EMAS @ AAMAS, 29-30/5/2023

TOWARDS DEVELOPING DIGITAL TWIN ENABLED MULTI-AGENT SYSTEMS

Stefano Mariani*, Marco Picone*, Alessandro Ricci°

*University of Modena and Reggio Emilia, Reggio Emilia, Italy

°University of Bologna, Cesena campus, Italy

EMAS 2023

MOTIVATIONS

- MAS lack principled approach to engineer the **digital <-> physical frontier**
  - there are model and methods for environment modeling
  - but the focus is mostly on *interface exposed to agents*
  - and the "nuts and bolts" of digital <-> physical connection lack structure
- DTs may fill in the gap!
  - uniform and interoperable access to resources
  - digital <-> physical synchronisation

GOALS

Better MAS environment engineering!

- **separation of concerns** MAS <-> CPS
- **independent evolution** MAS <-> CPS

How?

- put DTs between MAS and CPS
- let DTs handle interface towards CPS

DIGITAL TWINS

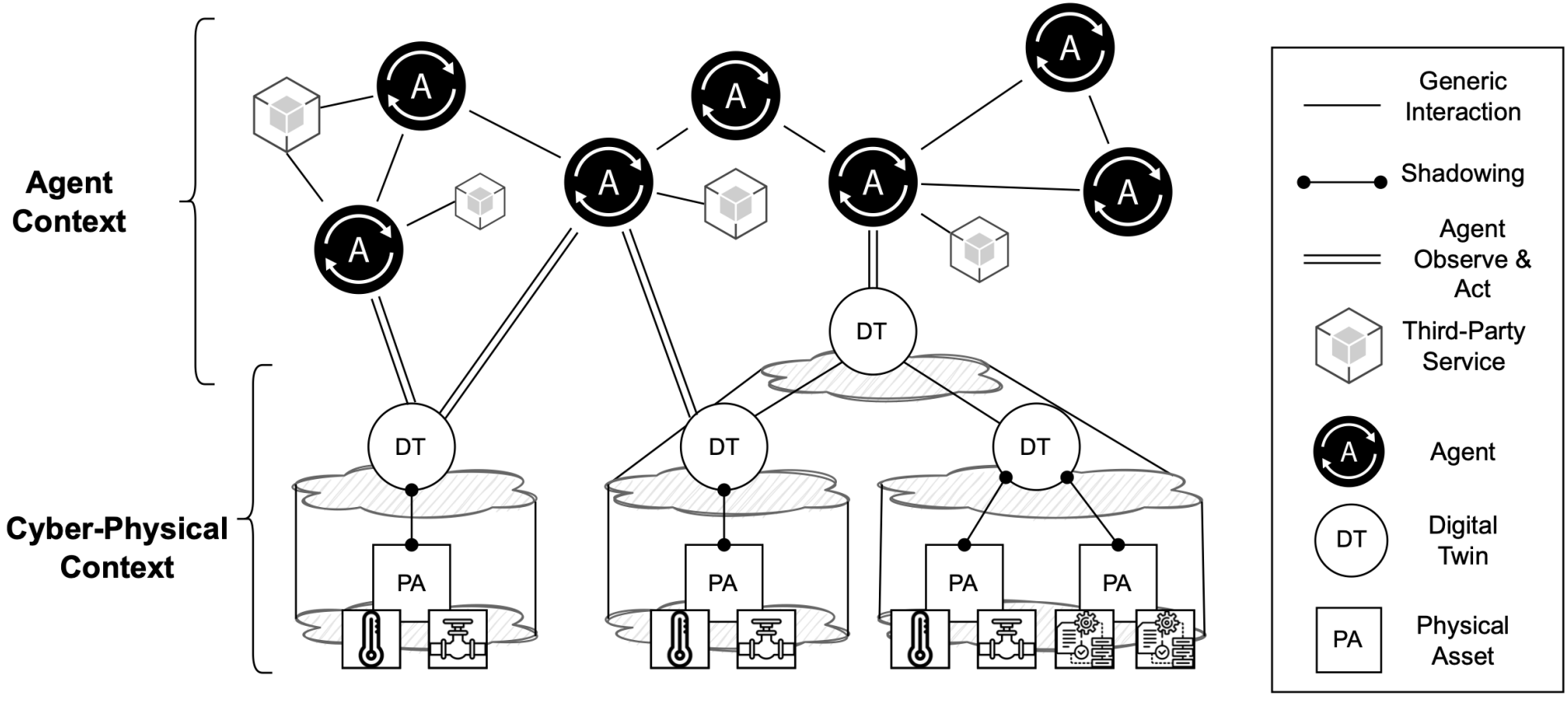
- *Virtualisation* of real world entities (**p**hysical **a**ssets)
- *Faithful* digital replicas
- Deeply *intertwined* with their physical twin
- Connected in a *web* of semantic overlays

