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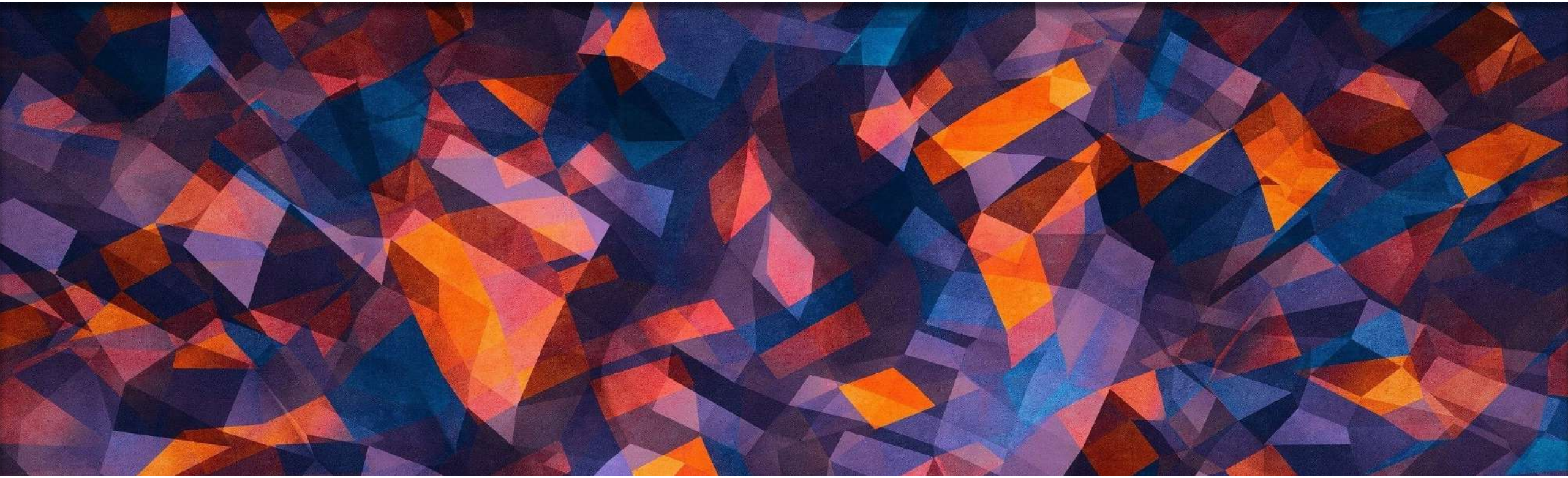


Hypermedia Multi-Agent Systems

Andrei Ciortea
School of Computer Science, University of St.Gallen, Switzerland
WIMMICS, INRIA Sophia Antipolis, France

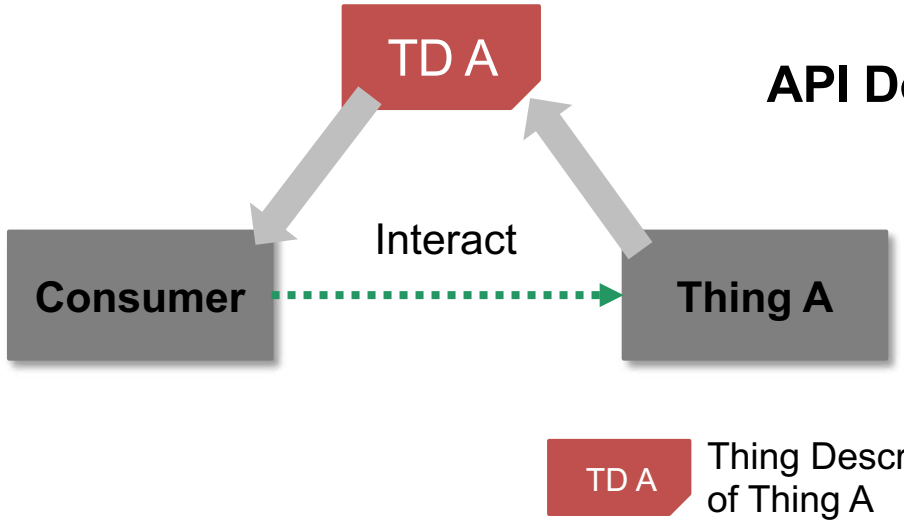
Universität St.Gallen

A Web for Machines

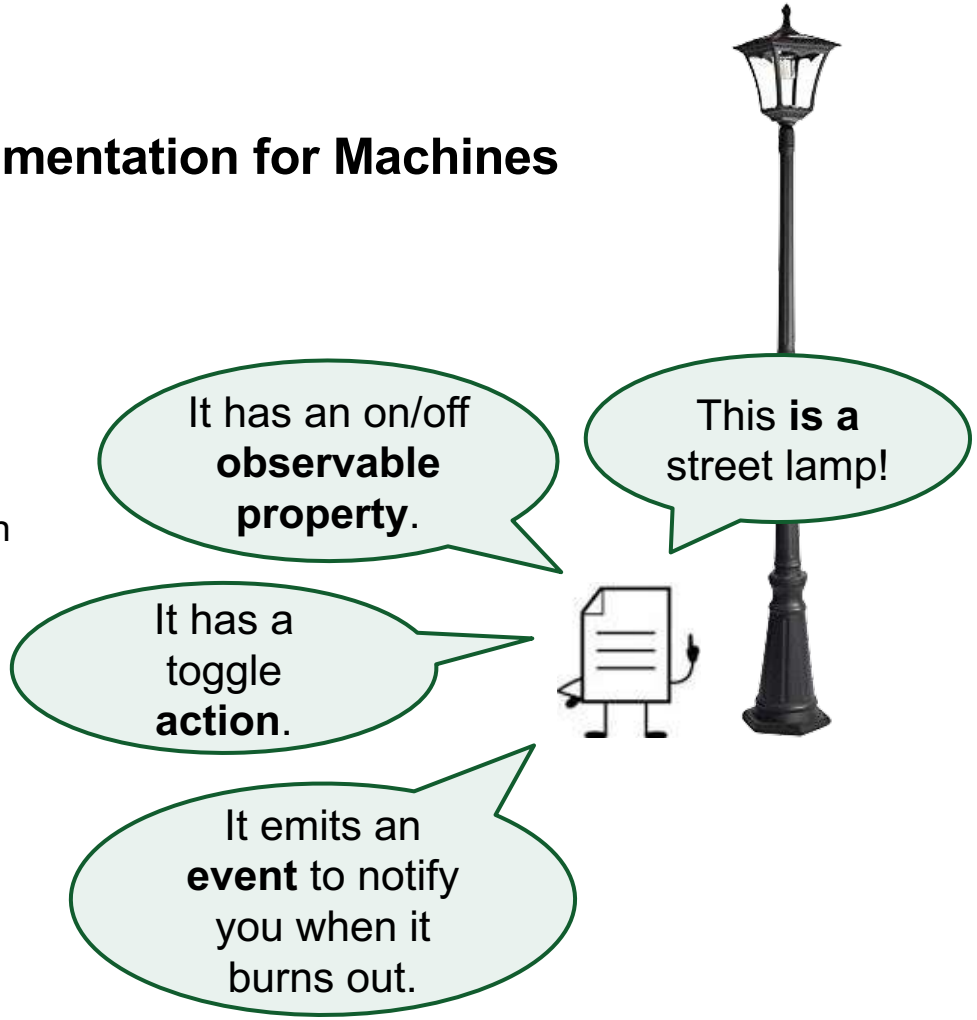
Sir Tim Berners-Lee (WWW'94):

https://videos.cern.ch/record/2671957

The W3C Web of Things

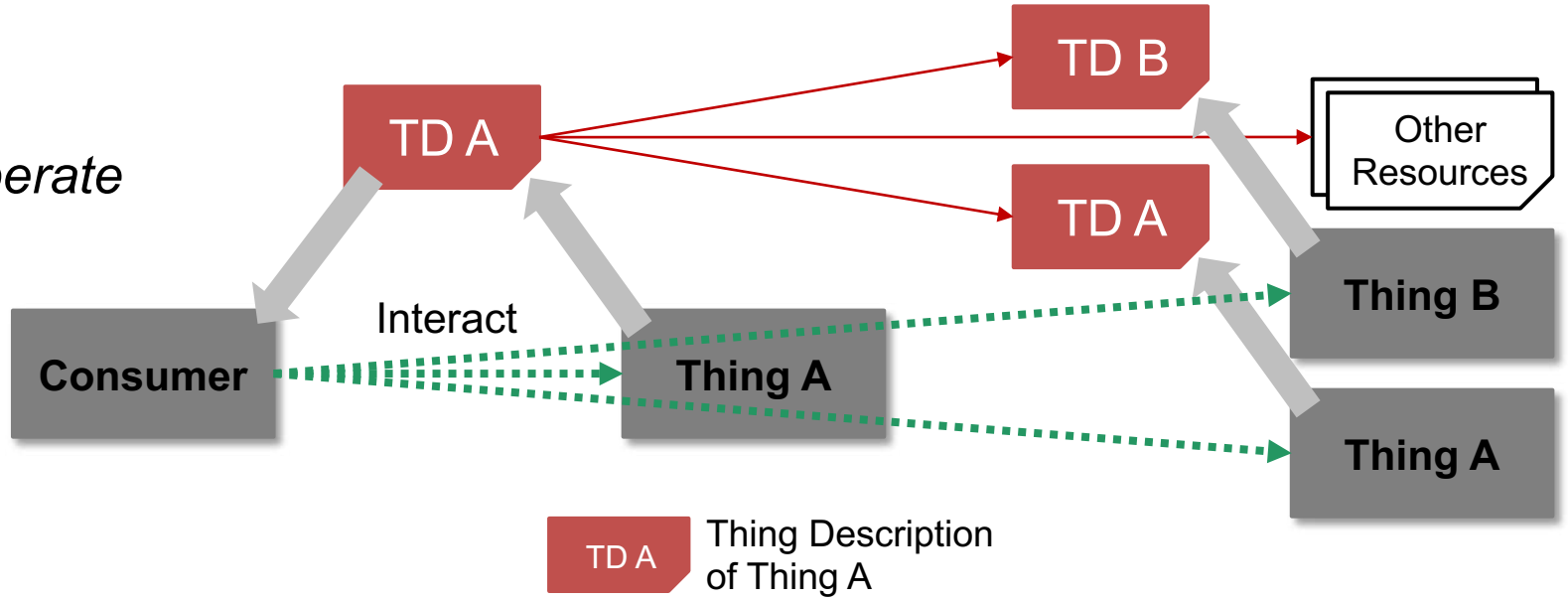


API Documentation for Machines



The W3C Web of Things

Ideally:
arrive-and-operate



Matthias Kovatsch et al. (eds.), Web of Things (WoT) Architecture, W3C Recommendation, 2020.

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The W3C Web of Things

Ideally:
arrive-and-operate

How to ***design*** hypermedia-based environments that ***support autonomous behavior***?

How to ***design*** software agents able to ***learn***, ***plan***, and ***adapt*** in order to achieve their tasks through ***flexible autonomous use of hypermedia***?

How to ***design***, ***represent***, and ***reason about interactions*** among autonomous agents, people, and any other resources on the Web?

How to ***design*** and ***govern communities*** of autonomous agents and people on the Web?

Matthias Kovatsch et al. (eds.), Web of Things (WoT) Architecture, W3C Recommendation, 2020.

Autonomous Agents and Multi-Agent Systems

Semantic Web and Linked Data

Web Architecture and the Web of Things

Agents on the Web: Community and Impact

May 2019 — HyperAgents 2019 @ TheWebConf 2019

Feb. 2021 — Dagstuhl Seminar 21072: "Autonomous Agents on the Web"

https://www.dagstuhl.de/21072

Feb. 2023 — Dagstuhl Seminar 23081: "Agents on the Web"

https://www.dagstuhl.de/23081

March 2023 — W3C WebAgents Community Group

https://www.w3.org/community/webagents/

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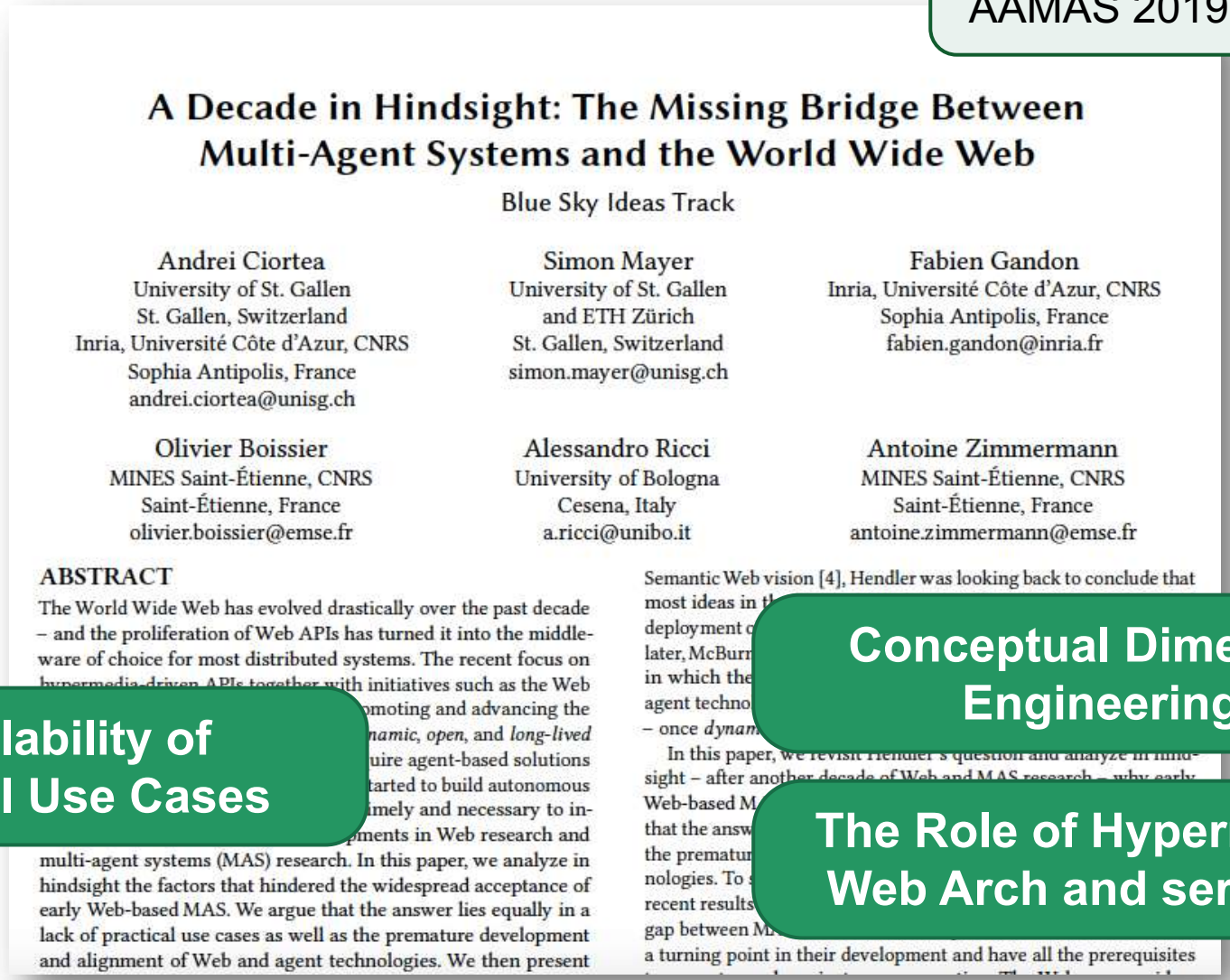
Today's Agenda

