Blockchain deconstructed

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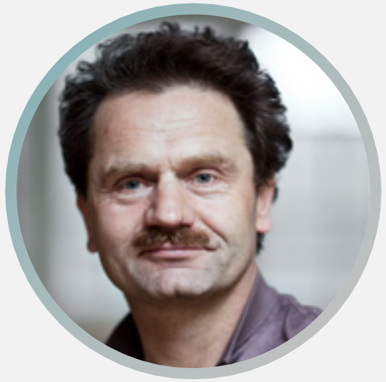

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Areas of interest

- Programming language technology
- Theoretical computer science (algorithms, semantics, logic)
- Blockchain technology
- Contract management
- Financial technology
- Enterprise systems

Related background

- European Blockchain Consortium (ebcc.eu)
- Steering committee chair, Innovation network for Finance IT (CFIR.dk)
- Principal investigator, Functional technology for high-performance architectures (FUTHARK)

Academic background and affiliations

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What is a blockchain/DL system?

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Any **peer-to-peer** decentralized system

- storing a **single, consistent tamper-proof record of events**
- admitting only **appending** of new events
- enforcing a fixed or user-defined **protocol** (**contract**) for appending new events
- Guaranteeing **unique ownership** of resources (no double spending)
- with **no trusted** or **privileged** parties
- based on **cryptographic** principles

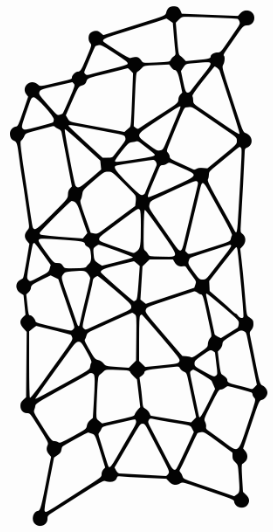
What is a blockchain/DL system?

A computer system characterized by

- organizational and technical **decentralization**;
- **tamper-proof recording** of events and their **evidence**; and
- guaranteed **resource preservation** and **credit limit** enforcement

Organizational and technical decentralization

- **Technical** decentralization: A distributed peer-to-peer system
- **Organizational** decentralization: No single or select group of organizations controls/has privileged rights to system compared to others
- **Governance policy** for regulating membership, functionality, conflict resolution, etc.
  - Group of organizations operating and using system can be open and self-authenticating (nonpermissioned, ”distributed ledger technology”) or closed and externally authenticated (permissioned, ”blockchain”).



