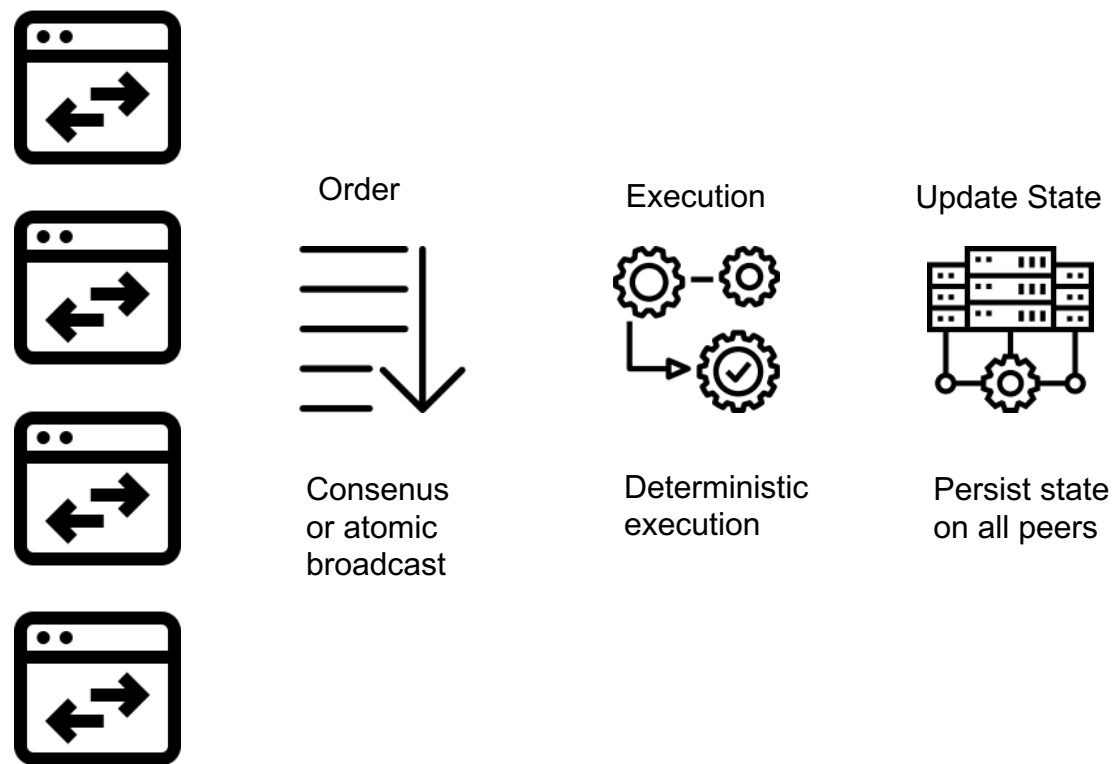
In the past, developing native chaincode for Fabric was very inconvenient. With recent versions, an external chaincode launcher was introduced, making working with Fabric in any capacity (e.g., development, testing, production) significantly easier. Several old tools and pipelines (e.g., Hyperledger Composer) are now obsolete and development is much more comparable to Solidity development.



Software Architecture Order-Execution vs. Execution-Order-Validate

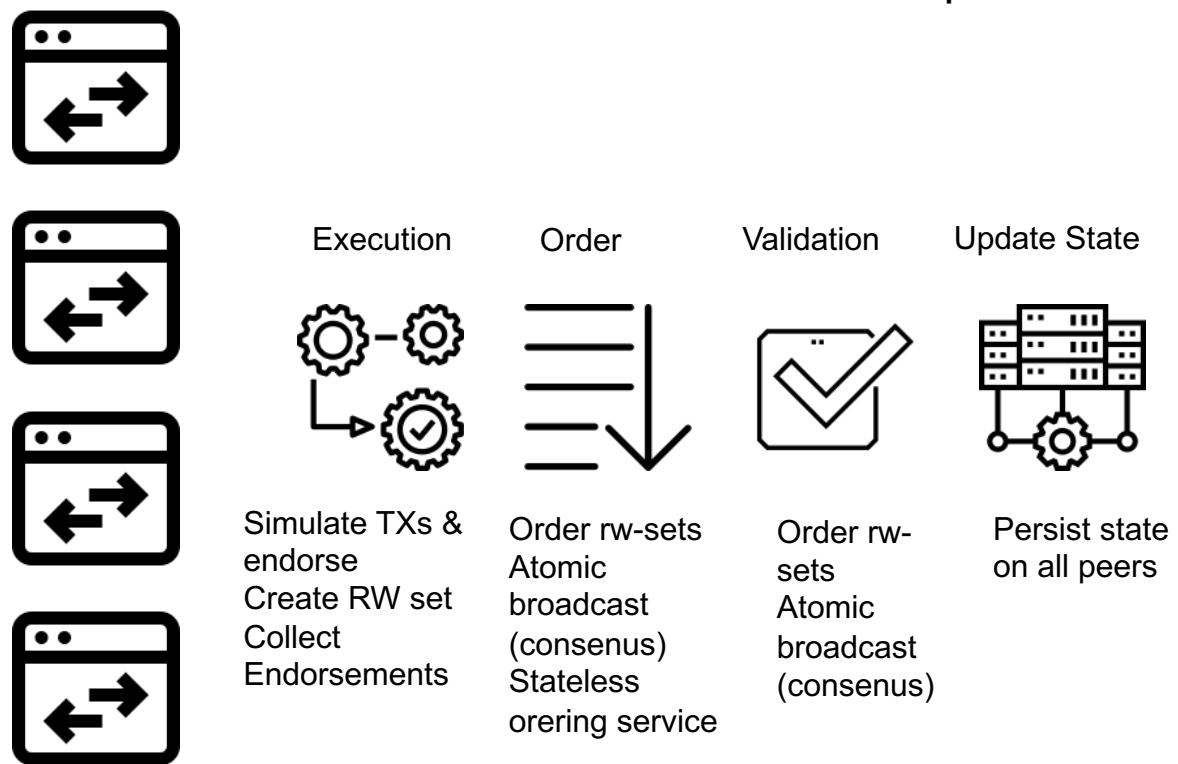


Order-Execution



Execution-Order-Validate

Parallel execution of unrelated operations



Limitations of Order-Execution Architecture

Sequential execution on all peers

Executing the transactions sequentially on all peers **limits** the effective **throughput** that can be achieved by the blockchain. In particular, since the throughput is inversely proportional to the execution latency, this may become a performance bottleneck for all but the simplest smart contracts.

Only endorsing peers execute Proposed TXs

Non-deterministic code

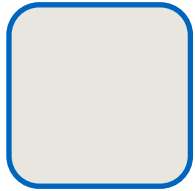
Agreement on the same state is an essential property of current blockchain systems. A single non-deterministic operation could have a devastating effect. This issue is addressed by programming blockchains in domain-specific languages like Solidity in Ethereum. Those languages are usually not as expressive and require additional learning by the programmer.