- Hypermedia Multi-Agent Systems
- Use Cases
  - Flexible Industrial Manufacturing
  - Tackling Online Disinformation
- Challenges
  - Efficient Interaction
  - Accountable Interaction

MAS and the Web: The Misalignment Problem

AAMAS 2019



A Decade in Hindsight: The Missing Bridge Between Multi-Agent Systems and the World Wide Web

Blue Sky Ideas Track

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Inria, Université Côte d'Azur, CNRS
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and ETH Zürich
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Alessandro Ricci
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Antoine Zimmermann
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Saint-Étienne, France
antoine.zimmermann@emse.fr

ABSTRACT

The World Wide Web has evolved drastically over the past decade – and the proliferation of Web APIs has turned it into the middleware of choice for most distributed systems. The recent focus on hypermedia-driven APIs together with initiatives such as the Web ...omoting and advancing the ...namic, *open*, and *long-lived* ...uire agent-based solutions ...tarted to build autonomous ...imely and necessary to in... ...pments in Web research and multi-agent systems (MAS) research. In this paper, we analyze in hindsight the factors that hindered the widespread acceptance of early Web-based MAS. We argue that the answer lies equally in a lack of practical use cases as well as the premature development and alignment of Web and agent technologies. We then present

Semantic Web vision [4], Hendler was looking back to conclude that most ideas in th... deployment o... later, McBurn... in which the... agent techno... – once *dynam*...

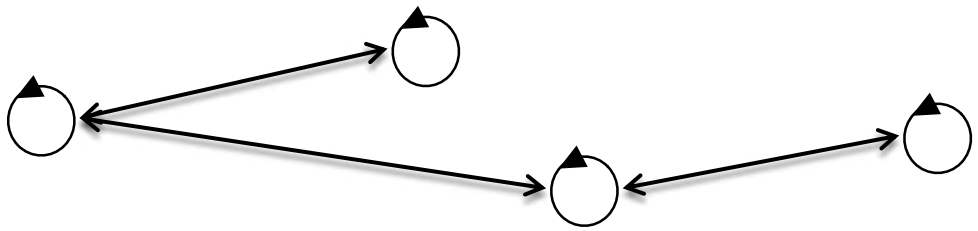
In this paper, we revisit Hendler's question and analyze in hindsight – after another decade of Web and MAS research – why early Web-based M... that the answ... the prematur... nologies. To ... recent results... gap between M... a turning point in their development and have all the prerequisites

Availability of Pratical Use Cases

Conceptual Dimensions for Engineering MAS

The Role of Hypermedia in the Web Arch and service design

MAS and the Web: The Misalignment Problem



What about the Web?

The Web as a transport layer in MAS:

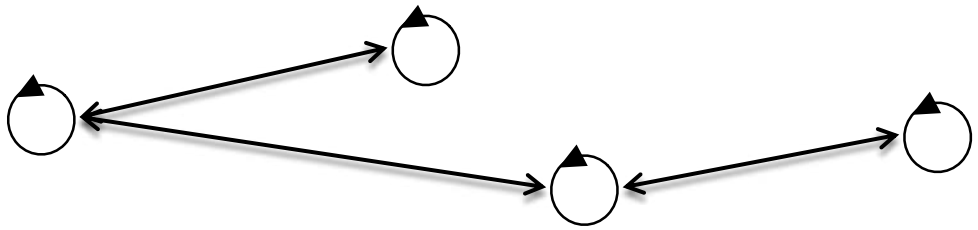
- WS-* standards (SOAP, WSDL, etc.)
- FIPA Agent Message Transport Protocol for HTTP

  Foundation for Intelligent Physical Agents (FIPA)
  http://www.fipa.org/specs/fipa00084/SC00084F.html

MAS remain **outside** of the Web and are **misaligned** with the Web architecture.

A. Ciortea, S. Mayer, F. Gandon, O. Boissier, A. Ricci, and A. Zimmermann, A Decade in Hindsight: The Missing Bridge Between Multi-Agent Systems and the World Wide Web, AAMAS 2019.

MAS – More Than Just Agents



What about the Web?

Environment [Weyns et al., 2007]

- workshop series: *Environment for Multiagent Systems (E4MAS)*

Organization [Boissier et al., 2006]

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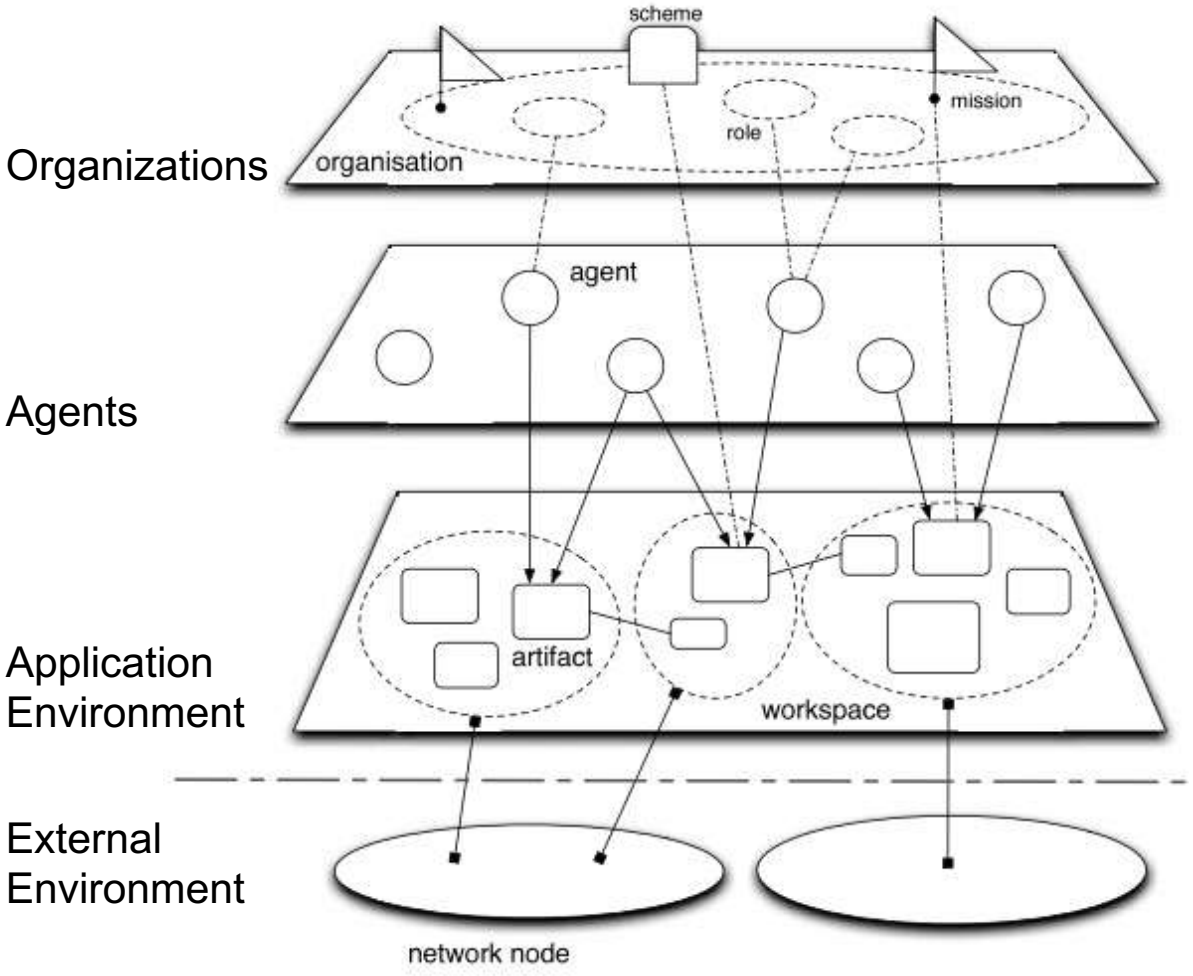

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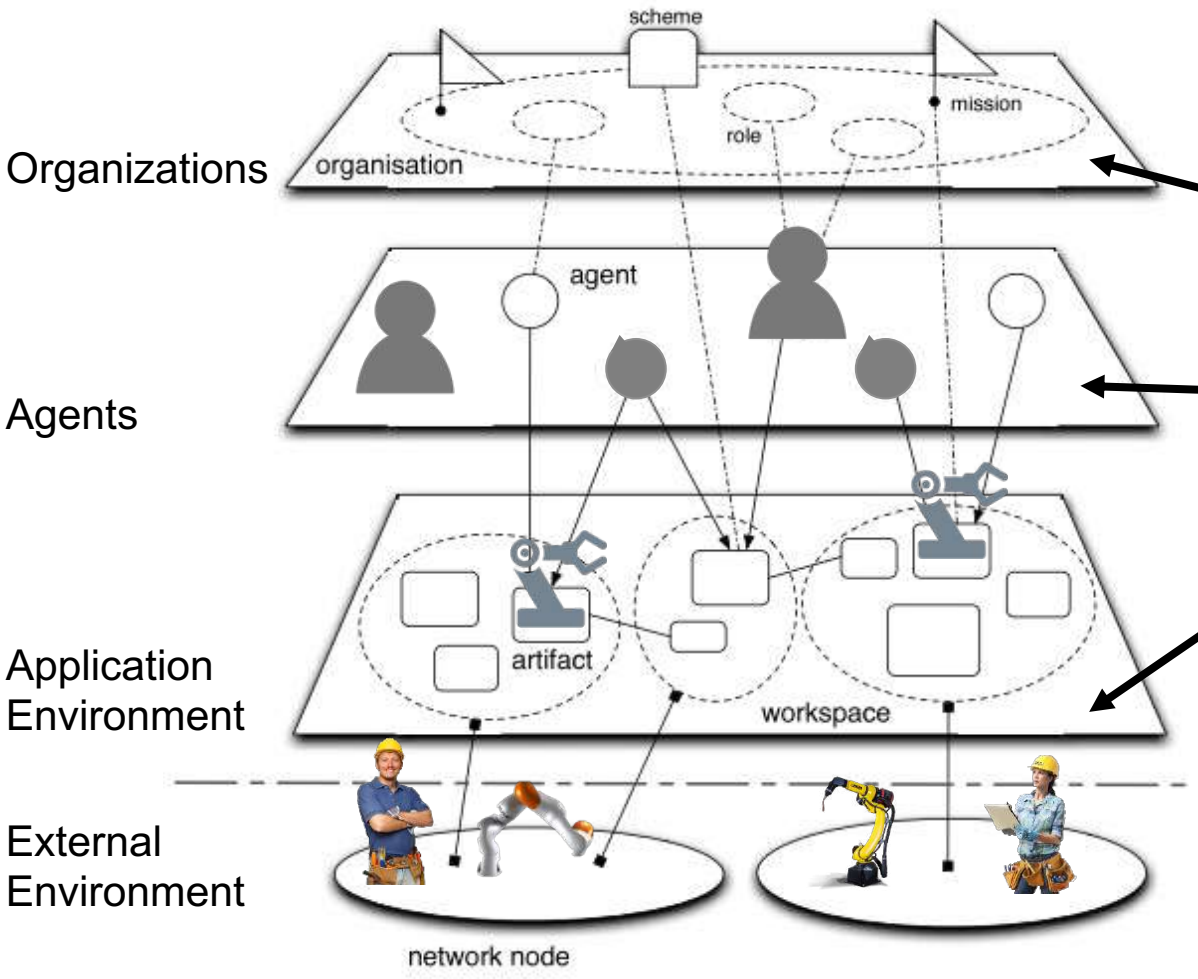