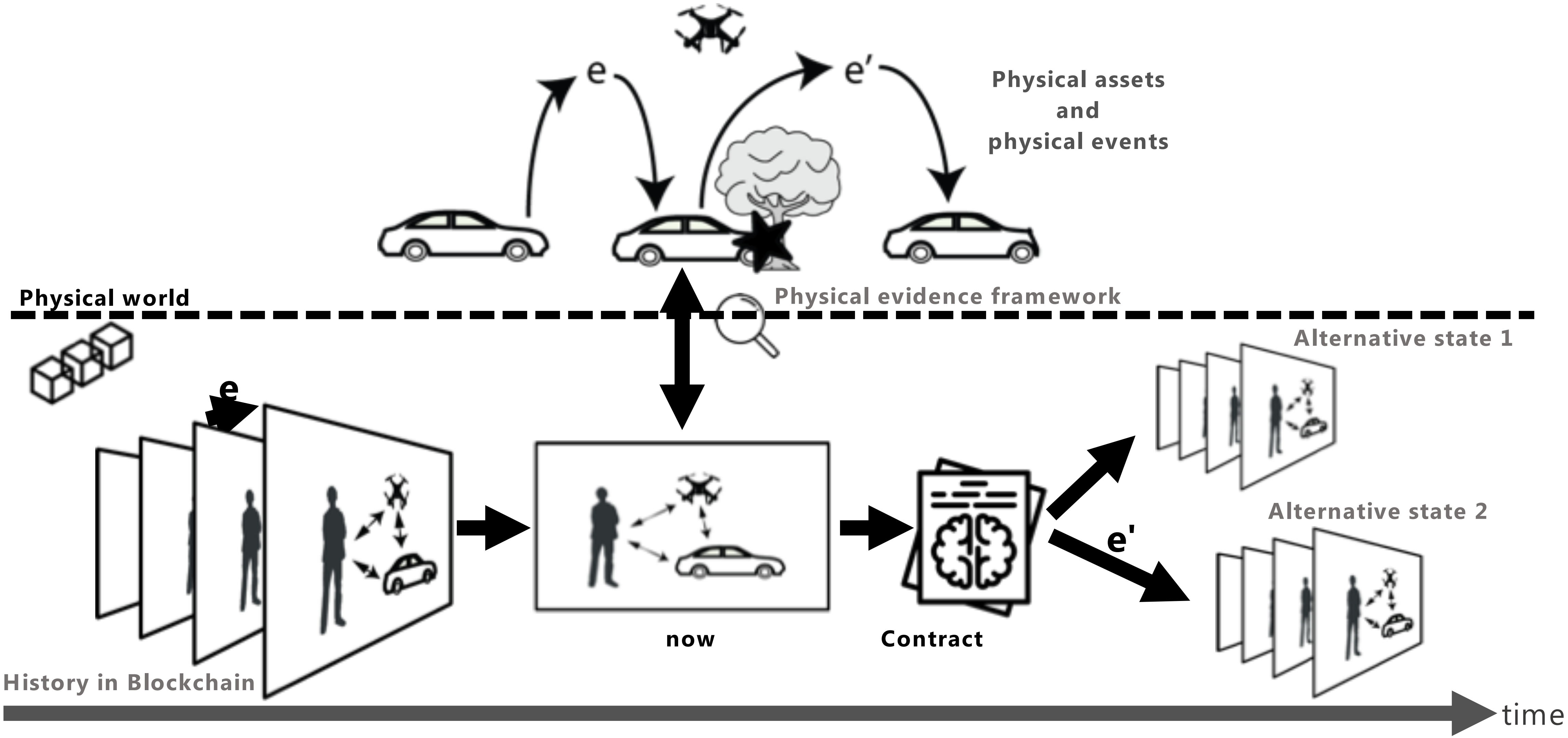
REA accounting model (extended information and contracts)

- **R**esource (= asset): Money, licenses, physical objects (trucks),…
- Information: Data, invoices,…
- **A**gent: Person, company, institution, autonomous device,…
- Contract: Specification of obligations, permissions and prohibitions
- **E**vent:
  - Atomic event:
    - A transfers R to B
    - A transforms R to R’
    - A informs B of I
    - …
  - Complex event: Set of events that satisfies a given (sub)contract

Tamper-proof recording of events and their evidence

- Event recording: Events are recorded
- Tamper-proof: They cannot subsequently be altered or deleted
- Evidence
  - for atomic events: signature, plus supporting evidence of event having happened (pictures, receipts, DNA samples, GPS data,)
  - for complex events: (mathematical) proof that a set of events is a correct execution of a contract

Digital Twin via physical evidence framework



Guaranteed resource preservation and credit limit enforcement

- **Resource preservation**: Transfers keep the sum of all resources invariant:
  - A transfers 50 ETH to B: The sum of all ETH is the same. Atomically, after event A has 50 ETH less; B has 50 ETH more.
  - We allow negative numbers
- **Credit limit enforcement**: A transfer is only *valid* and *effected* if the credit limits of each agent are respected. For above transfer:
  - If A owns 60 ETH and has credit limit 0: Valid.
  - If A owns 30 ETH and has credit limit 0: Invalid.
  - If A owns 30 ETH and has credit limit 20: Valid.
- No-double-spend guarantee = all agents have credit limit 0.

Use cases for adaptive credit limits

- **Full-reserve monetary system**: One agent (the central bank) has no credit limit (or dynamic credit limit according to some governance regime), all others have credit limit 0.
- **Fractional-reserve monetary system**: A designated set of agents ("banks") have a dynamic credit limit, all other have credit limit 0.
- **Demand-driven production of physical assets**: A car manufacturer has no credit limit (they produce cars on demand), all others have credit limit 0.