Ricci, A. et al.: Web of digital twins. Transactions on Internet Technology, ACM. 2021.

SEPARATION OF CONCERNS

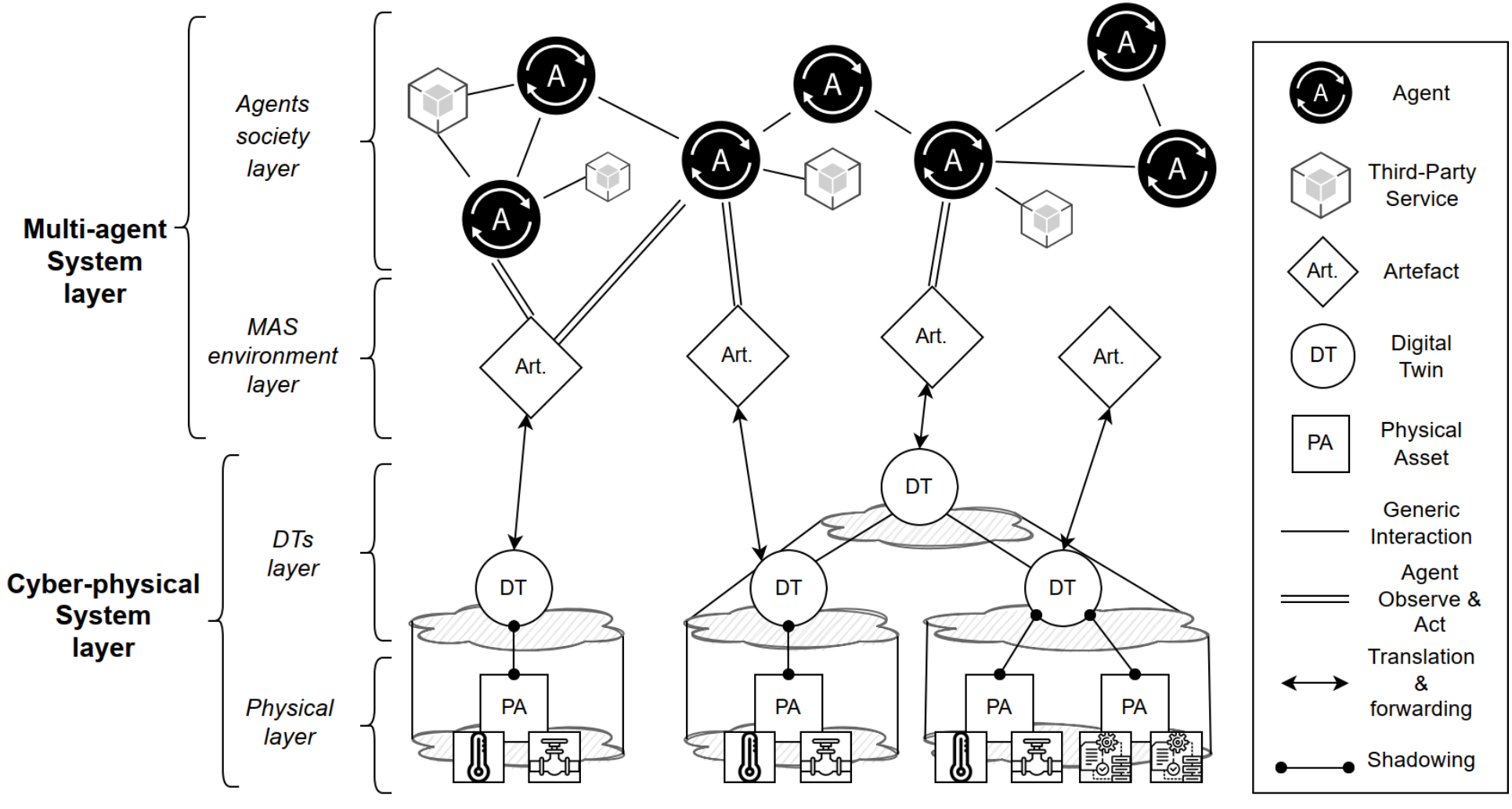
- DTs operate with *full knowledge* of the **local context** of their associated PA
  - access to data
  - available actions
  - knows nothing about other PAs
- Agents operate with *partial knowledge* of the **global context** of the application
  - application goals
  - available DTs
  - knows nothing about how to operate on PA