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Hybrid Manufacturing Organizations @ Siemens
[Ciortea et al., 2018]

collectives of people and artificial agents working towards common goals

autonomous behavior

non-autonomous behavior

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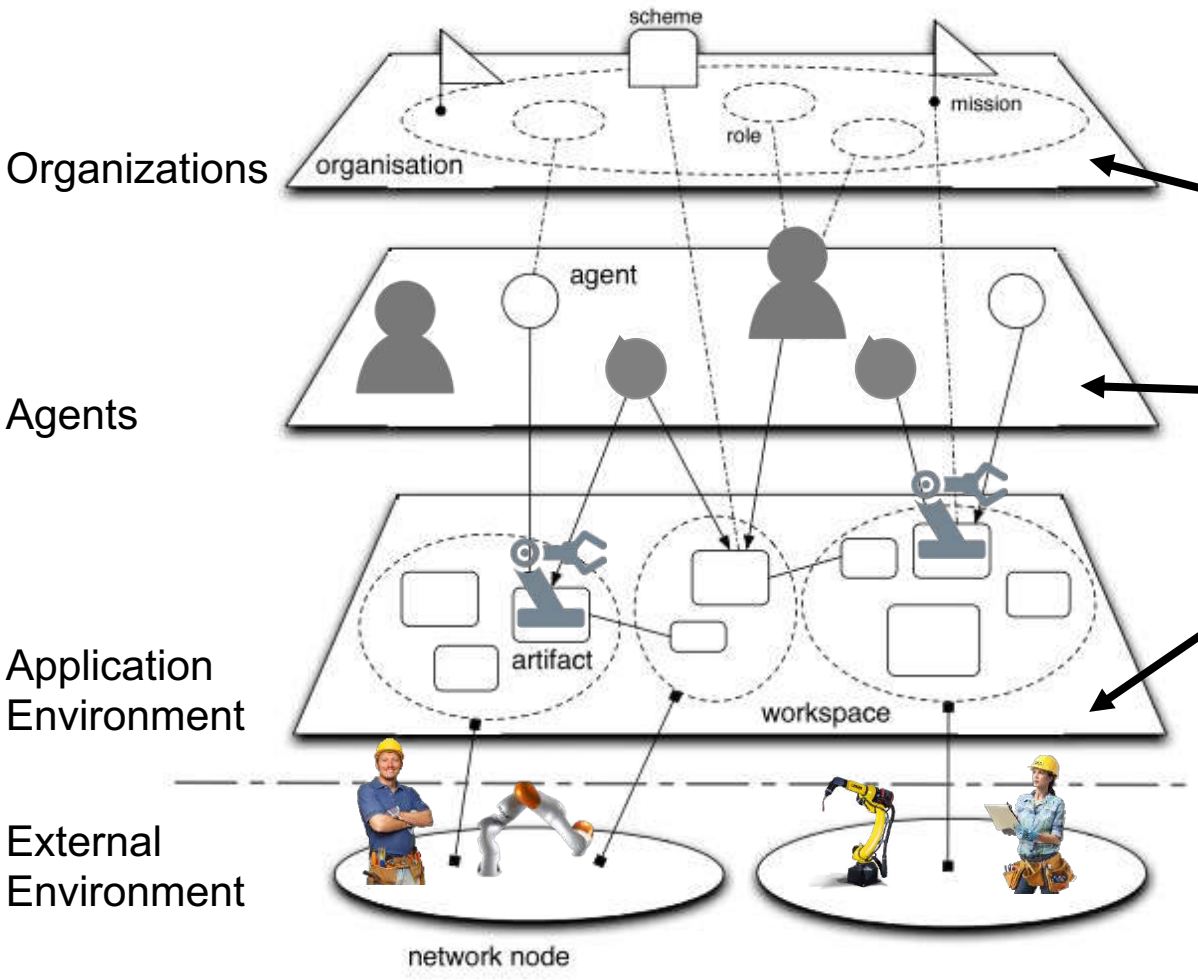

Organizations

Agents

Application Environment

External Environment

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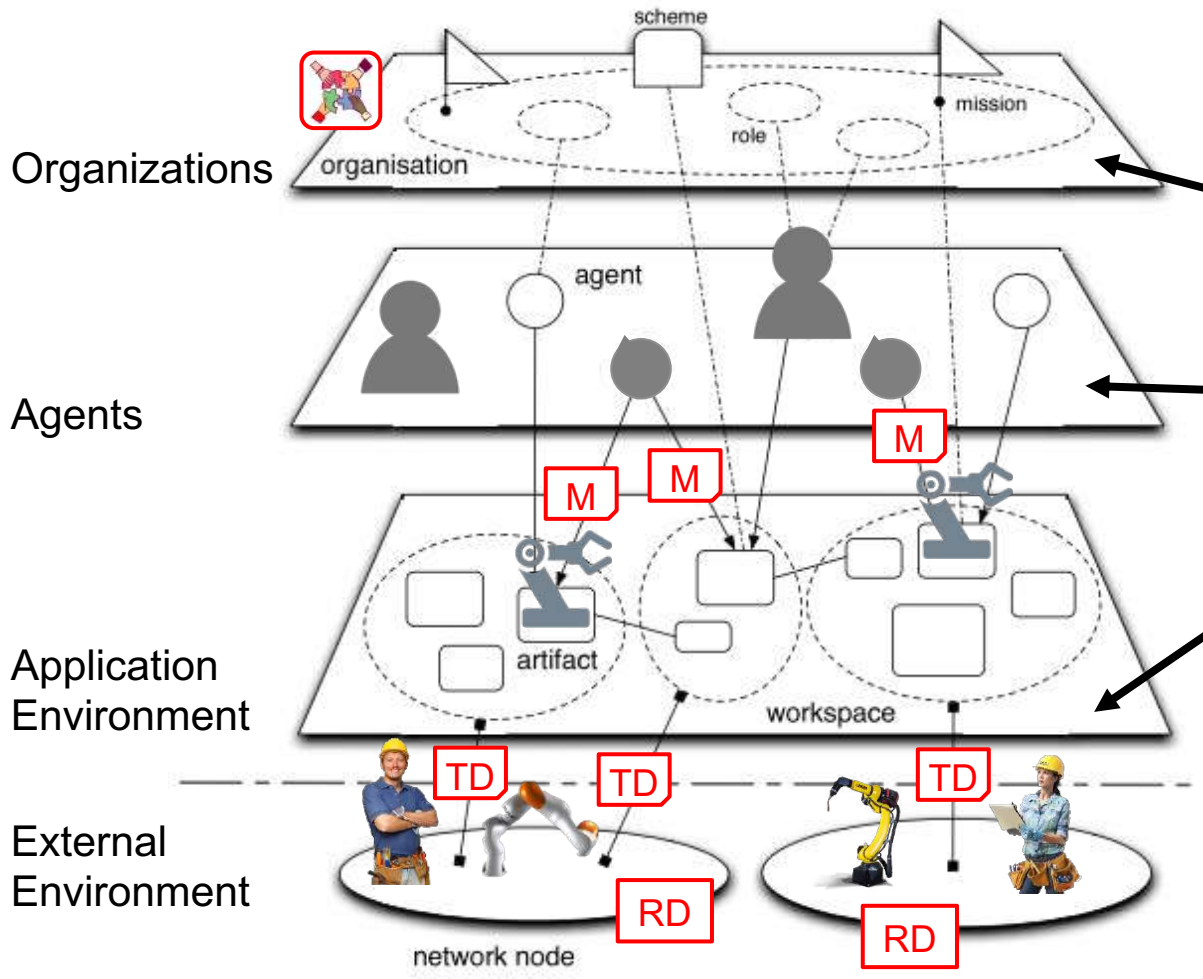

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Web Resources

- Semantic Specs. of Organizations
- M — Artifact Manuals (functionality desc.)
- TD — W3C WoT Thing Desc. (interface desc.)
- RD — Resource Directory
- WoT Devices

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Universität St.Gallen

The Role of Hypermedia in the Web Model

Mon
20 Oct
2008

REST APIs must be hypertext-driven

Posted by Roy T. Fielding under software architecture, web architecture

[51] Comments

I am getting frustrated by the number of people calling any HTTP-based interface a REST API. Today's example is the SocialSite REST API. That is RPC. It screams RPC. There is so much coupling on display that it should be given an X rating.

What needs to be done to make the REST architectural style clear on the notion that hypertext is a constraint? In other words, if the engine of application state (and hence the API) is not being driven by hypertext, then it cannot be RESTful and cannot be a REST API. Period. Is there some broken manual somewhere that needs to be fixed?

https://roy.gbiv.com/untangled/2008/rest-apis-must-be-hypertext-driven

The Role of Hypermedia in the Web Model

> "When I say [hypermedia] I mean the simultaneous presentation of information and controls such that the **information becomes the affordance** through which **the user obtains choices** and **selects actions**."
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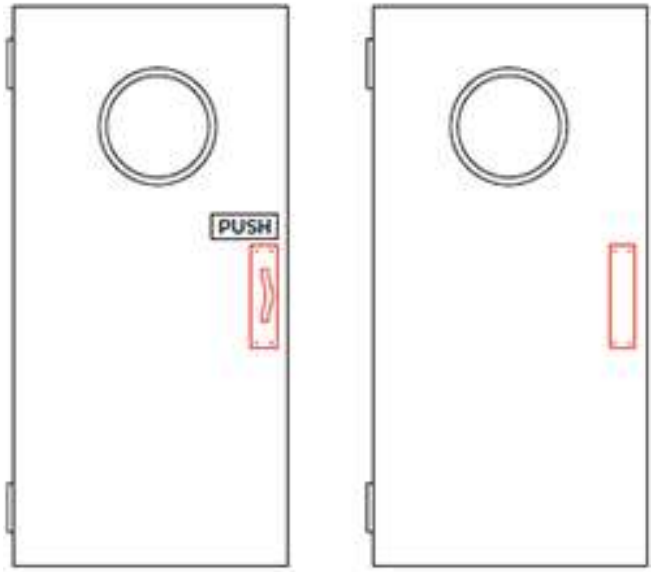
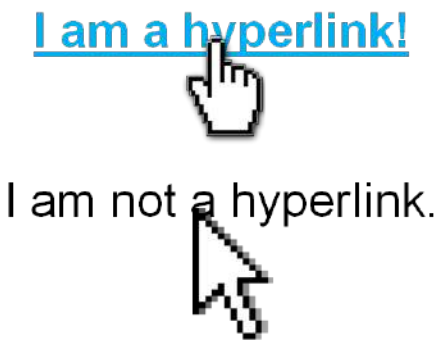
> – Roy T. Fielding, *A Little REST and Relaxation*, ApacheCon Europe, 2008

Affordances in everyday life:



How do affordances look like **on the Web**?



http://google.com

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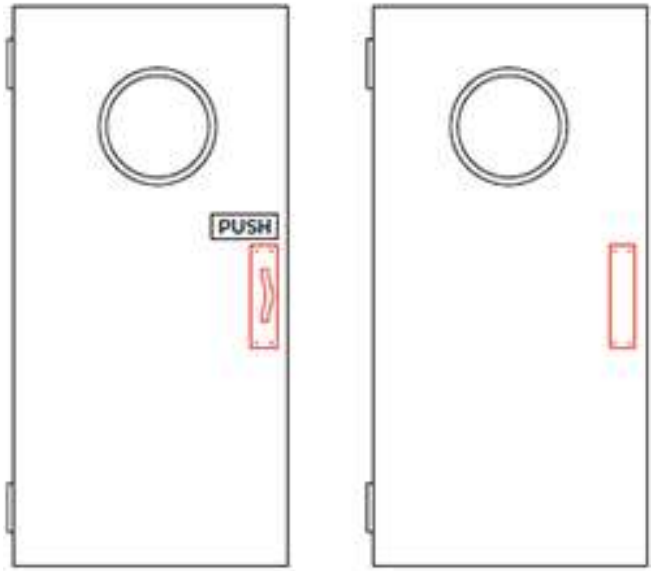

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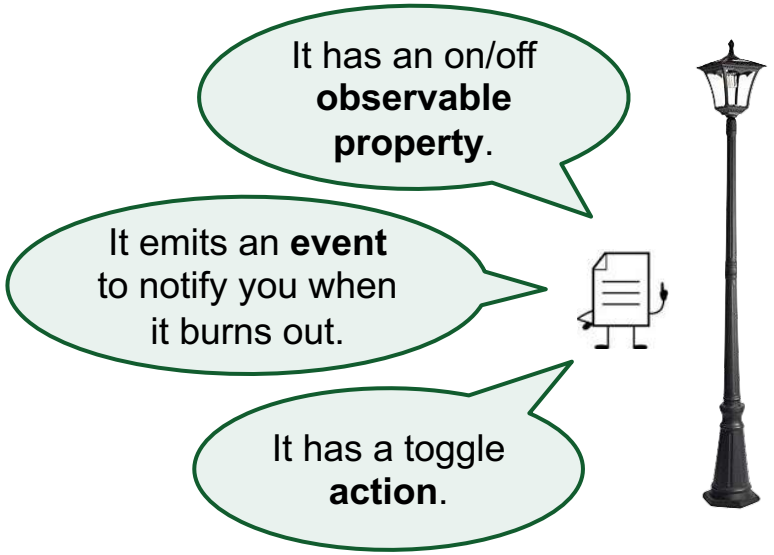

W3C WoT Thing Description
(API Documentation for Machines)

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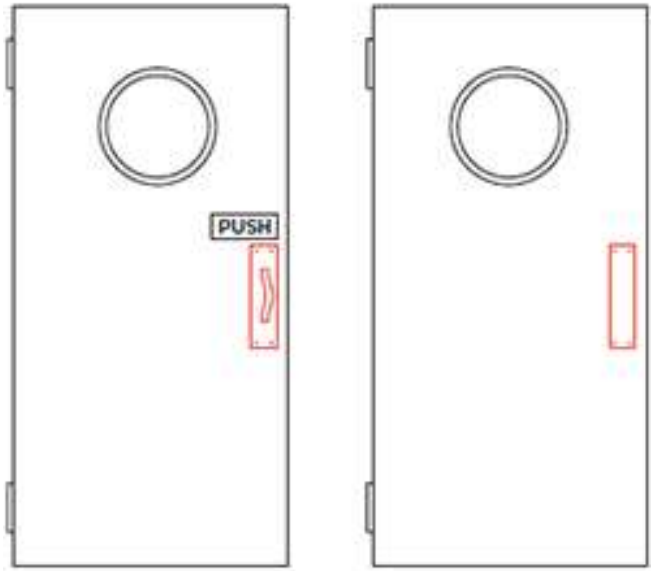