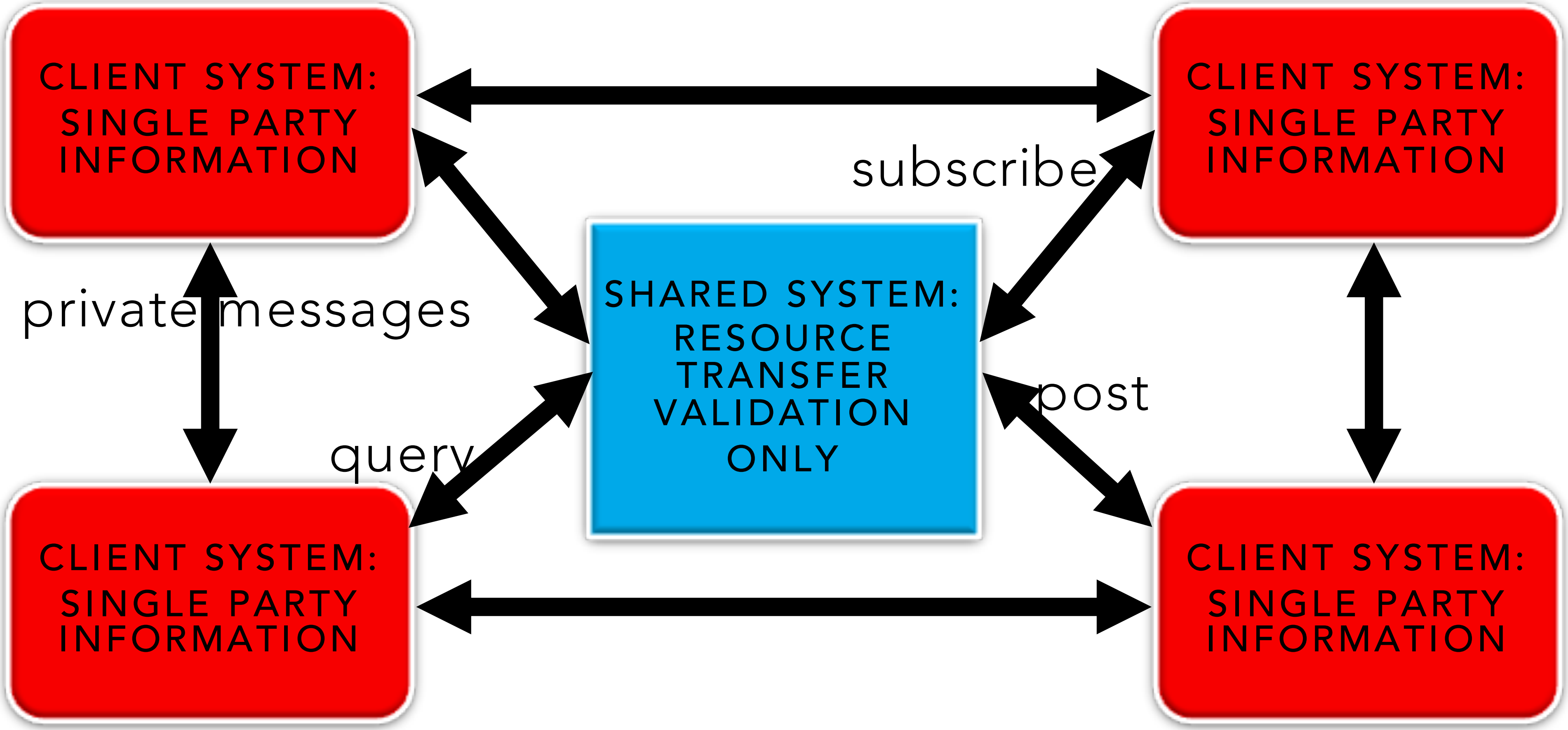
Commutativity theorem, part 1

- **Theorem:** If every agent has an infinite credit limit, then all resource transfers are valid and can be executed in arbitrary order. (Each order results in the same state of ownership.)
- **Corollary**: Contract execution involving *k* agents requires only consensus by the *k* agents on which events have happened.
- Note, usually *k=2*. The Internet with TLS (with tamper-proof recording of message sending) is a permissioned blockchain/DL system if there are no credit limits!