Mariani, S. et al.: Agents and Digital Twins for the engineering of cyber-physical systems: opportunities, and challenges.
Annals of Mathematics and Artificial Intelligence, Springer. To appear.



This separation allows for assigning clear responsibilities during system design!

CONCEPTUAL ARCHITECTURE I



ARTEFACTS IN A&A

- Bring level of *abstraction* closer to AOP
- by *encapsulating* env. resources as agents' tools
- thus *mapping* MAS env. resources to available perceptions and admissible actions

Omicini, A., Ricci, A., Viroli, M.: Artifacts in the A&A meta-model for multi-agent systems. Autonomous Agents and Multi-Agent Systems 17(3), 432–456 (2008)

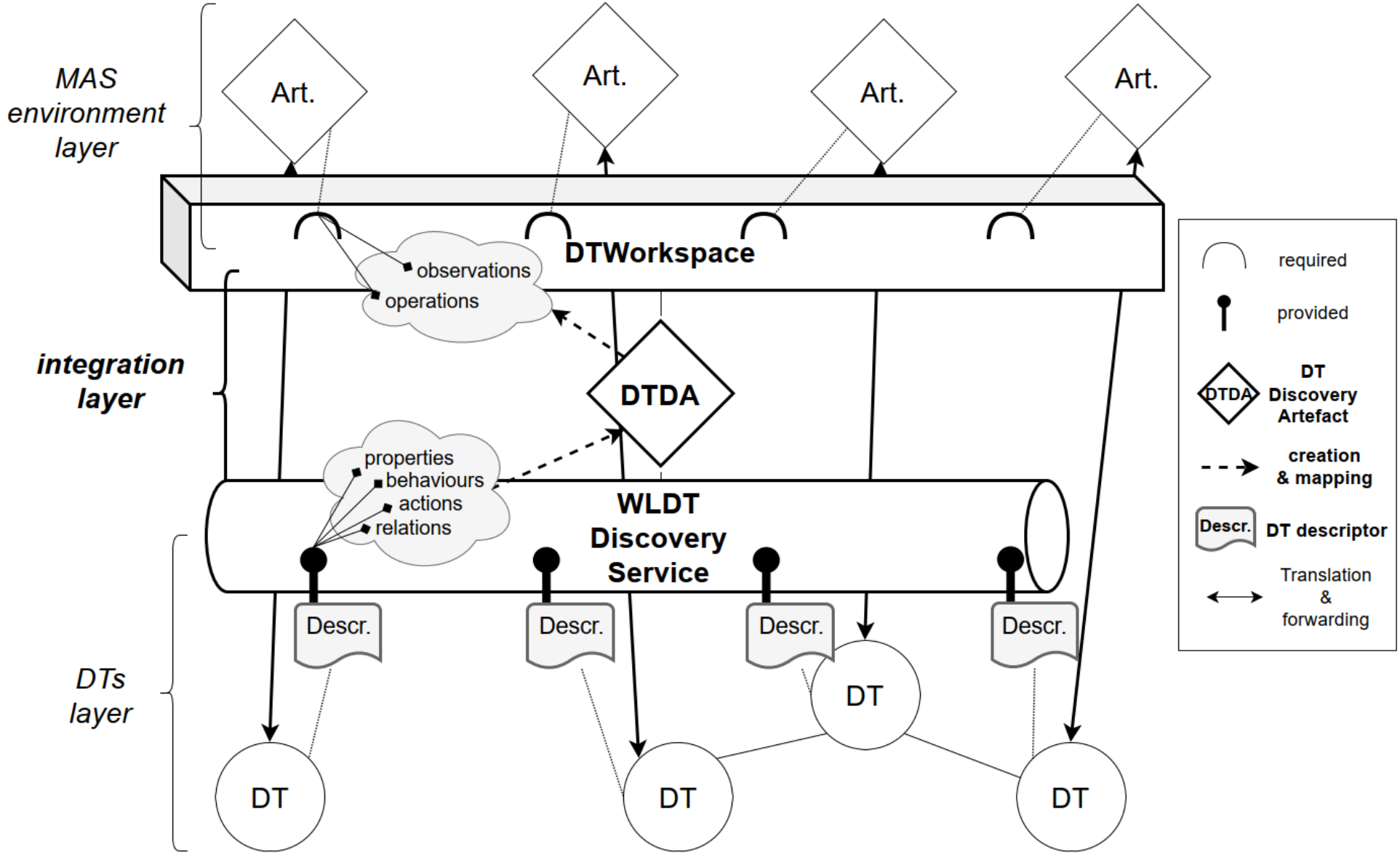
CONCEPTUAL ARCHITECTURE II

- DTs promote development paradigm closer to devices
- Artefacts promote development paradigm closer to agents

Integrating the two enables our goals!

But **how**, *in practice*?

TECHNICAL ARCHITECTURE


MAS environment layer
integration layer
DTs layer
Art.
Art.
Art.
Art.
DTWorkspace
observations
operations
DTDA
properties
behaviours
actions
relations
WLDT Discovery Service
Descr.
Descr.
Descr.
Descr.
DT
DT
DT
DT
required
provided
DTDA
DT Discovery Artefact
creation & mapping
Descr.
DT descriptor
Translation & forwarding

ENABLER TECHNOLOGIES

- JaCaMo: jacamo.sourceforge.net
  - MAS development and execution platform
  - embraces the A&A meta-model via CArtAgO
  - **programmatic** management of artefacts
- WLDT: github.com/wldt
  - DTs development and execution platform
  - **discovery service**
  - web-ready DT descriptor

DTS LAYER

- **DTDescriptor**: JSON/XML representation of the DT