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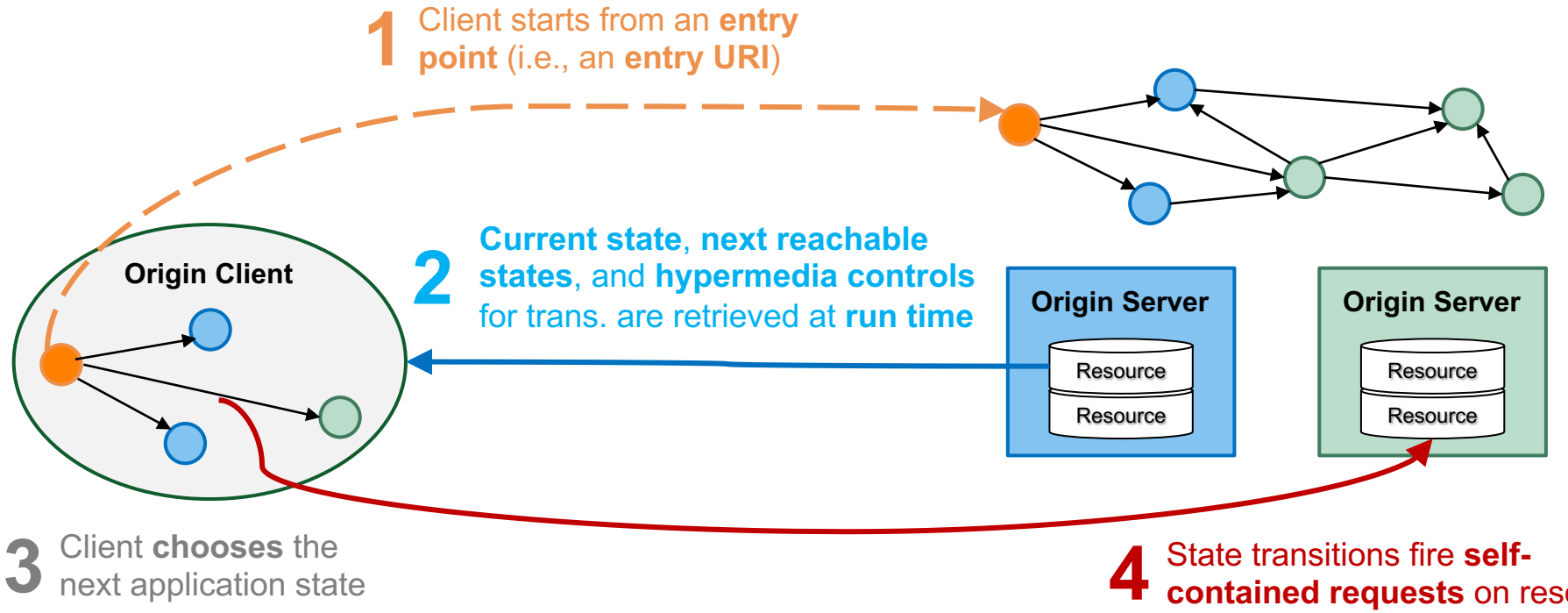

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Hypermedia-driven interaction “decouples” the Web architecture:

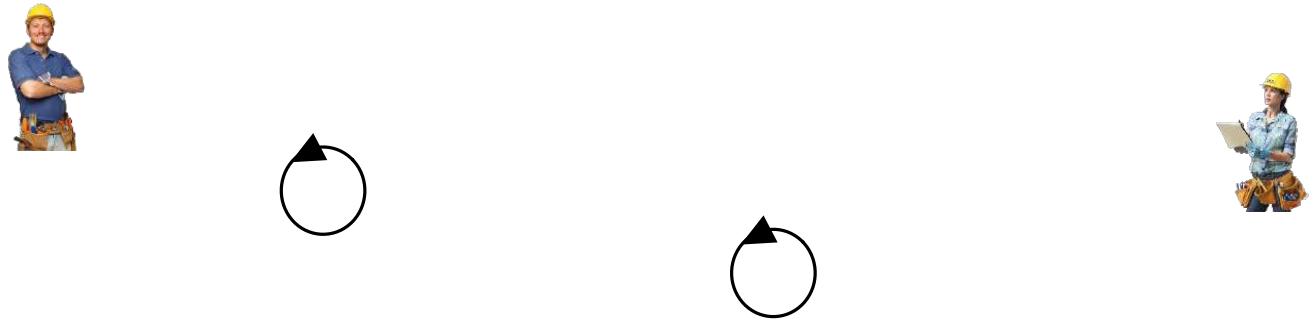
- **URIs**, possible transitions to **next application states**, and the **means to transition** to those states are advertised in the hypermedia – they are **never hard-coded** into clients!

  ⇒ components can be ***developed***, ***deployed***, and can ***evolve independently*** from one another

Hypermedia Multi-Agent Systems

The Web is no longer a **hidden transport layer**, but a **rich application layer**!

The systems are **weaved into the hypermedia fabric of the Web**



Distributed hypermedia environment

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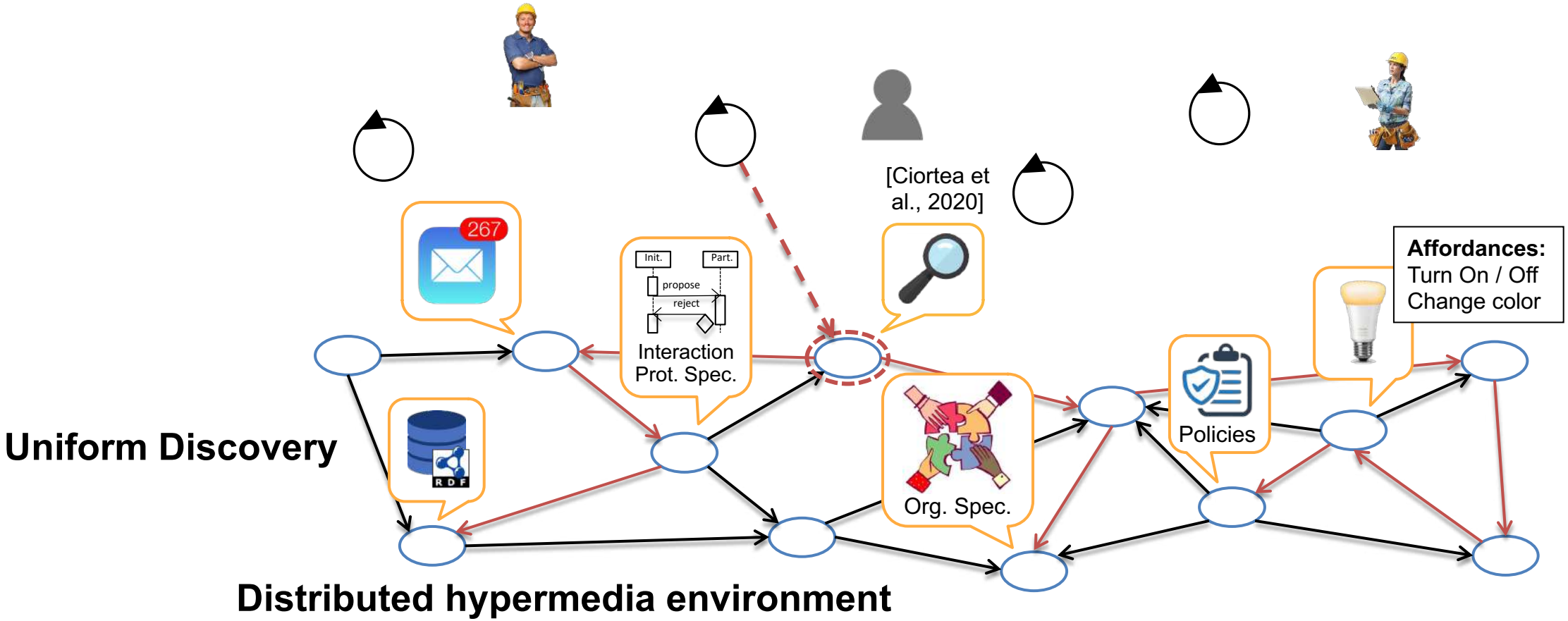

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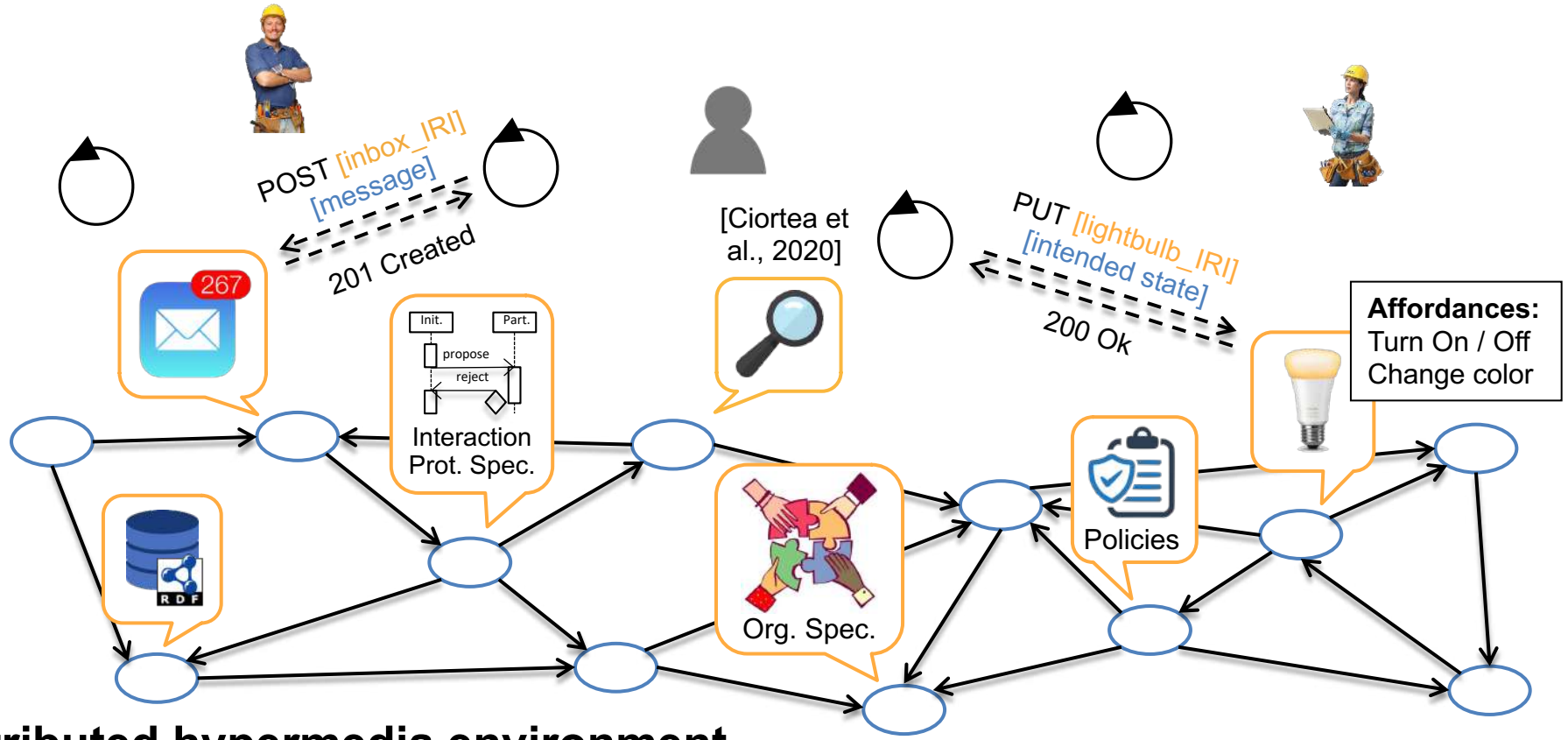

Uniform Action

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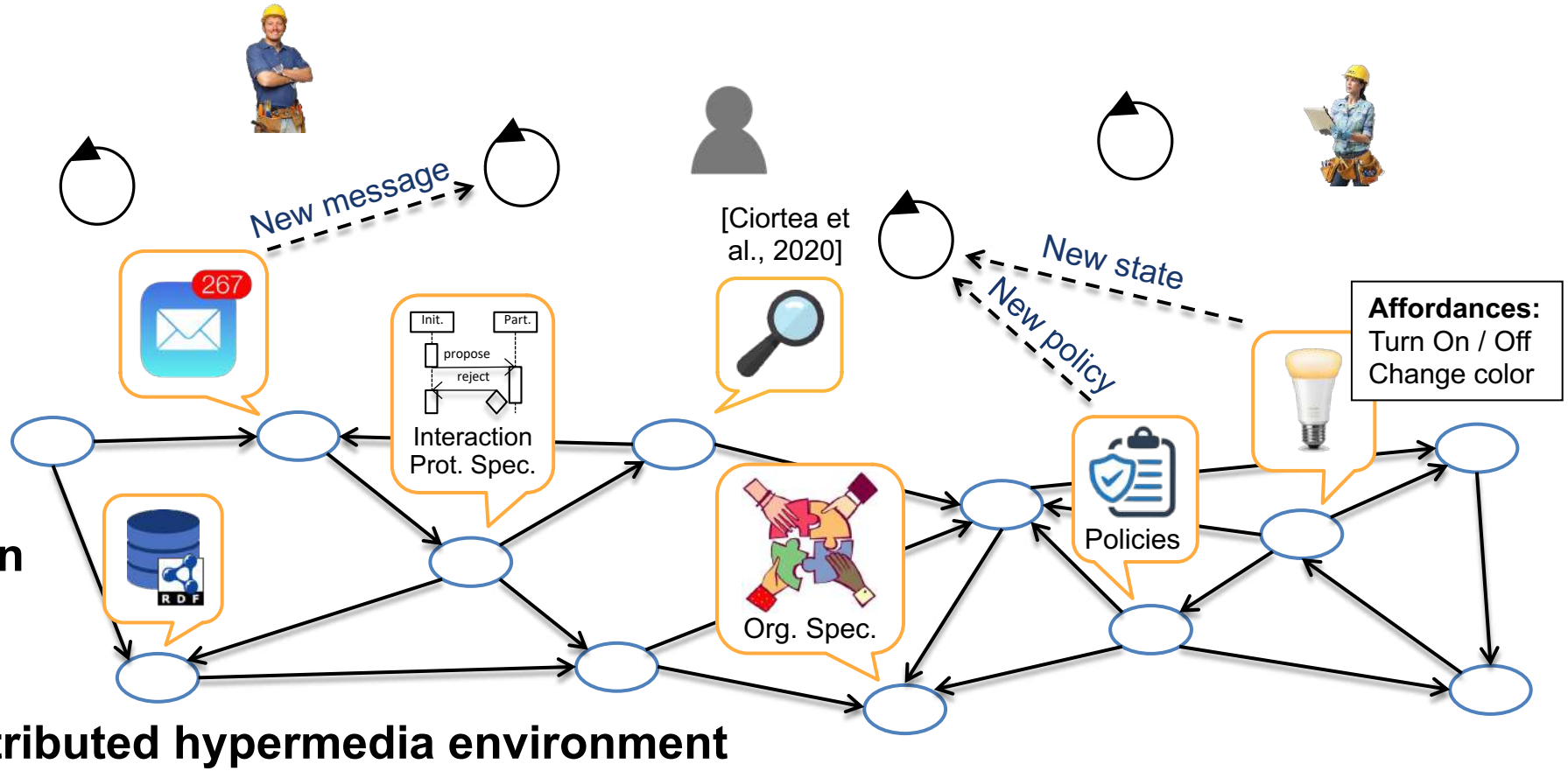