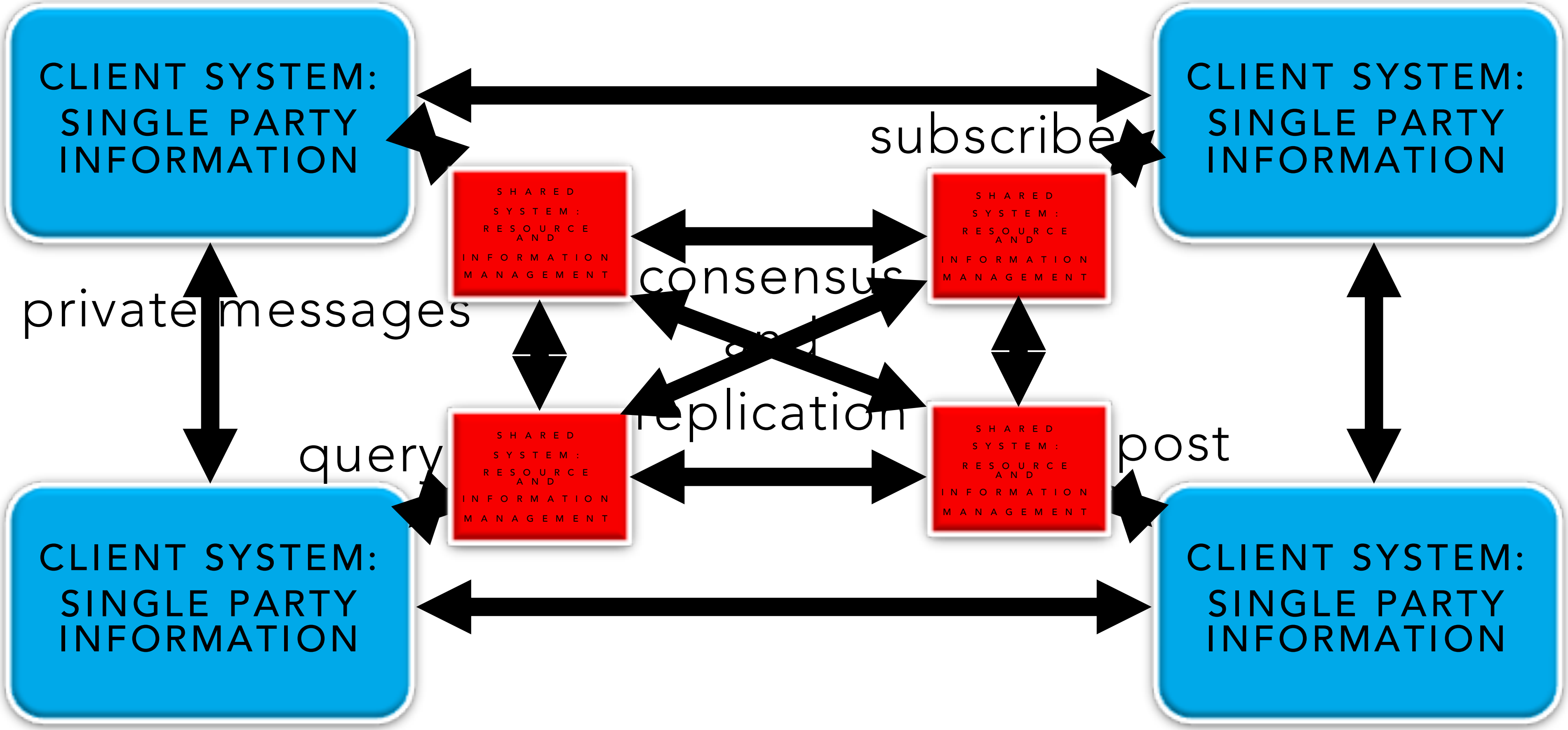
Commutative theorem, part 2

- If some agents have finite credit limits, outside validation of their resource transfers is required.
  - Point-to-point communication between the two agents only is *insufficient*.
  - *Some* information about resource transfers must be "leaked" to other nodes for validation.

Canonical distributed ledger architecture (functional view)



Canonical distributed ledger architecture (distributed systems view)



Conclusions and open problems

- No consensus on globally total order of events is *necessary*
  - Current blockchain/DL systems solve an unnecessarily hard problem (transaction order consensus)
- Not even consensus on partial order of events is strictly *necessary*.
- Consensus on resource transfers needs to ensure that the *set* of all eventually validated resource transfers respects all credit limits.
- *Specialized* consensus protocols for resource transfers are conceivable and needed for scalability:
  - Hierarchical clearing and settlement (hierarchical "sharding" by partititioning of agents)
  - Time- and resource-sensitive validation (bigger transfers require more time)
  - Insurance (appyling transaction fees to covering losses due to overdrafts detected too late)
  - …

Thank you!