Applications written in general purpose PL need to follow endorsement policies. If RW-sets differ → Rejection by endorsing peers

Confidentiality of execution

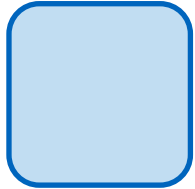
It often suffices to propagate the same state to all peers instead of running the same code everywhere. Because everyone has to execute everything in the Order-Execution cycle, inherent confidentiality is not provided. Confidentiality can only be achieved through additional data encryption leading to considerable overhead.

Only a few trusted endorsing peers execute the TXs against the chaincode, the rest just updates the state (RW set)



Committing peer

Maintains the state of the blockchain and commits transactions. It verifies endorsements and validate the results of a transaction.



Endorsing peer

An endorsing peer is always also a committing peer. The difference is that an endorsing peer additionally takes transaction proposals and executes them to create endorsements.

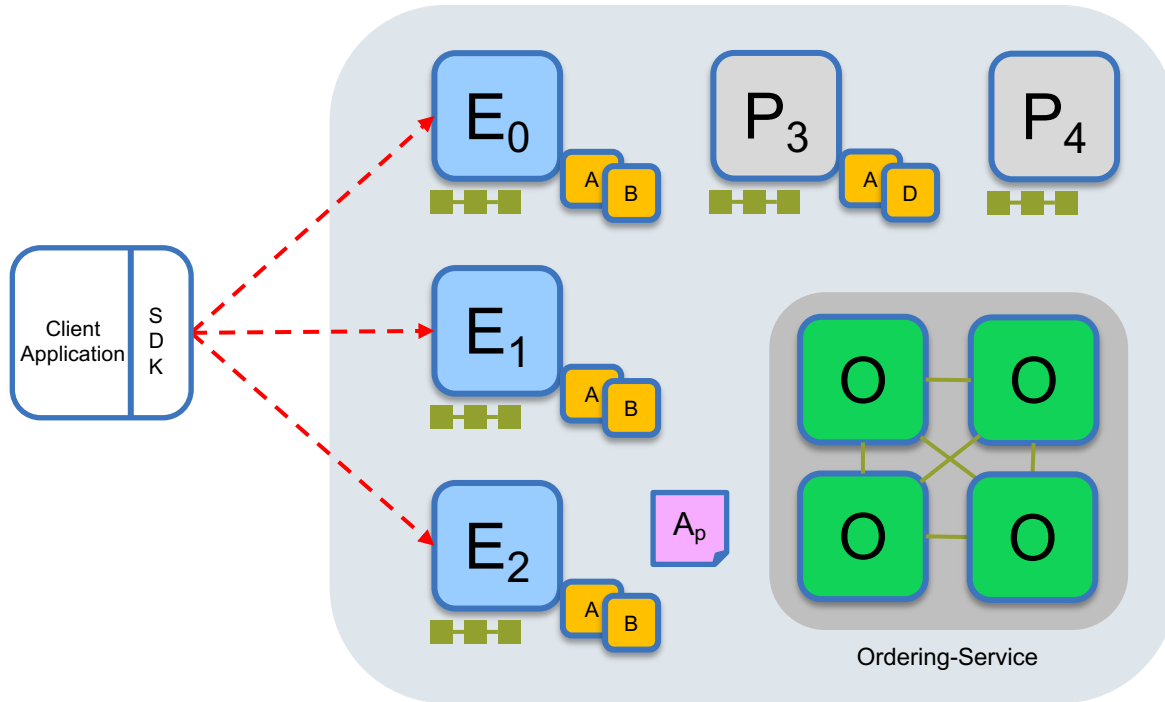


Ordering service node

Applications must submit transactions to an ordering service node. The node then collects transactions and orders them sequentially. The transactions are then put into a new block and delivered to all peers of a specific channel. Does neither hold ledger nor chaincode.

Transaction Flow (Step 1)

Application Submits Transaction Proposal

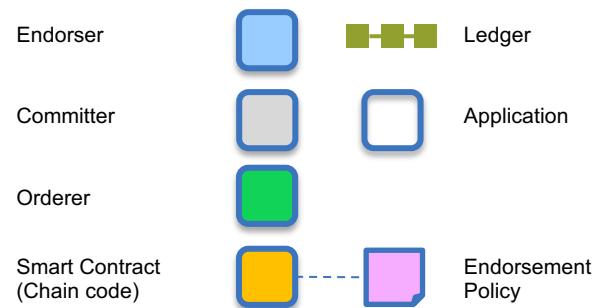


Application creates a transaction proposal for **chaincode A** and sends it to all peers that are part of the endorsement policy A_p

Endorsement Policy A_p

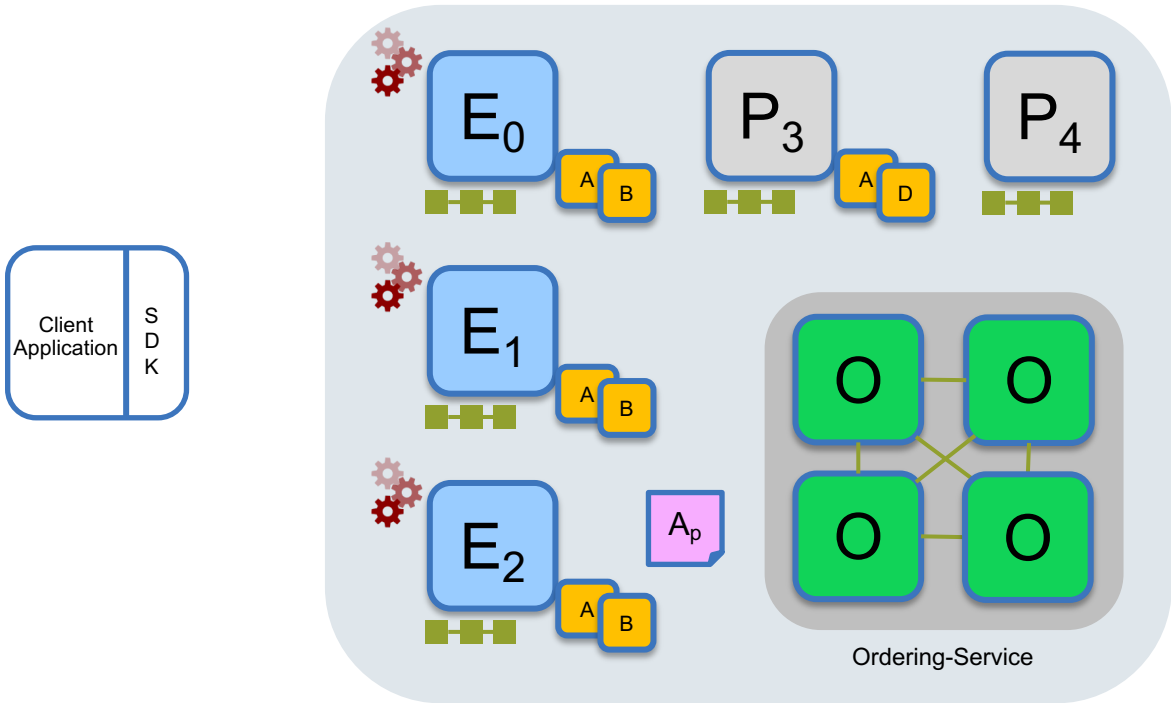
- E_0 , E_1 and E_2 must sign the transaction
- (P_3 , P_4 are not part of the policy)