Uniform Perception

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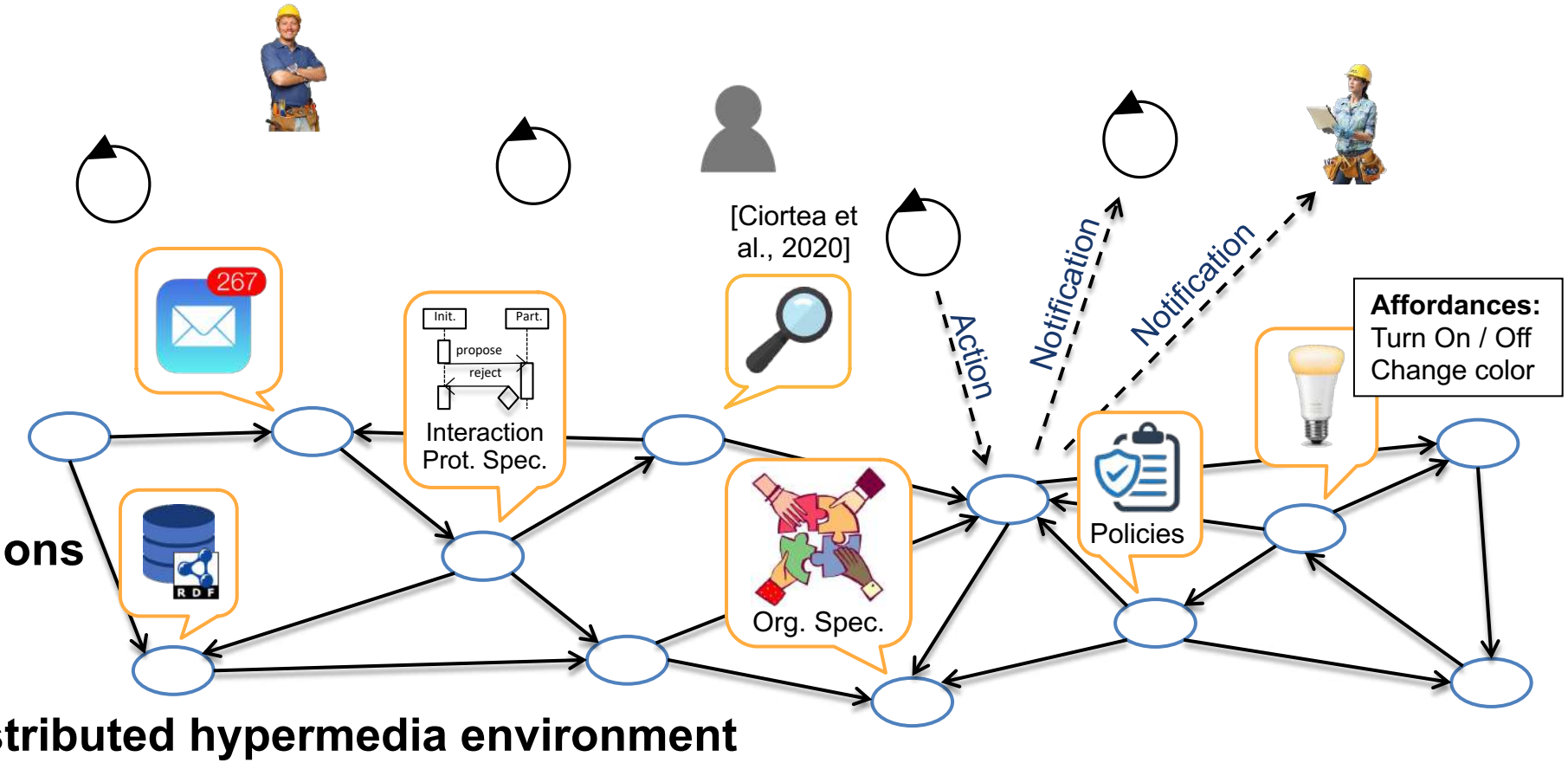

Stigmergic Interactions

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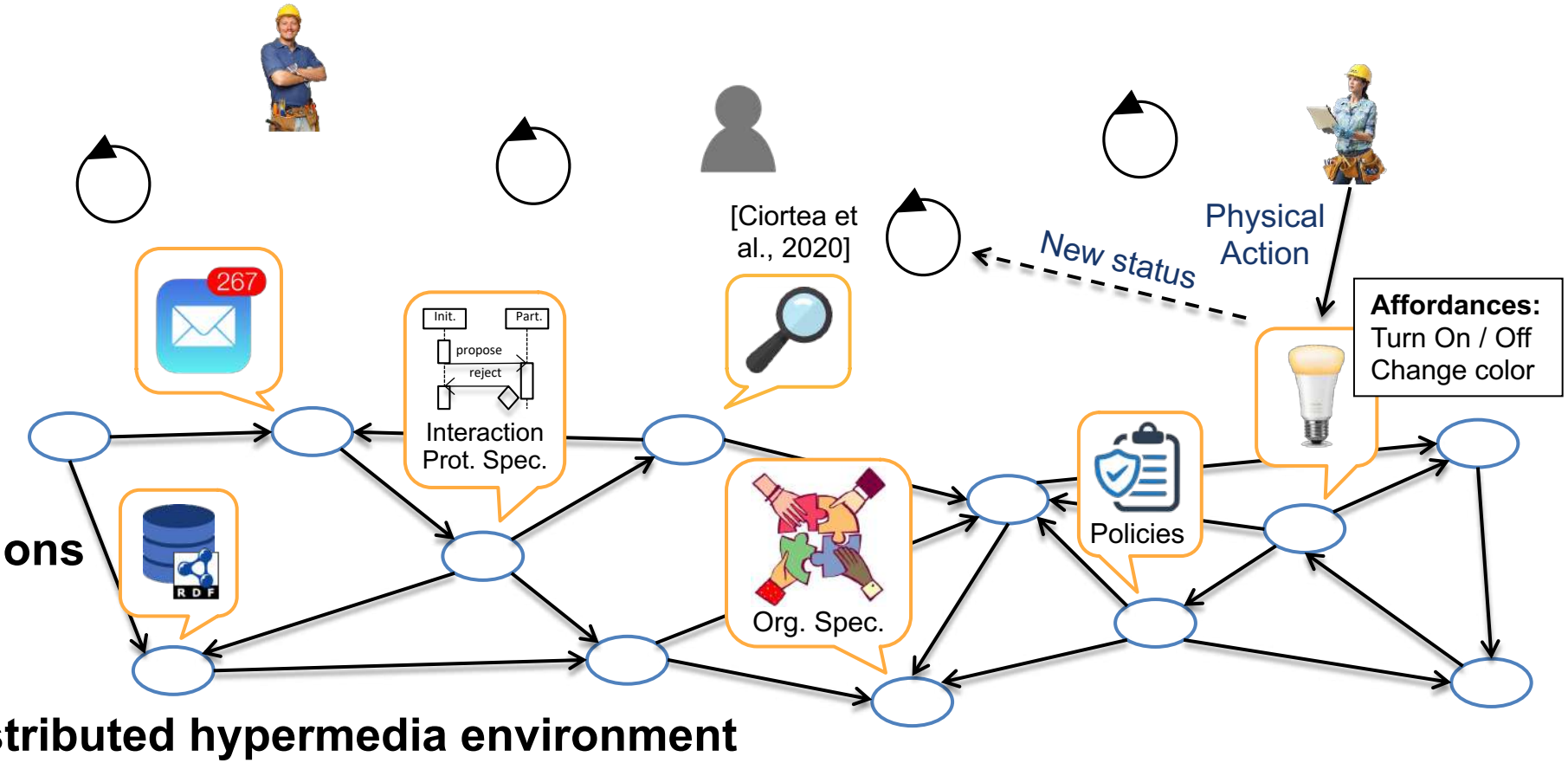

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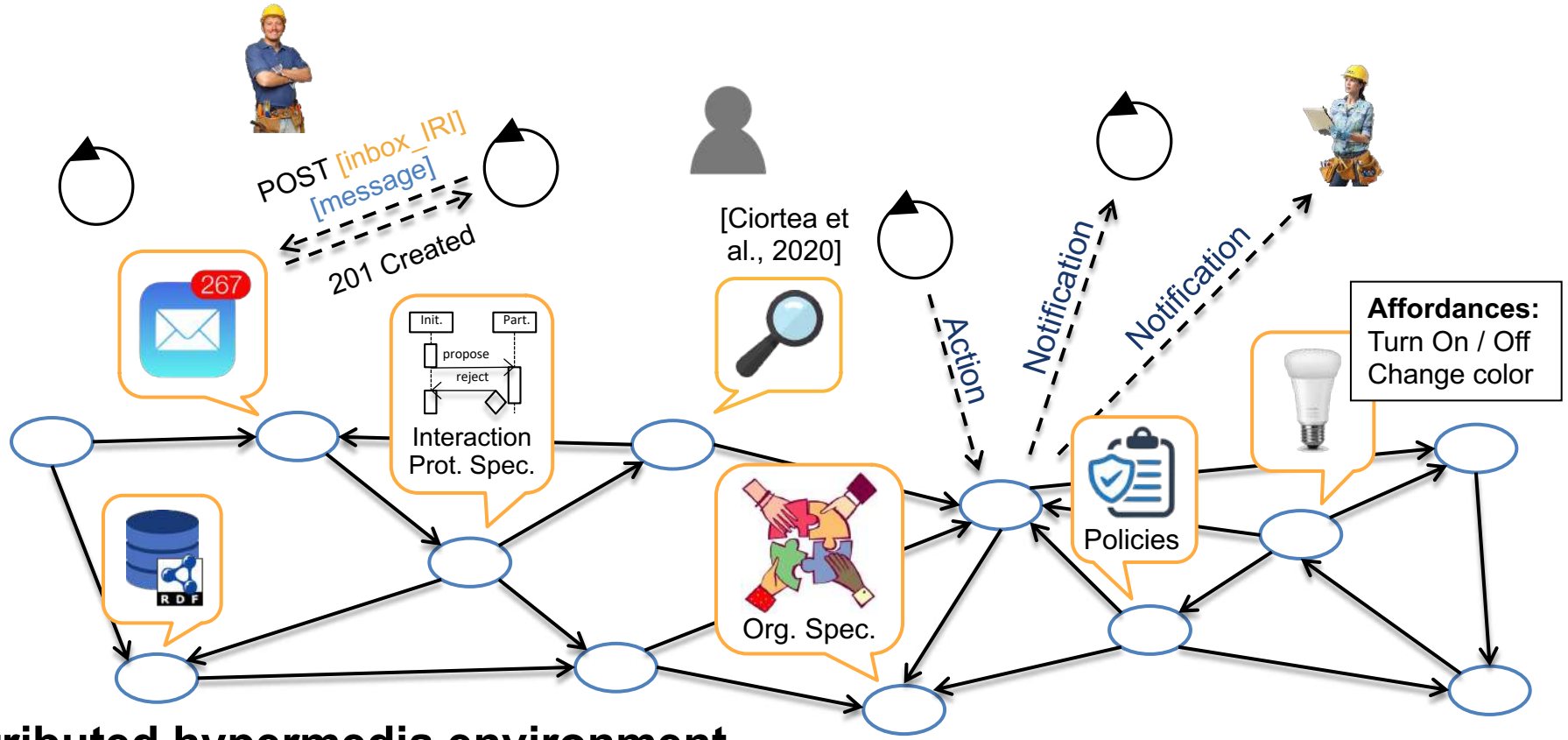

Rich, dynamic, ecosystems

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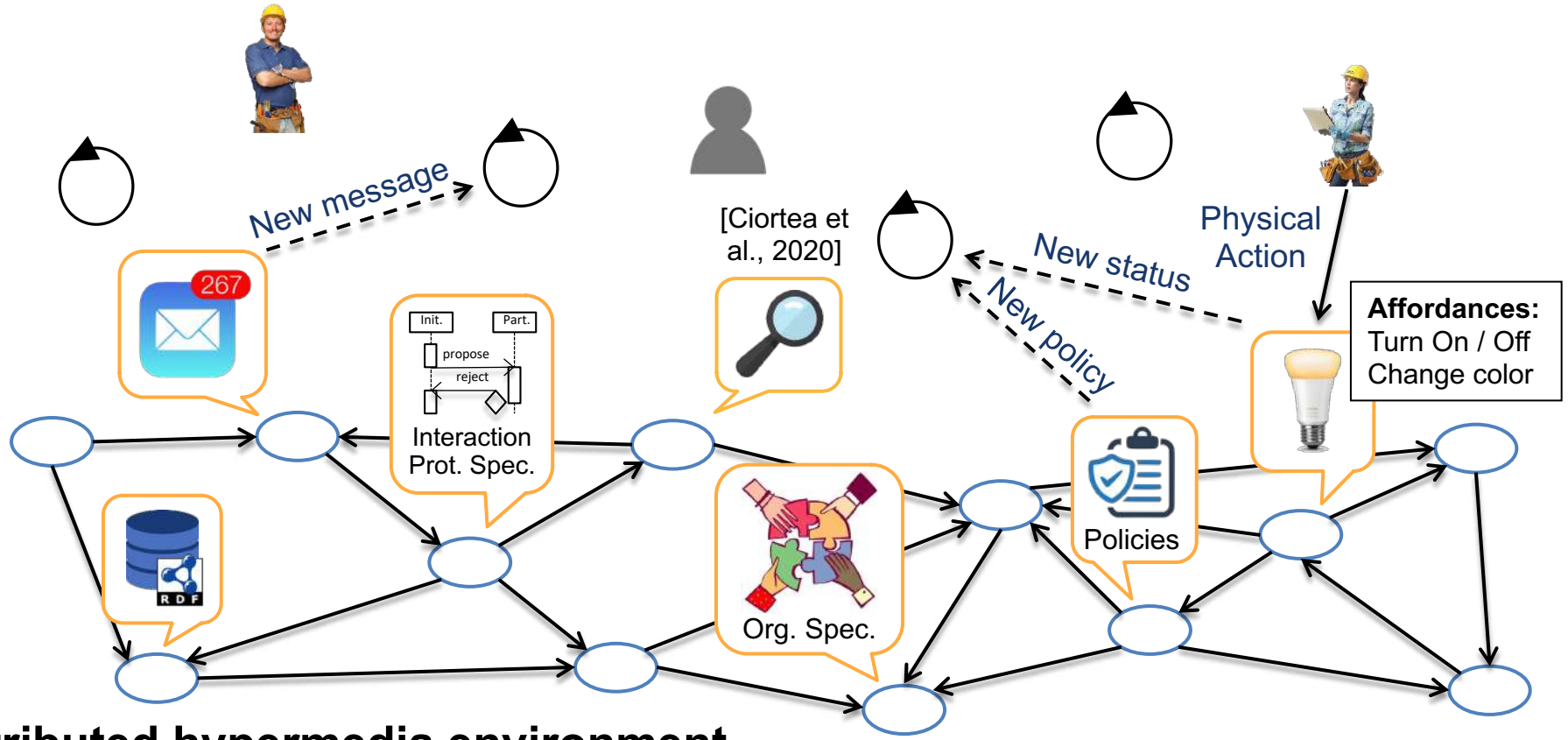

