Orchestration of Blockchain-based Digital Twins

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Introduction

Industry 4.0:

- Paradigm shift in how industrial activities are conceived and executed;
- Exploits sensors, actuators, autonomous components, and inter-connectivity of systems;
- Aimed to improve the efficiency of factories.

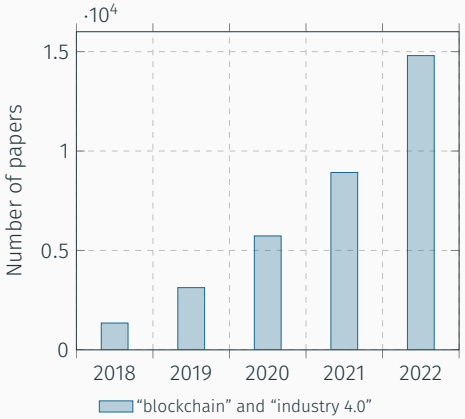
Digital Twins (DTs):

- *Virtual* copies of *physical* machines (or systems);
- Mirror facets of a product, process, or service;
- Enable data-driven decisions, leveraging sensors' data.

Motivation

Increasing interest in using blockchains in **Industry 4.0**; Why?

- Information transparency and decentralization;
- Improve traceability:
  - Products (e.g., supply chains);
  - Data provenance;
  - Non-functional requirements;
  - DTs lifecycle;
- Many more...

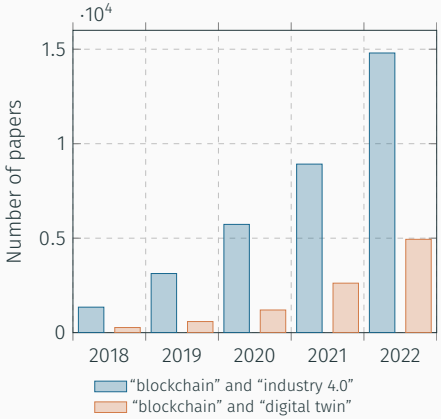


(from Google Scholar)

Motivation

Interest also in **blockchain-based DTs**.
They target some key challenges:

- Data sharing and linking;
- Untrustworthy data dissemination;
- Traceability;
- Predictive maintenance;
- Store authorization information;
- Automate event-based interaction.



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Related Work

Recently, **service composition** has been proposed in DT settings; so far:

- [Sahal et al., 2022] show the key importance of DTs **collaboration**;
- [Catarci et al., 2019] envision an architecture that takes advantage of **automatic composition** to realize the physical manufacturing processes;
- [Pernici et al., 2020] suggest combining **Service Oriented Architectures** with Cyber Physical Systems.

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- [Pernici et al., 2020] suggest combining **Service Oriented Architectures** with Cyber Physical Systems.

However: Although events are already used to automate **blockchain-based DTs** interaction, no approach exploits the literature on **(web) service composition**.

Contribution

We design a preliminary framework for orchestrating blockchain-based DTs:

- We translate smart contracts representing DTs in Finite State Machines (FSMs);
- We combine them to implement new services, i.e., **target services**;
- The composition resorts to the well-known Roman Model for service composition [Berardi et al., 2003].

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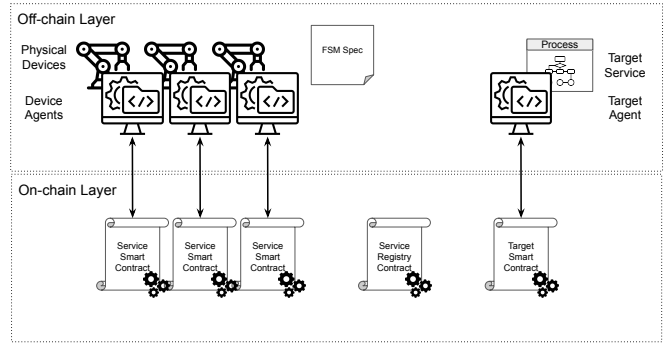
The blockchain plays a fundamental role in:

1. Data management (of the manufacturing process and of DTs);
2. Process design (exploiting the Roman Model);
3. Process execution by means of automated event-based communication.

Proposed Framework

- Off-chain layer: where the industrial process takes place;
- On-chain layer: trustless notarization and machine-to-machine communication.



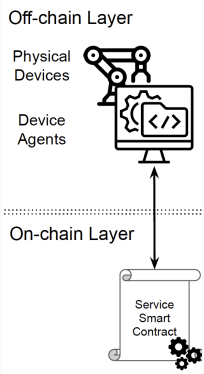
Proposed Framework: Available Services

Off-chain layer:

- Physical device: can execute tasks;
- Device Agent: oversees the relation between physical device and its DT.

On-chain layer:

- Service (Smart) Contract:
  - On-chain DT of a physical device;
  - Accepts action requests for the physical device;
  - Can notify the device agent.
- Service Registry Contract: directory of available services.



Proposed Framework: Target Services

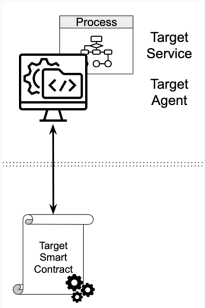
New target services as a composition of available service contracts.