Since only the peers E_0 , E_1 and E_2 are part of the endorsement policy A_p , it is not required to send the transaction proposal to P_3 and P_4



Transaction Flow (Step 2)

Endorsing Peers Execute the Transaction Proposal



E₀, E₁ and E₂ will each simulate the execution of the *proposed* transaction from the application.

None of these executions will update the ledger.

The **simulation will be used to capture** the read and write operations on the ledger. After the transaction is executed, each peer will have a generated **read/write set** (RW set)

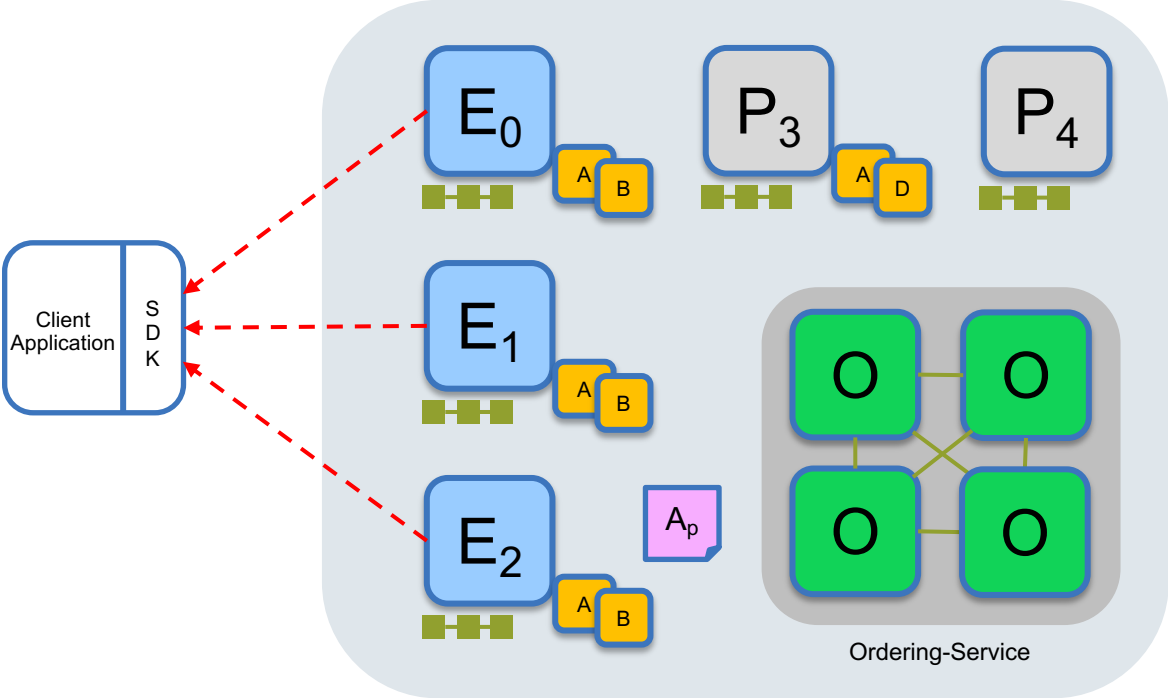
```
<TxReadWriteSet>
  <NsReadWriteSet name="chaincode1">
    <ReadSet>
      <read key="K1", version="1">
      <read key="K2", version="1">
    </ReadSet>
    <WriteSet>
      <write key="K1", value="V1">
      <write key="K3", value="V2">
      <write key="K4", isDelete="true">
    </WriteSet>
  </NsReadWriteSet>
</TxReadWriteSet>
```

Source: <https://www.hyperledger.org/resources/universities#educators>

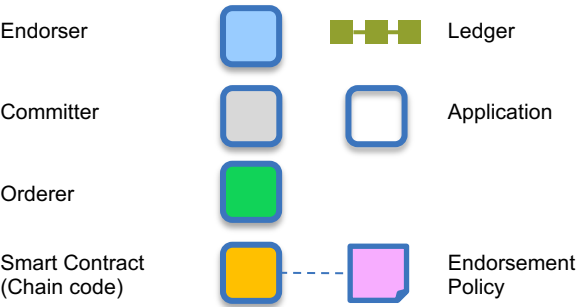
Transaction Flow (Step 3)