  - properties (e.g. temperature, location, local time)
  - actions (e.g. turn on, turn off, set temperature)
  - behaviours (e.g. turn on until temp > 18)
  - relations to other DTs (e.g. thermostat linked to A/C system)
  - metadata (e.g. connection protocol, URL)
- **WLDTDiscoveryService**: advertise & discover DTs
  - exposes DTDescriptor to known address

INTEGRATION LAYER I

- **DTDiscoveryArtefact**: automatically creates artefacts connected to DTs
  - DT property <-> artefact observable prop.
  - DT action <-> artefact operation
  - DT behaviour <-> observable prop. + operation
  - DT relation <-> artefact link
- exploits JaCaMo and WLDT services to
  - *programmatically* create artefacts in workspace
  - do the mapping above
  - set-up bi-directional comm. link artefact <-> DT

DEVELOPERS' POINT OF VIEW

- MAS side
  - develop their agents
  - configure DTDiscoveryArtefact with well-known URL of WLDTDiscoveryService
  - start the automatic "creation & mapping" process (ad-hoc operation)
- CPS side
  - develop their DTs
  - publish them to the WLDTDiscoveryService

Little agreement is required -> loose coupling
(both at design and run time)

CONCLUSION & OUTLOOK

- The proposed integration promotes separation of concerns and independent evolution
- We expect to open source the integration during summer 😊
  - JaCaMo components are already available (workspaces, artefacts, links, programmatic API)
  - Some WLDT components are now underway (discovery service)
- Enabling experimentation of the synergies between agents and DTs!

THANKS

FOR YOUR ATTENTION

Stefano Mariani

ARE THERE QUESTIONS?

(we hope so 😊)