Off-chain layer:

- Target Service: an industrial process to accomplish;
- Target Agent: a bridge with the on-chain layer;

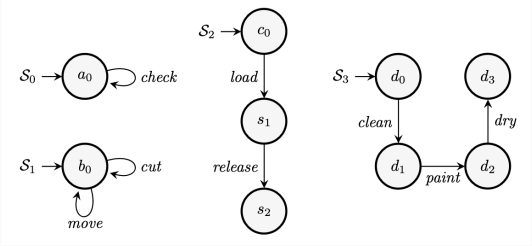
On-chain layer:

- Target Contract: on-chain representative of the target service; result of composition.



Service Composition

Available Services



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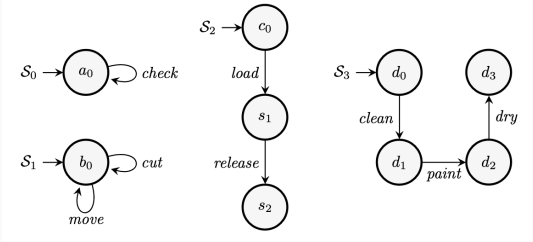
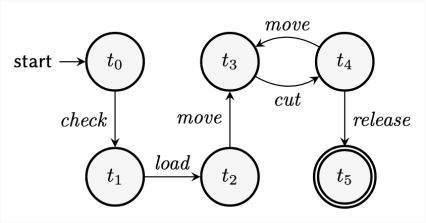


Target Service



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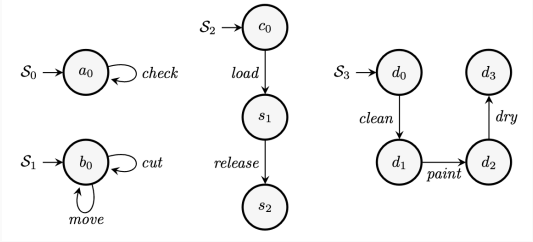

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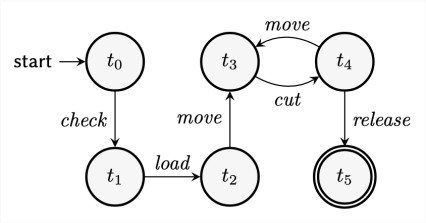
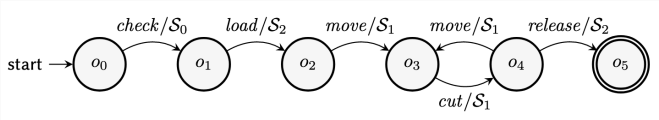


Orchestration (by the Roman Model)



Proposed Framework: Workflows

The proposed framework supports 5 main operations:

1. Registration;
2. Composition;
3. Setup;
4. Execution;
5. Clean-up.

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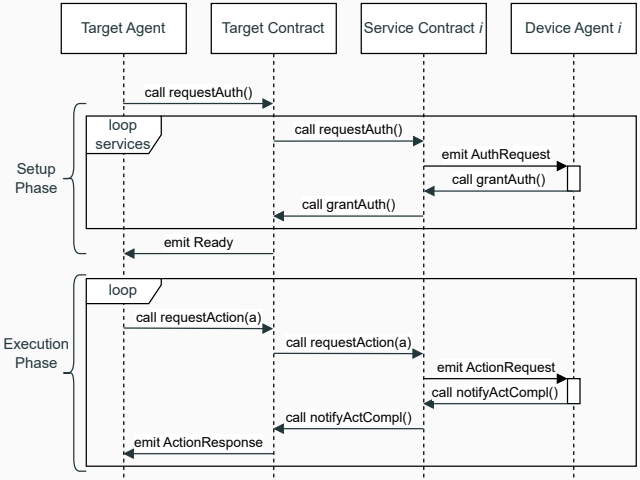

Conclusion

- Blockchain-based DTs can leverage the literature on service composition;
- Modeling DTs as FSMs, we combined them using the Roman model:
  - Pro: simple approach;
  - Con: limitations in how complex smart contracts can be modeled.

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Future works:

- Framework enhancing: e.g., error handling, authorization revocation;
- Contract composition: e.g., consider non-functional requirements; run-time composition updates.
- Use cases and validation.

Thank you

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References (1)

- Berardi, D., Calvanese, D., De Giacomo, G., Lenzerini, M., and Mecella, M. (2003). **Automatic composition of e-services that export their behavior.** In *Proc. of ICSOC'03*, pages 43–58. Springer.
- Catarci, T., Firmani, D., Leotta, F., Mandreoli, F., Mecella, M., and Sapio, F. (2019). **A conceptual architecture and model for smart manufacturing relying on service-based digital twins.** In *Proc of IEEE ICWS'19*, pages 229–236. IEEE.

References (2)

- Pernici, B., Plebani, P., Mecella, M., Leotta, F., Mandreoli, F., Martoglia, R., Cabri, G., et al. (2020).
  Agilechains: agile supply chains through smart digital twins.
  In *Proc of ESREL2020 PSAM15*, pages 2678–2684. Research Publishing Singapore.
- Sahal, R., Alsamhi, S. H., and Brown, K. N. (2022).
  ***Digital Twins Collaboration in Industrial Manufacturing*, pages 59–72.**
  Springer.