Read/Write Set is Signed and Returned to the Application



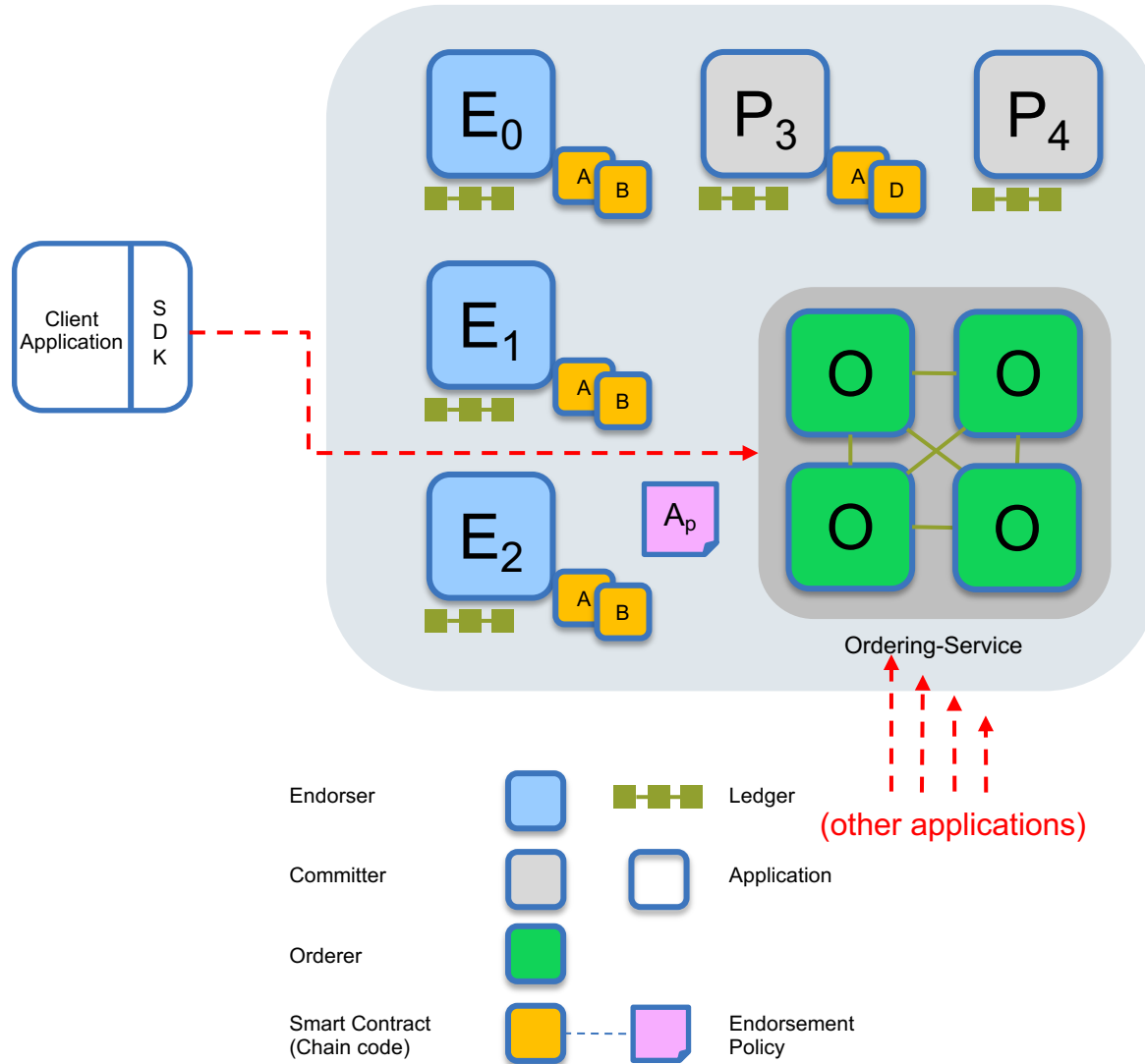
E_0 , E_1 and E_2 will each sign their generated read/write set and return it to the application that invoked the transaction.



Source: <https://www.hyperledger.org/resources/universities#educators>

Transaction Flow (Step 4)

Signed Responses are Sent to the Ordering Service



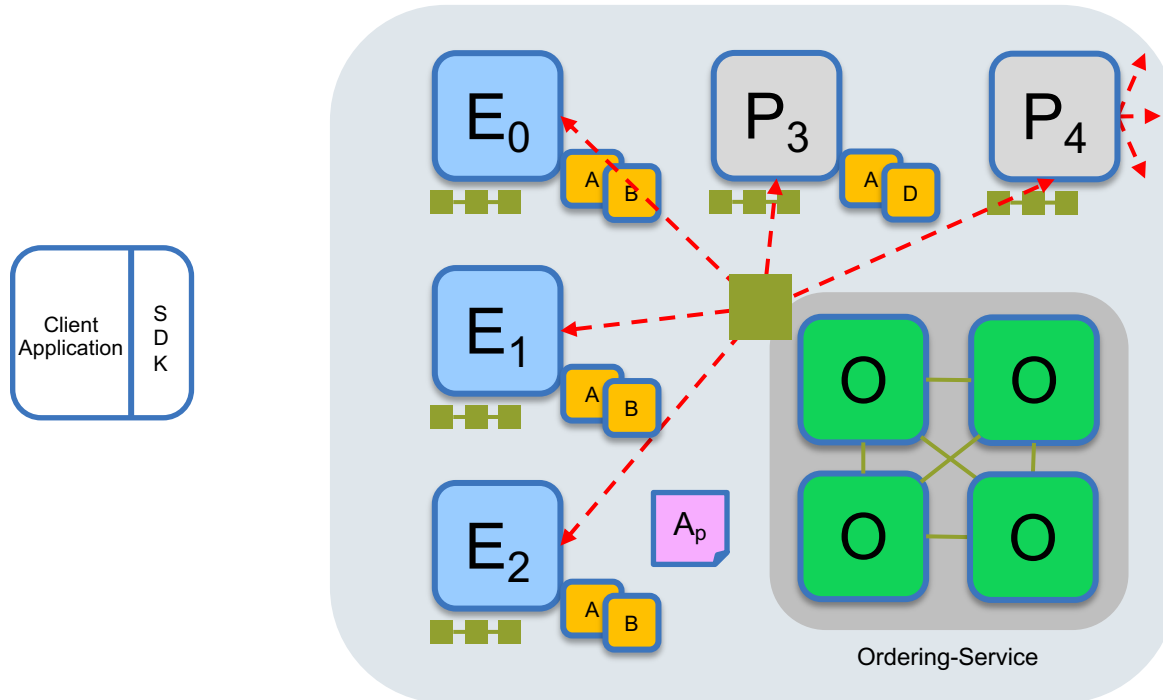
The application submits the signed responses from E_0 , E_1 and E_2 to the ordering service.

The ordering service is responsible to order all transactions from all applications in the network. The service tries to **serialize** the incoming transactions.

Source: <https://www.hyperledger.org/resources/universities#educators>

Transaction Flow (Step 5)

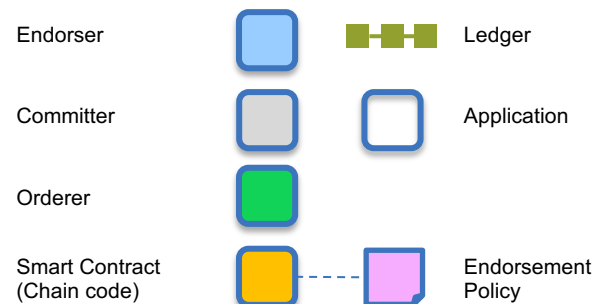
Ordering Service Distributes New Block to all Committing Peer



The ordering service creates a new block based on the incoming transactions. The block will then be broadcasted to all committing peers in the channel.