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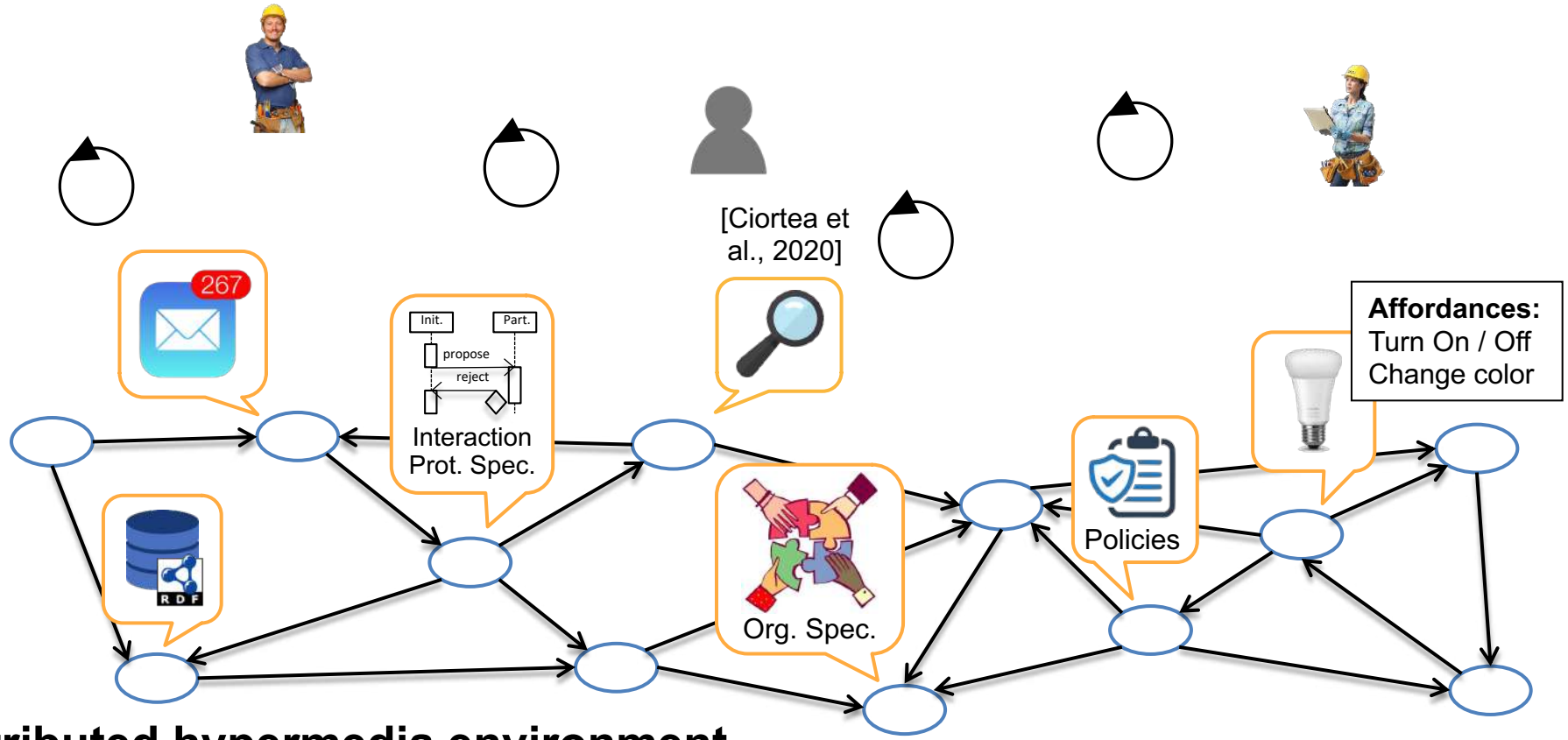

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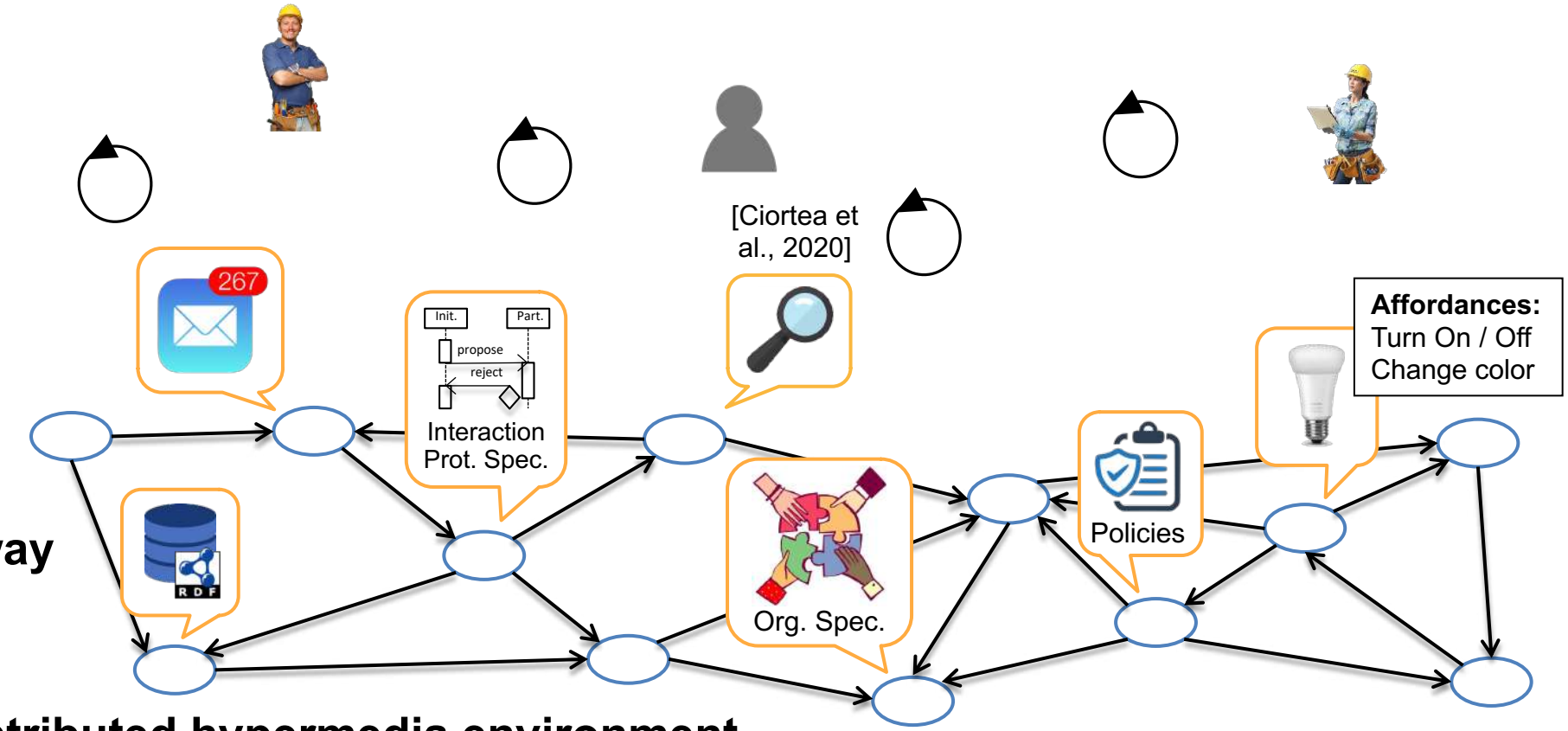
Andrei Ciortea, Simon Mayer, Simon Bienz, Olivier Corby, and Fabien Gandon. Autonomous search in a social and ubiquitous Web. Pers Ubiquit Comput. 2020.

Hypermedia Multi-Agent Systems

The Web is no longer a ~~**hidden transport layer**, but a~~ **rich application layer**!

~~The systems are **weaved into the hypermedia fabric of the Web**~~



What if we strip away the hypermedia?

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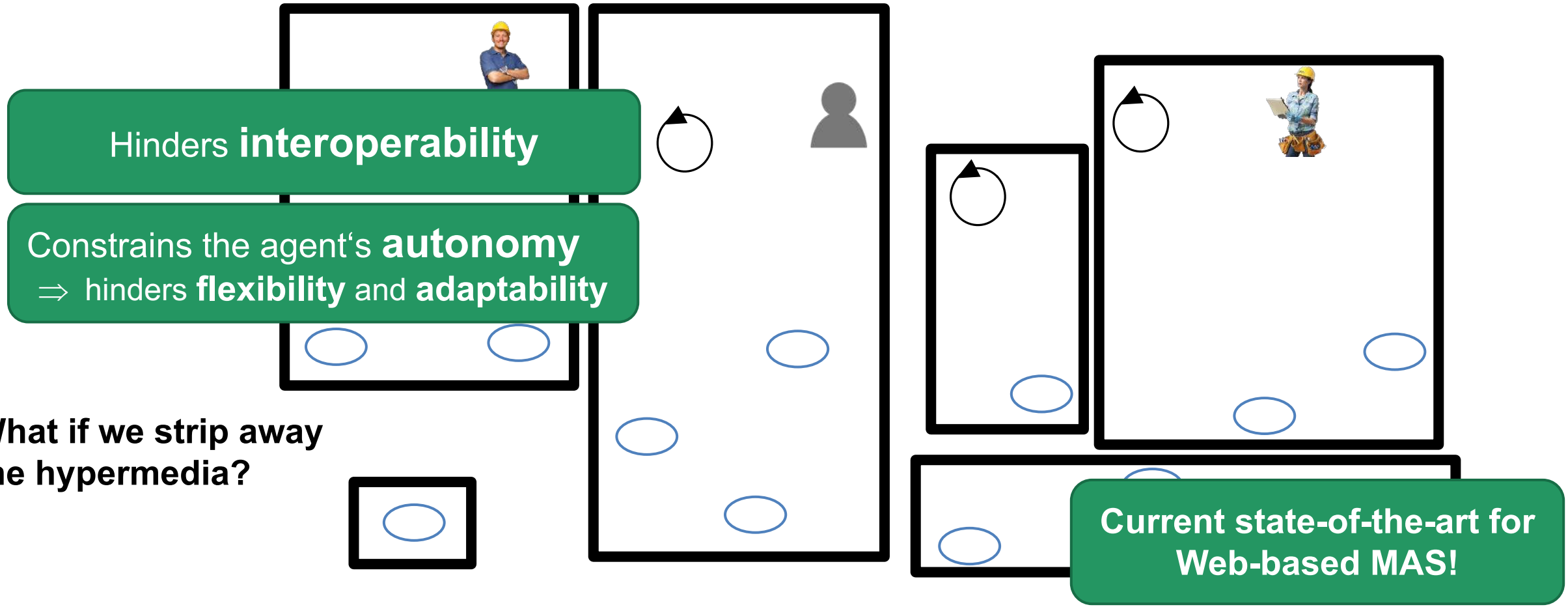

Hinders **interoperability**

Constrains the agent's **autonomy**
⇒ hinders **flexibility** and **adaptability**

What if we strip away the hypermedia?

Current state-of-the-art for Web-based MAS!

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Universität St.Gallen

Towards a Fundamental Contribution

To define a new class of Web-based multi-agent systems (MAS) that **inherit** the architectural properties of the Web, **preserve** the properties of MAS, and are **human-centric**.

⇒ properties of the Web: Internet-scalability, evolvability, simplicity, etc.

⇒ properties of MAS: adaptability, openness, robustness, etc.

⇒ human-centric: transparency, usability, accountability, etc.

Contribute a **thorough set of knowledge to science** about the design of Web-based MAS

HyperAgents

Hypermedia Communities of People and Autonomous Agents (HyperAgents)

https://project.hyperagents.org

IntellIoT

Intelligent, distributed, human-centered and trustworthy IoT environments

https://intelliot.eu

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Industrial Manufacturing

Tackling Online Disinformation

Use Case: Flexible Industrial Manufacturing

Lot-size-one problem: **unique** products at **mass production costs**

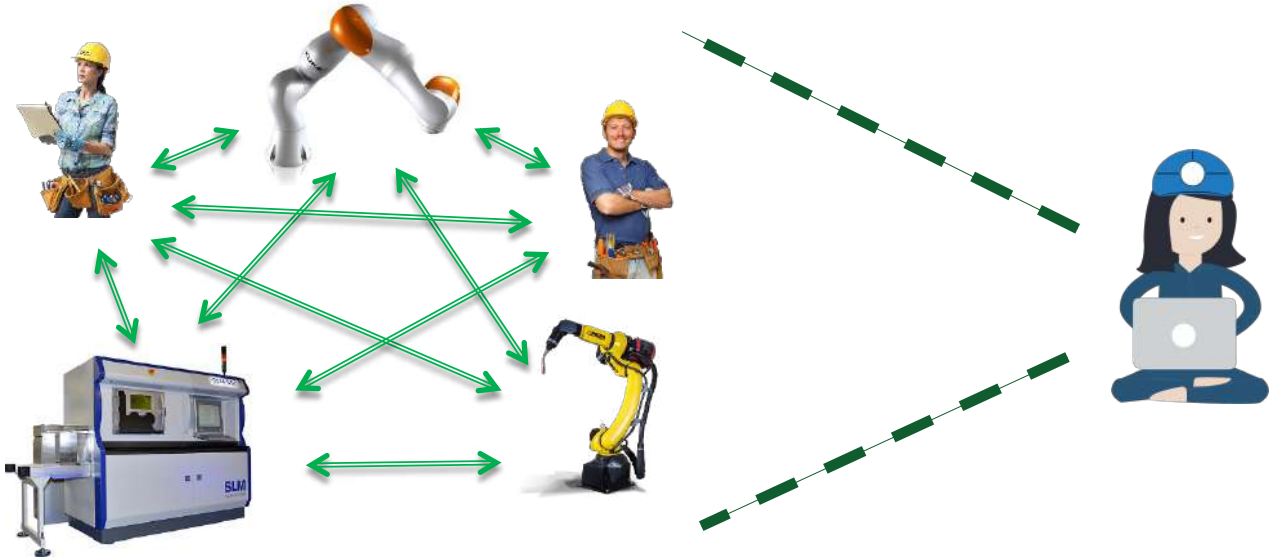
- customization is **expensive**: production lines are **optimized**, **inflexible**, and have **large lifespans** (> 30yr)

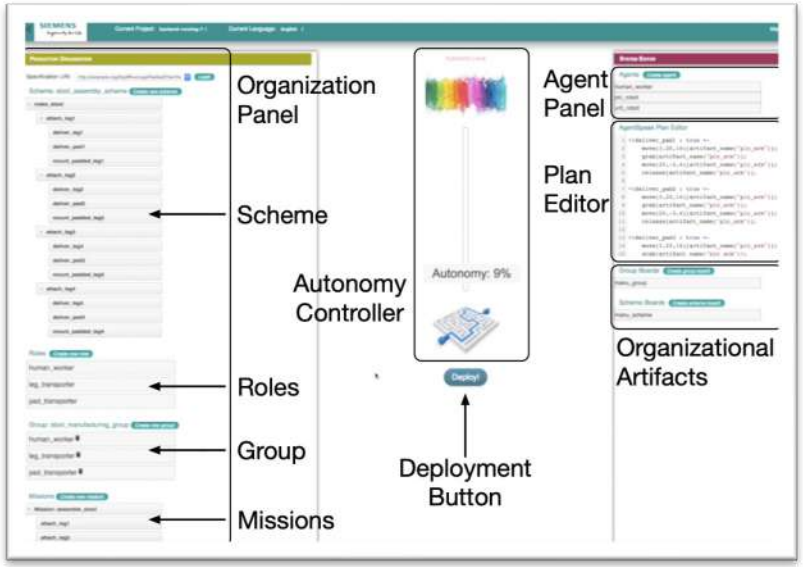
⇒ we need production lines that can be **repurposed on-the-fly**

SIEMENS

Early proof-of-concept for Hypermedia MAS in manufacturing:

- hybrid manufacturing organizations
- end-user programming for production engineers





Andrei Ciortea, Simon Mayer, and Florian Michahelles. Repurposing Manufacturing Lines on the Fly with Multi-Agent Systems for the Web of Things, AAMAS 2018.

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AAMAS 2018

Repurposing Manufacturing Lines on the Fly with Multi-agent Systems for the Web of Things

Andrei Ciortea
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Berkeley, CA 94704, USA
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ABSTRACT

Multi-agent systems (MAS) have long been envisioned as a key enabling technology in manufacturing, but this promise is yet to be realized: the lack of proper models, architectures, tooling, and the high level of expertise required for designing and programming

significance: we are witnessing an accelerating trend towards highly customized products across a broad range of industrial domains. For industry, *mass-customization* means that products in lot sizes of as little as a single item now have to be manufactured at the price of mass-produced goods. This development challenges the

IntellioT

https://intelliot.eu/

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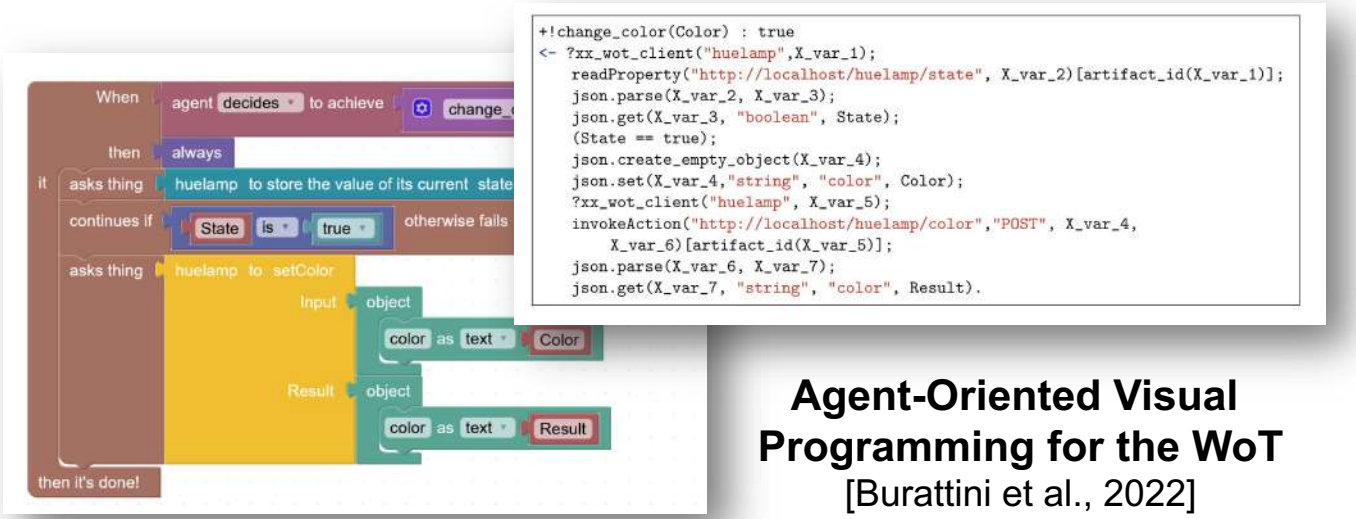

Agent-Oriented Visual Programming for the WoT
[Burattini et al., 2022]

S. Burattini, A. Ricci, S. Mayer, D. Vachtsevanou, J. Lemée, A. Ciortea, and A. Croatti: Agent-Oriented Visual Programming for the Web of Things, EMAS 2022
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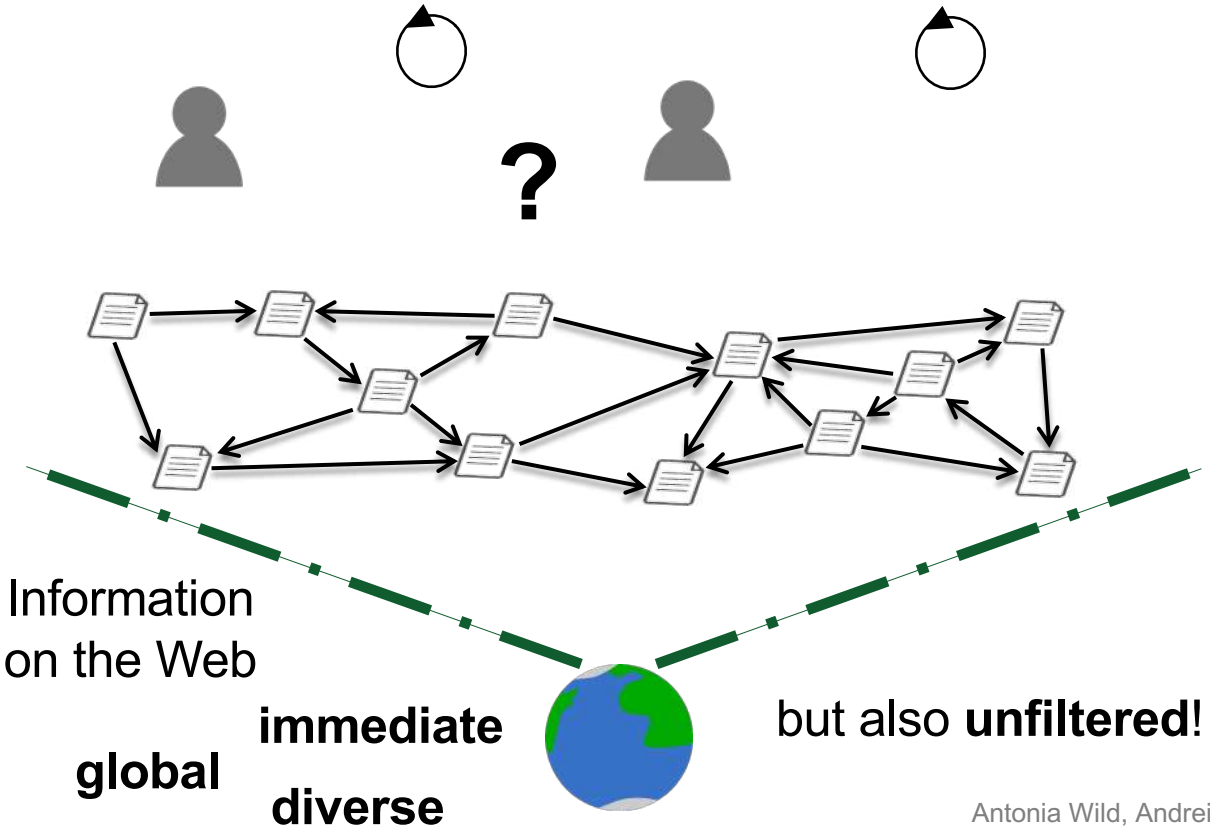
Use Case: Tackling Online Disinformation

Credibility analysis of online information is hard

- automated fact-checking can **scale** but **lacks accuracy**
- manual fact-checking is more **accurate** but **lacks scale**



https://euvsdisinfo.eu/

Antonia Wild, Andrei Ciortea, and Simon Mayer. Designing Social Machines for Tackling Online Disinformation, DecentWeb 2020.
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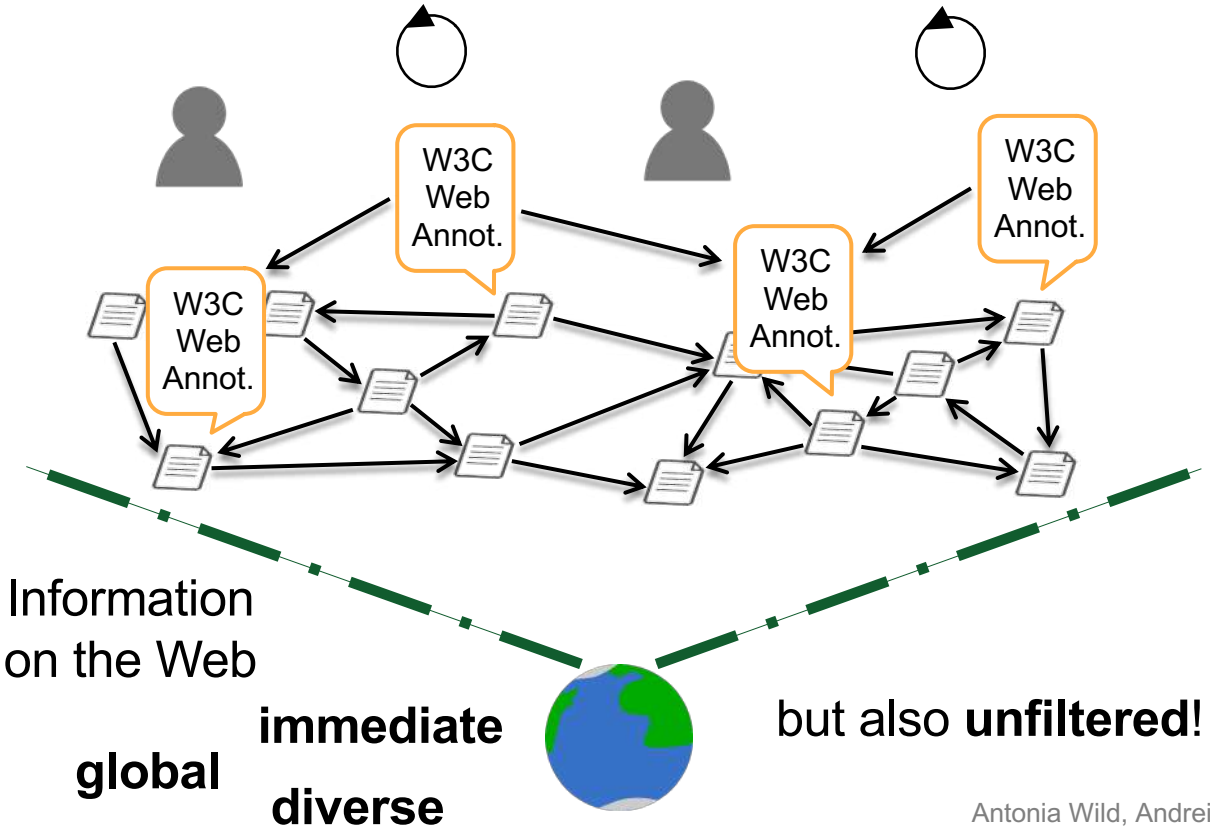