Currently, the ordering service supports three different ordering algorithms:

- SOLO (single node, development)
- Kafka (blocks map to topics)
- Raft (crash fault tolerant (CFT), follows a “leader and follower” model)



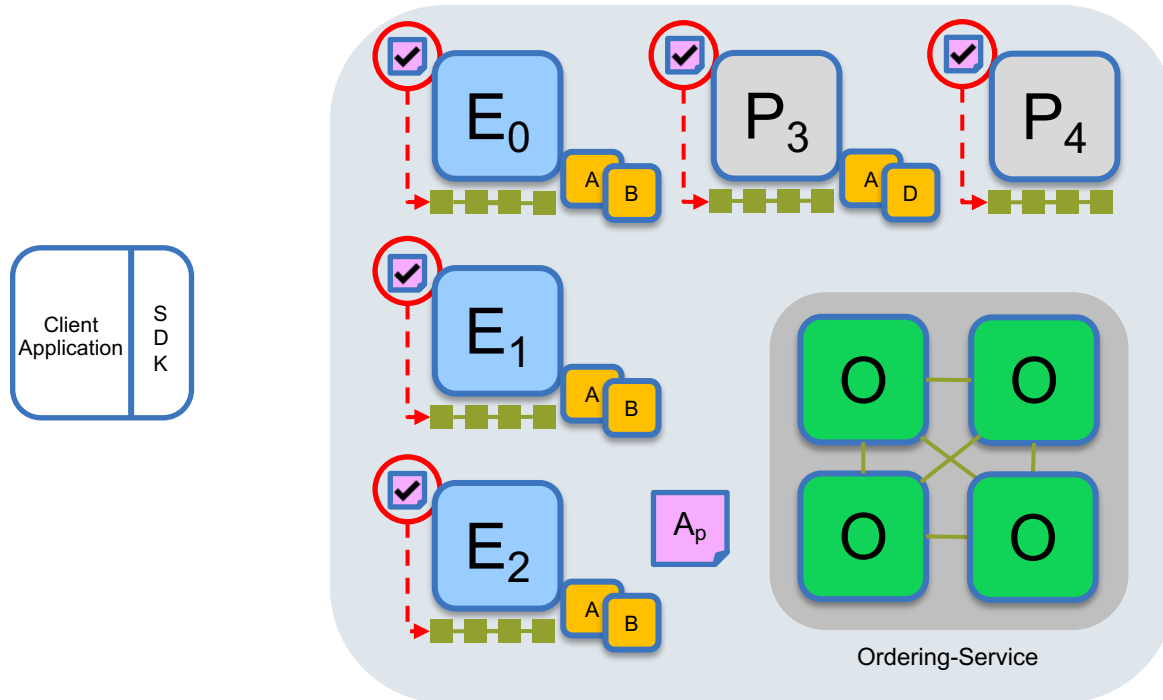
Source: <https://www.hyperledger.org/resources/universities - educators>

- Raft is a crash fault tolerant ordering service.
- It uses a “leader and follower” model, in which a leader is dynamically elected among the ordering nodes in a channel, and that leader replicates messages to the follower nodes.
 - Because the system can sustain the loss of nodes, including leader nodes, as long as there is a majority of ordering nodes remaining, Raft is said to be “crash fault tolerant” (CFT). In other words, if there are three nodes in a channel, it can withstand the loss of one node.
- Raft is the first step toward Fabric’s development of a Byzantine-Fault Tolerant (BFT) ordering service.



Transaction Flow (Step 6)

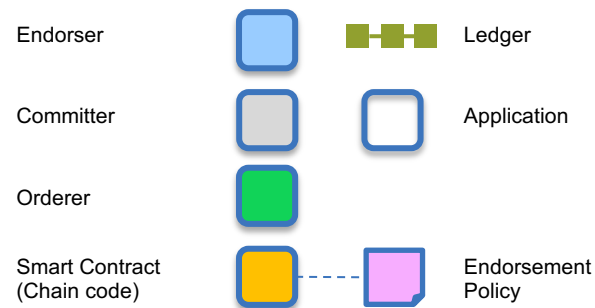
Committing Peers Validate the Transaction



All committing peers in the channel validate the transaction (read/write set) according to the endorsement policy of the chaincode A.

If the transaction is valid, the **read** and write set is written to the ledger and added as a new block to the blockchain.

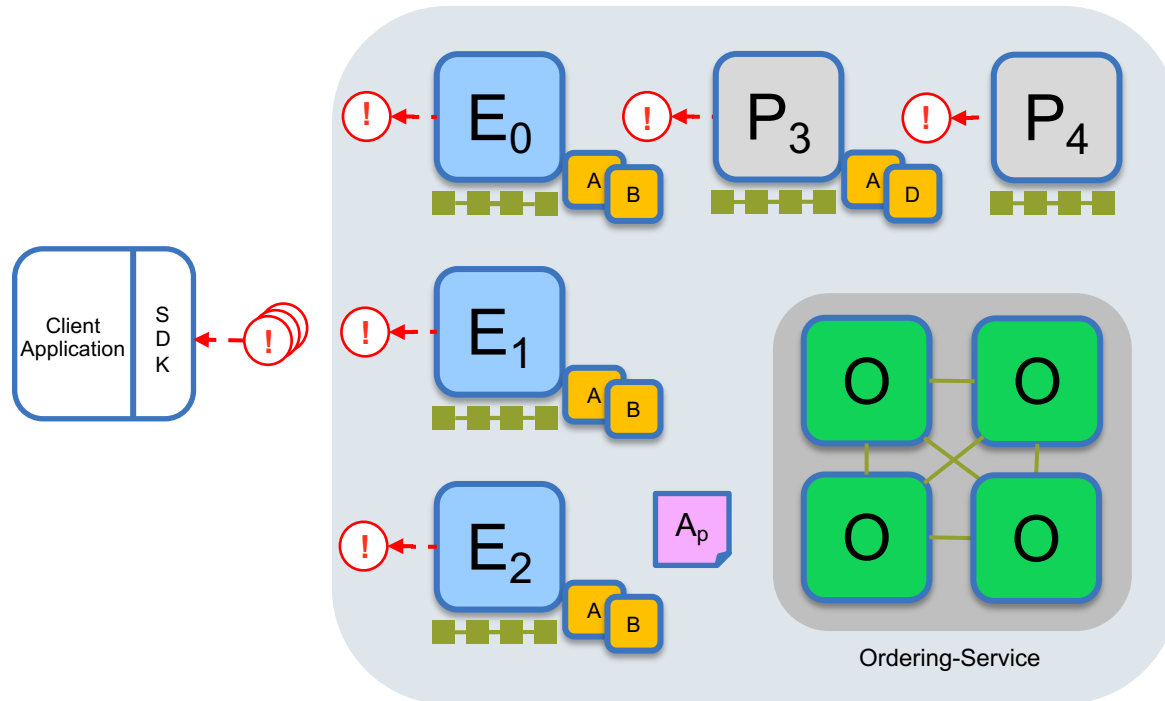
The databases used for caching are updated with the new state information accordingly.



Source: <https://www.hyperledger.org/resources/universities#educators>

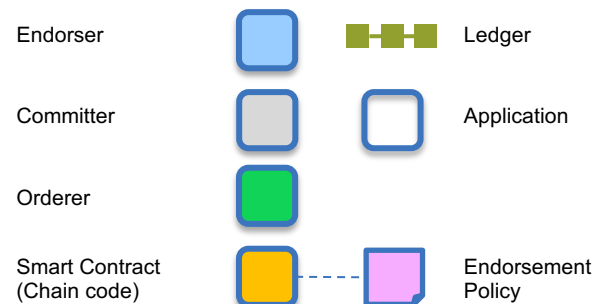
Transaction Flow (Step 7)

Notify Application

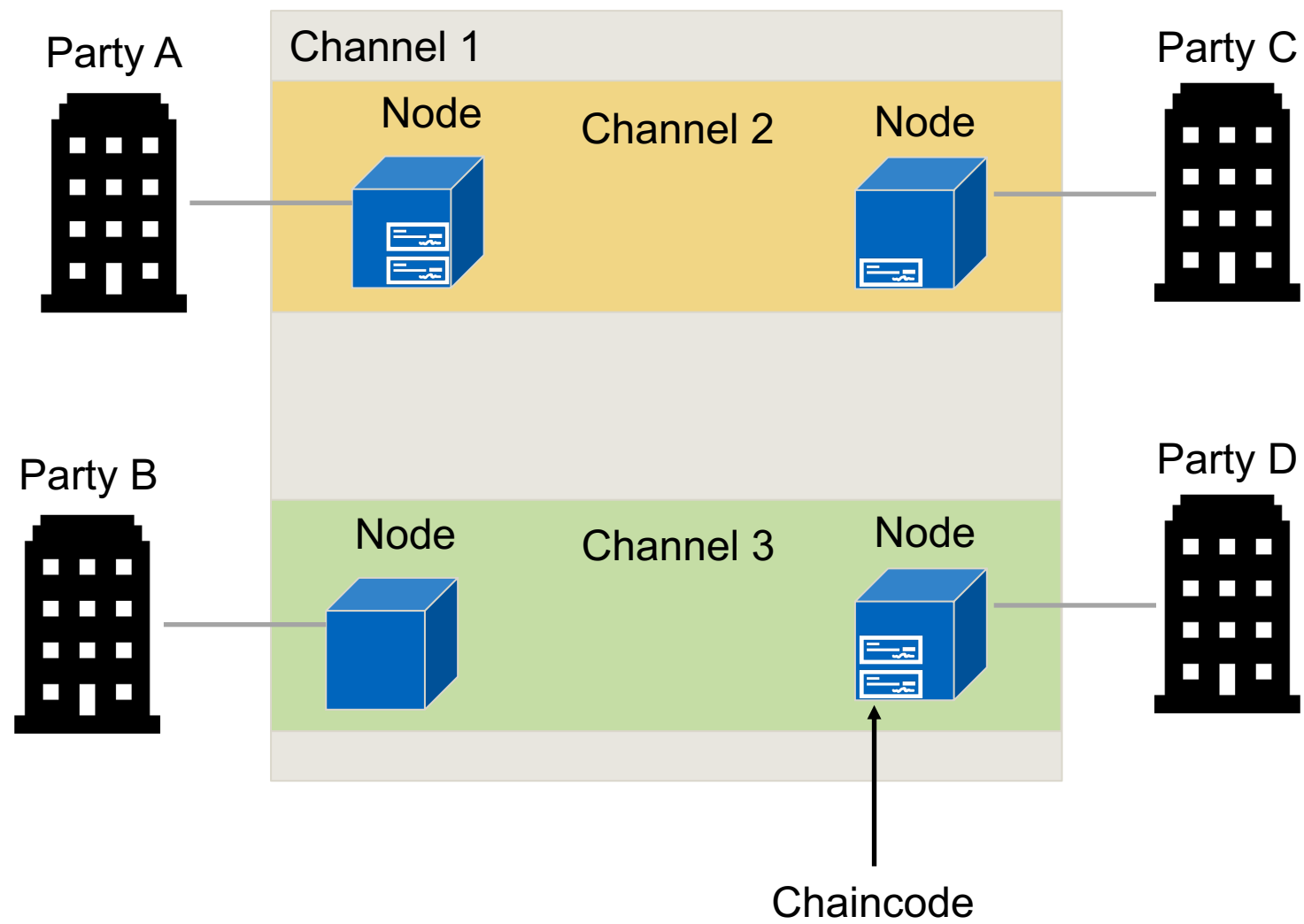


Applications can register to be notified by the peers once the transaction is done. The peers will emit an event that indicates if the transaction succeeded or failed.

Applications can also subscribe to state changes of the ledger, i.e., a connected peer will then notify them if new blocks are added to the chain.



Source: <https://www.hyperledger.org/resources/universities#educators>

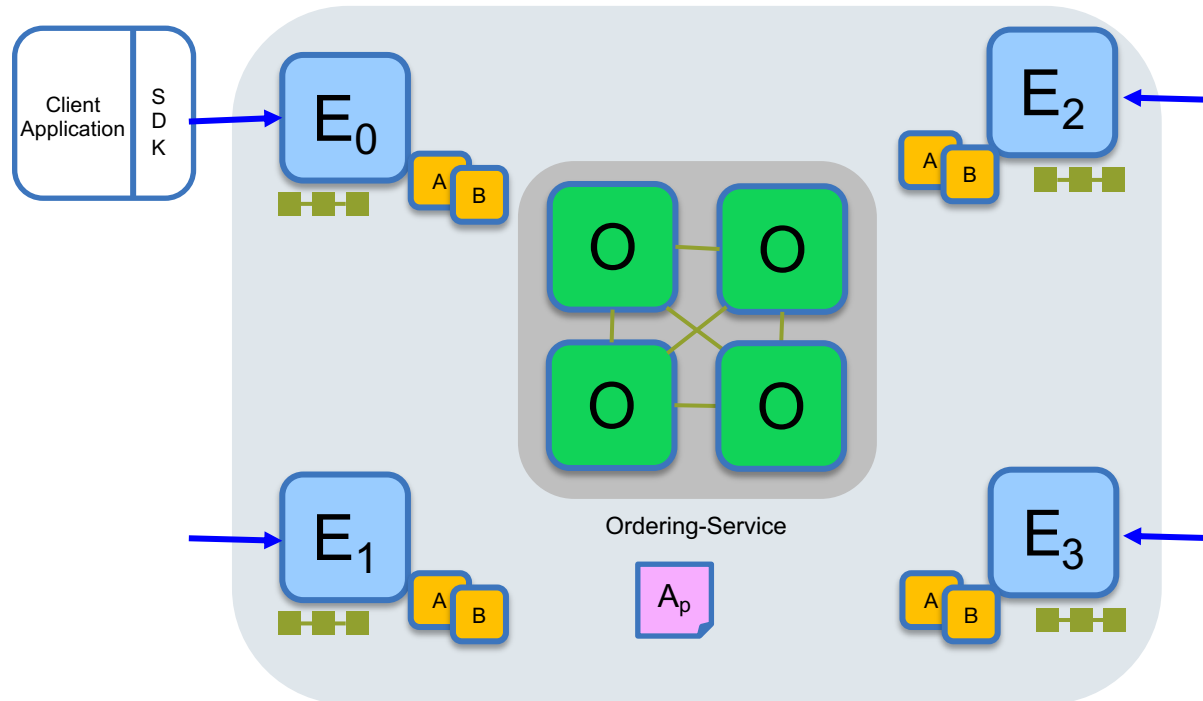


A channel is a separate blockchain.

This blockchain is only managed by a subset of all available nodes as defined by the membership service provider.

- Separate channels isolate transactions on different ledgers
 - Consensus takes place within a channel by members of the channel
 - Other members on the network are not allowed to access the channel and will not see transactions on the channel
 - A chaincode may be deployed on multiple channels with each instance isolated within its channel
 - Peers can participate on multiple channels
- ➔ Concurrent execution for performance and scalability

Single Channel Network

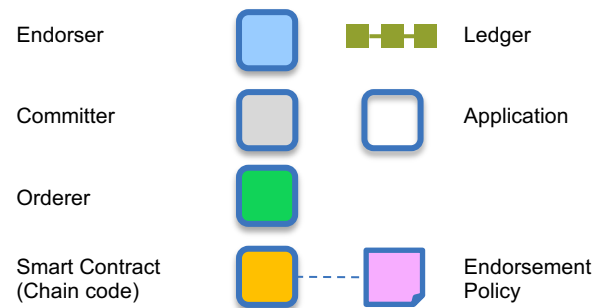


All peers connected to the same channel (**blue**)

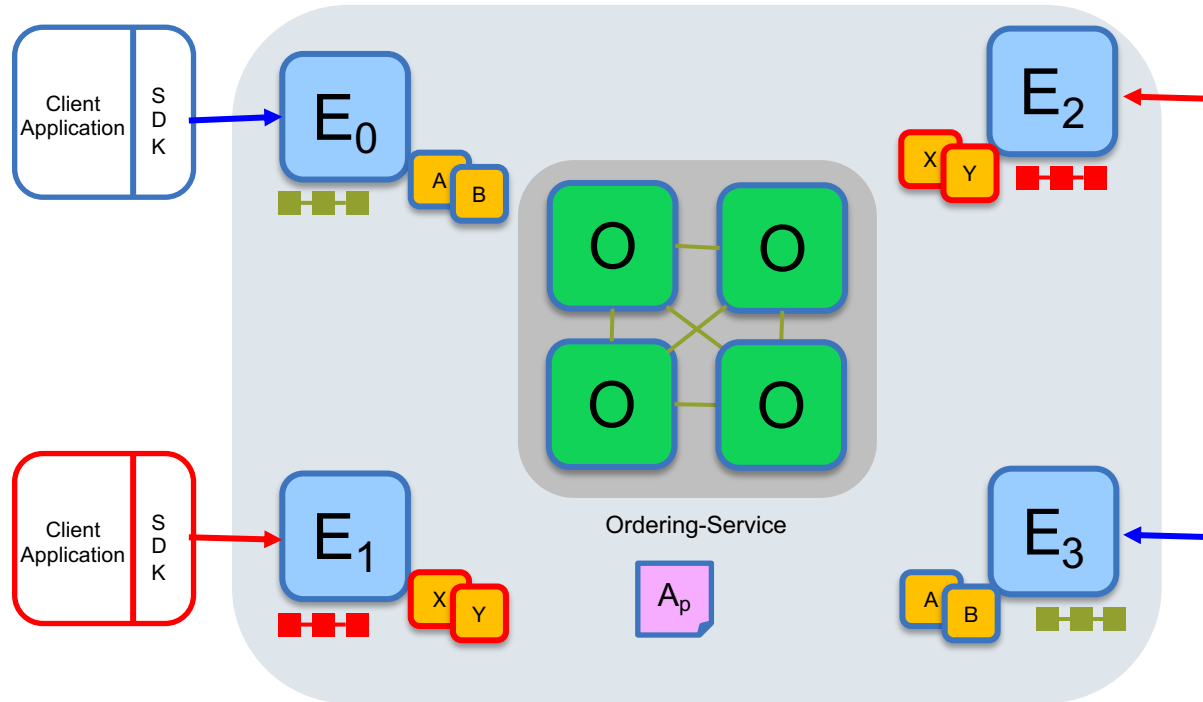
All peers have the same chaincode and maintain the same ledger

Endorsements by peers E_0 , E_1 , E_2 , and E_3

A single channel network is similar to traditional, public blockchain network where the whole world state is shared with all participating nodes.



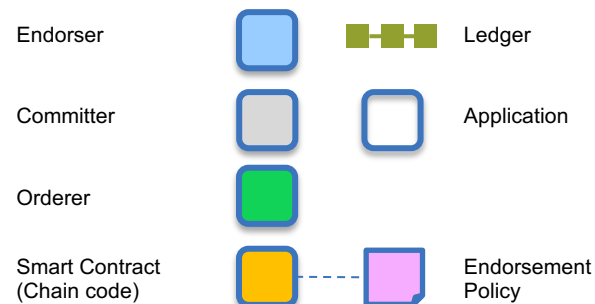
Multi Channel Network



Peers E_1 and E_2 connect to the **red** channel for **X** and **Y** chaincodes.

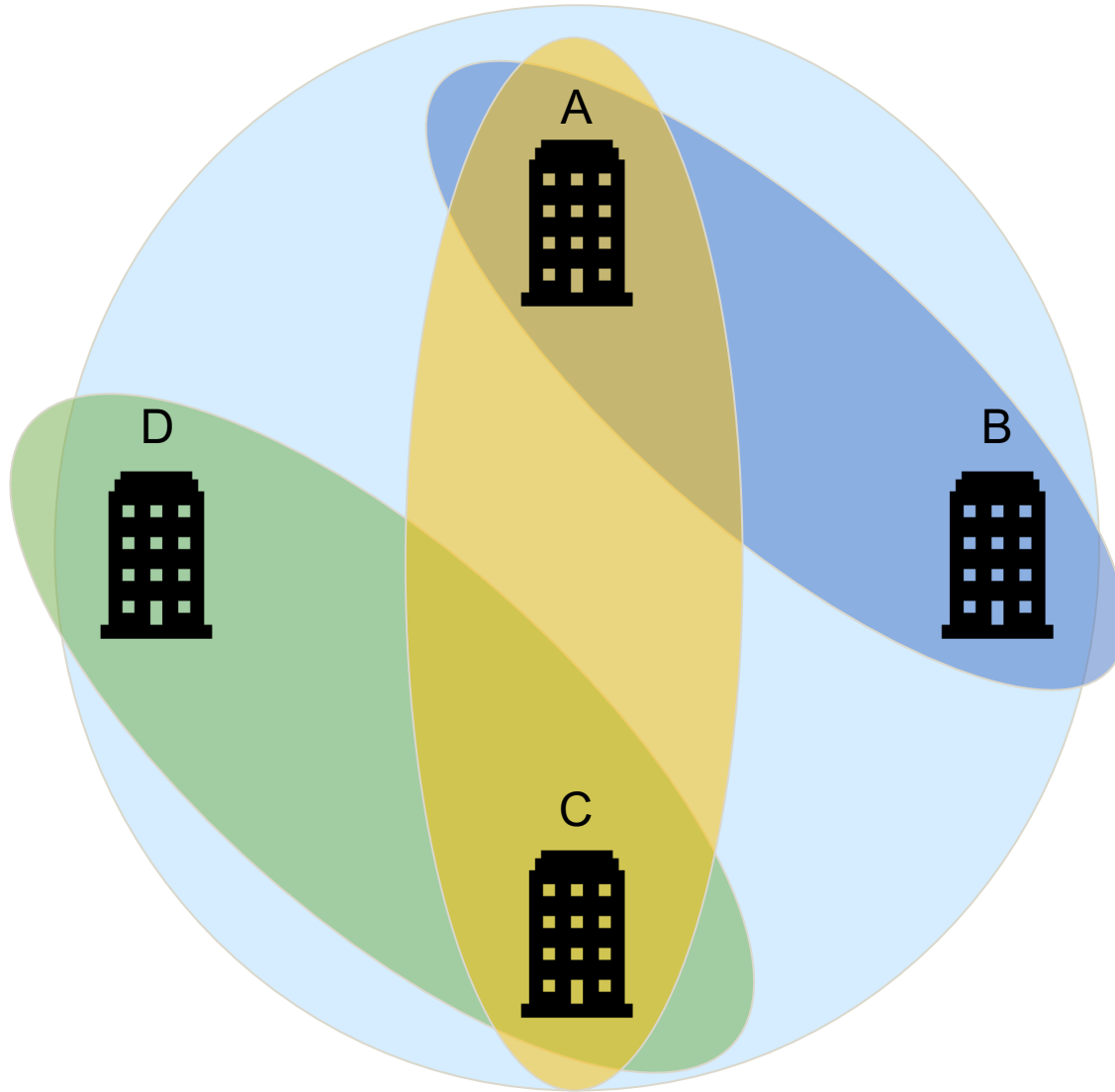
Peers E_0 and E_3 connect to the **blue** channel for **A** and **B** chaincodes.





Fabric support multi channel networks. Each peer only shares the ledger with nodes that are in the same channel. Smart contracts also operate on a channel basis and are not globally available.



Source: <https://www.hyperledger.org/resources/universities#educators>

Example of a Multi Channel Network



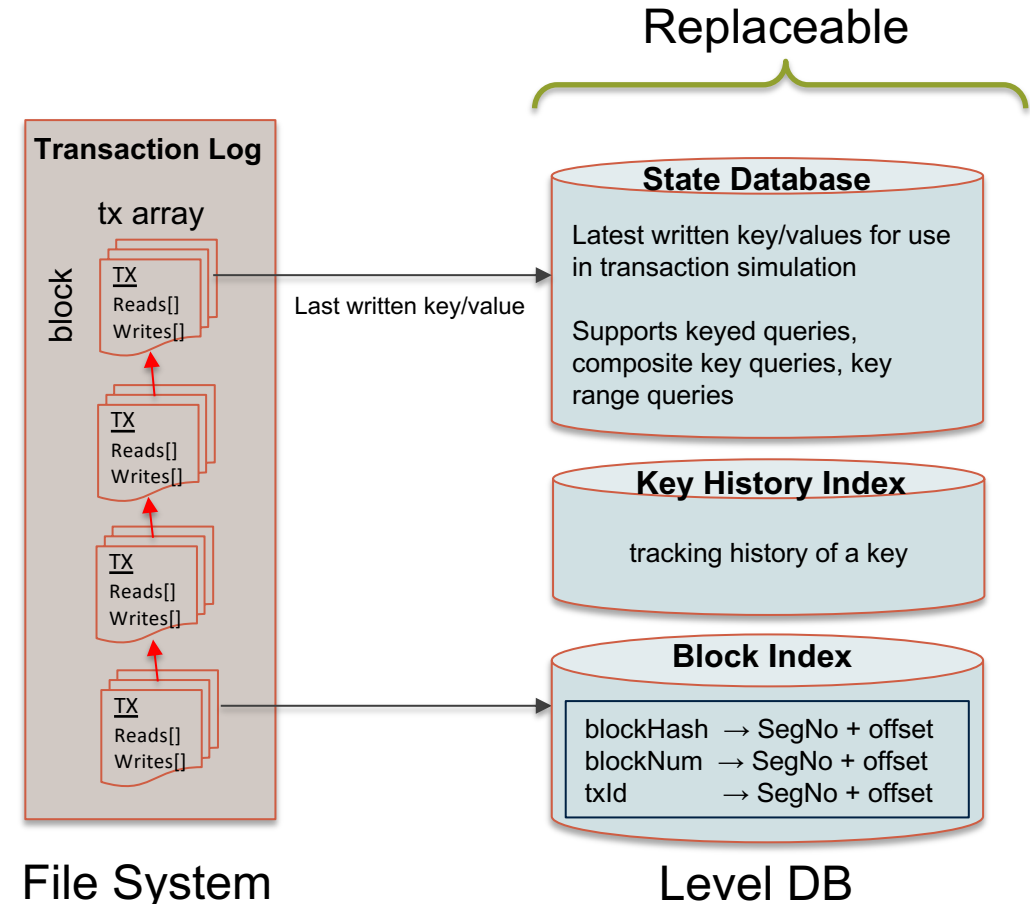
-  A ledger that is shared among all consortium members
-  A ledger that is shared between A and B (C and D cannot access it)
-  A ledger that is shared between C and D (A and B cannot access it)
-  A ledger that is shared between A and C (B and D cannot access it)

A block in Fabric consists of transactions that define reads and writes on the shared state data.

The blockchain is saved on the file system, just like in Ethereum and most other blockchain systems.

Reading from the blockchain can be slow when the blockchain on the file system has to be scanned.

Fabric uses a database that contains the current state of the ledger. This provides peers a very efficient data structure to retrieve ledger information.



Source: <https://www.hyperledger.org/resources/universities#educators>

While the core principles have stayed the same since Fabric 1.0, many additional features and user experience improvements have been introduced. Here is an overview of just some of them:

Fabric Gateway

- Provides an abstraction layer (a simplified API) that clients can use for easy interaction with the blockchain

Channel Administration Improvements

- Now it is possible to remove peers from a channel
- Easier joining of new peers to a channel by loading a snapshot from an existing peer

Smart Contract Administration Improvements

- Multi-party agreement on chaincode parameters and chaincode updates
- Policy changes without repackaging chaincode and reinstalling it
- Installing multiple chaincodes packaged together as one package

If you are interested in working with Fabric, the documentation has become a great place to start.