W3C Web Annotations: transparency **at source** on the **open Web**

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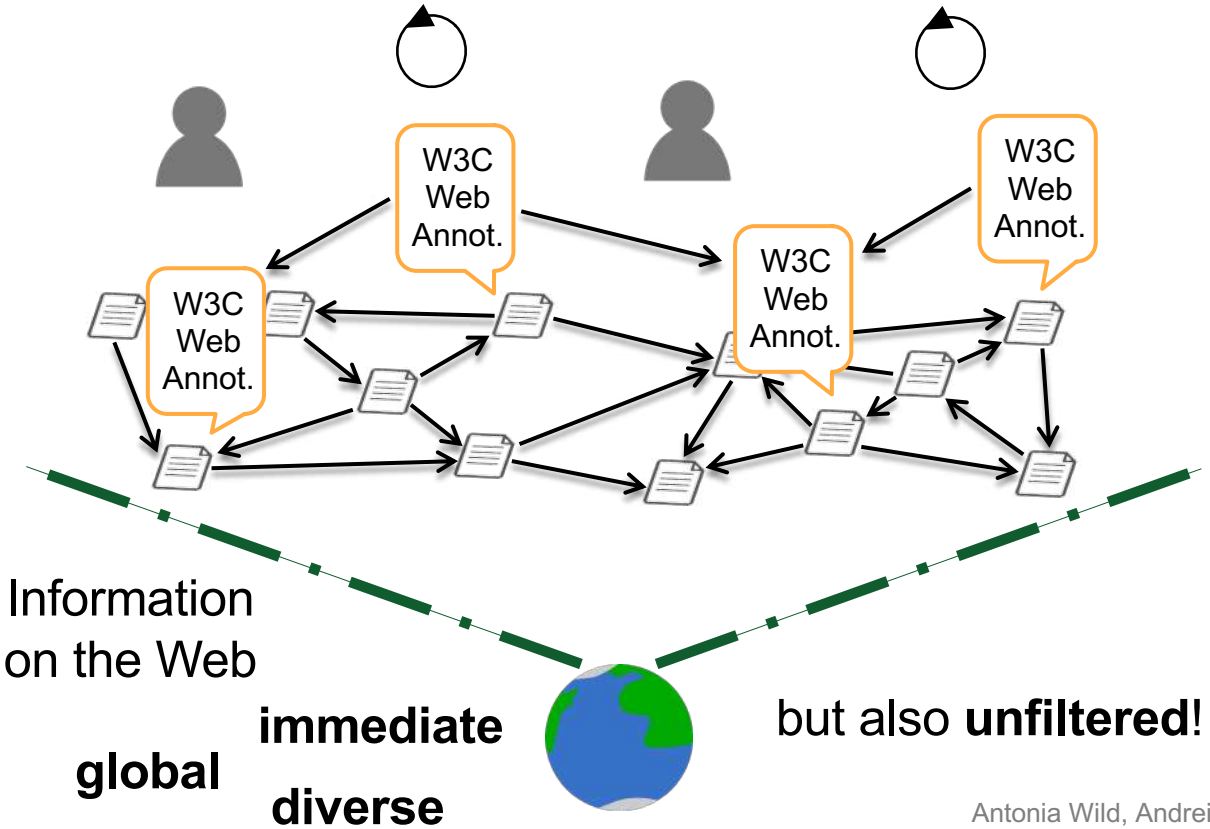

W3C Web Annotations: transparency **at source** on the **open Web**

Fact-checking workflows defined by experts

What's missing: designing hybrid organizations of people and autonomous agents

— and deploying them **at scale**!

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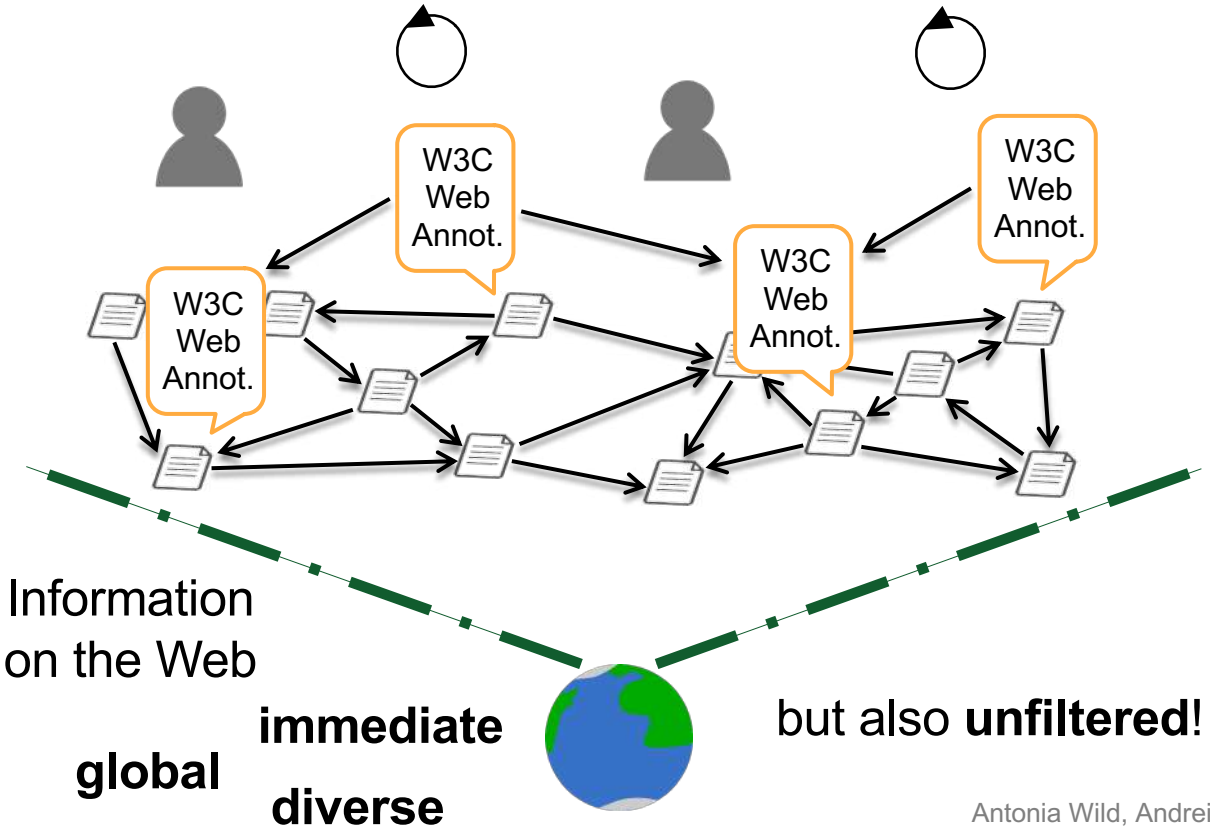
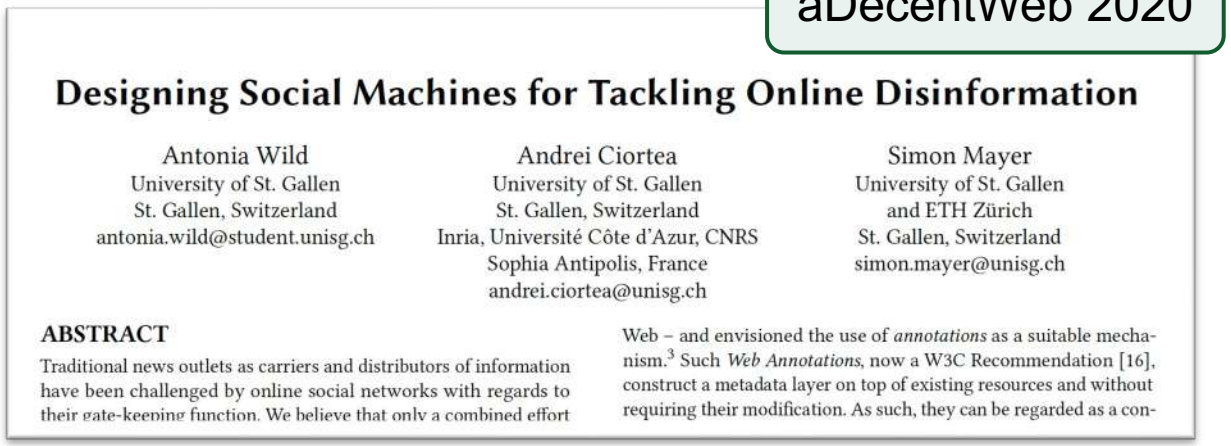


aDecentWeb 2020



Designing Social Machines for Tackling Online Disinformation

Antonia Wild
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Simon Mayer
University of St. Gallen
and ETH Zürich
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ABSTRACT

Traditional news outlets as carriers and distributors of information have been challenged by online social networks with regards to their gate-keeping function. We believe that only a combined effort

Web – and envisioned the use of *annotations* as a suitable mechanism.[3] Such *Web Annotations*, now a W3C Recommendation [16], construct a metadata layer on top of existing resources and without requiring their modification. As such, they can be regarded as a con-

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Universität St.Gallen

Today's Agenda

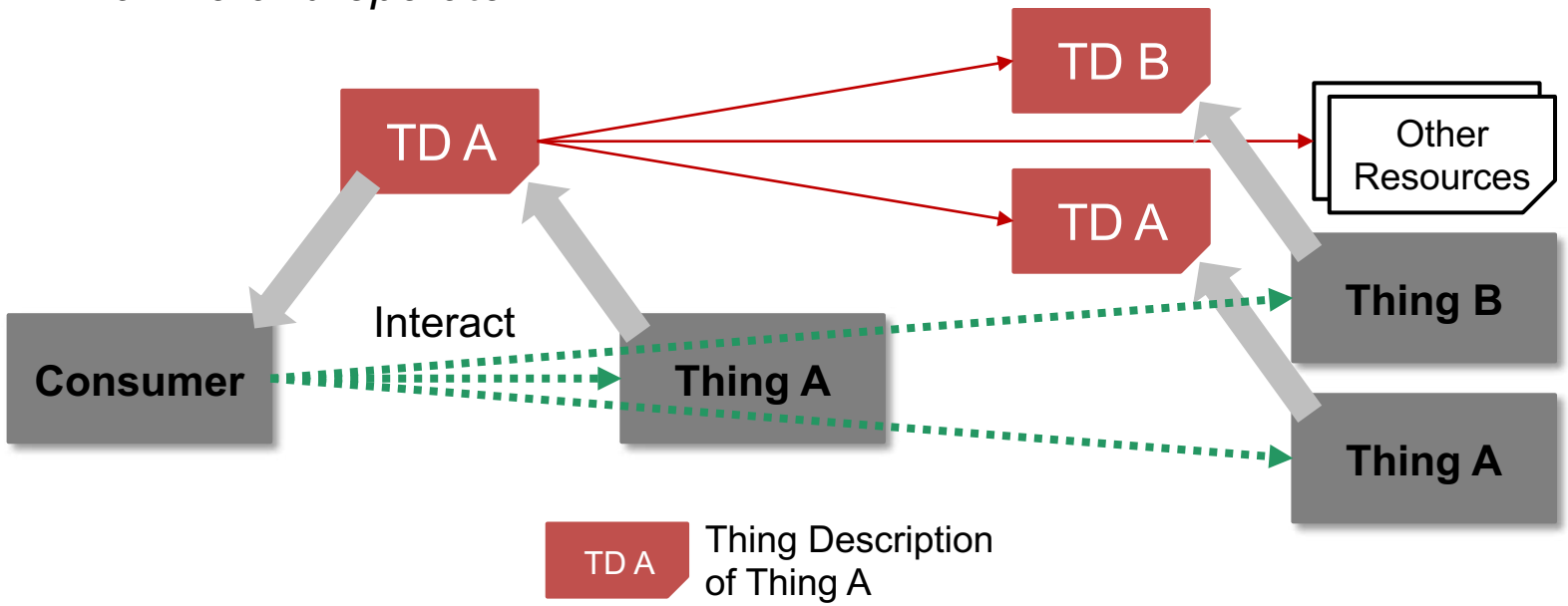
- Hypermedia Multi-Agent Systems
- Use Cases
  - Flexible Industrial Manufacturing
  - Tackling Online Disinformation
- Challenges
  - Efficient Interaction
  - Accountable Interaction

Challenges: Efficient Interaction

Heterogeneous Agents

Hypermedia Environments:
Large, Unknown, Dynamic

Ideally:
arrive-and-operate




```
{
    "@context": [
        "https://www.w3.org/2019/wot/td/v1",
        { "saref": "https://w3id.org/saref#" }
    ],
    "id": "urn:dev:ops:32473-WoTLamp-1234",
    "title": "MyLampThing",
    "@type": "saref:LightSwitch",
    "securityDefinitions": {"basic_sc": {
        "scheme": "basic",
        "in": "header"
    }},
    "security": ["basic_sc"],
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        "status": {
    },
    "actions": {
        "toggle": {
            "@type": "saref:ToggleCommand",
            "forms": [{
                "href": "https://mylamp.example.com/toggle"
            }]
        }
    },
```

Interaction Affordances:
observable properties,
observable events, and actions

Matthias Kovatsch et al. (eds.), Web of Things (WoT) Architecture, W3C Recommendation, 2020.

A TD Document for a lamp.

Challenges: Efficient Interaction

OWL ontologies

Concept defined in the SAREF ontology

```
{
    "@context": [
        "https://www.w3.org/2019/wot/td/v1",
        { "saref": "https://w3id.org/saref#" }
    ],
    "id": "urn:dev:ops:32473-WoTLamp-1234",
    "title": "MyLampThing",
    "@type": "saref:LightSwitch",
    "securityDefinitions": {"basic_sc": {
        "scheme": "basic",
        "in": "header"
    }},
    "security": ["basic_sc"],
    "properties": {
        "status": {
            "@type": "saref:OnOffState",
            "type": "string",
            "forms": [{
                "href": "https://mylamp.example.com/status"
            }]
        }
    },
    "actions": {
        "toggle": {
            "@type": "saref:ToggleCommand",
            "forms": [{
                "href": "https://mylamp.example.com/toggle"
            }]
        }
    },
```

A TD Document for a lamp.

"A device of category `saref:Actuator` that consists of a switch, accomplishes the task `saref:Lighting`, performs the `saref:OnOffFunction`, measures the property `saref:Light`, and can be found in the state `saref:OnOffState`. It can offer a switch on service."

Smart Appliances REFerence (SAREF) ontology. ETSI.

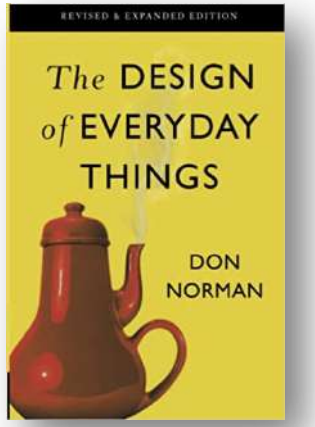
Challenges: Efficient Interaction

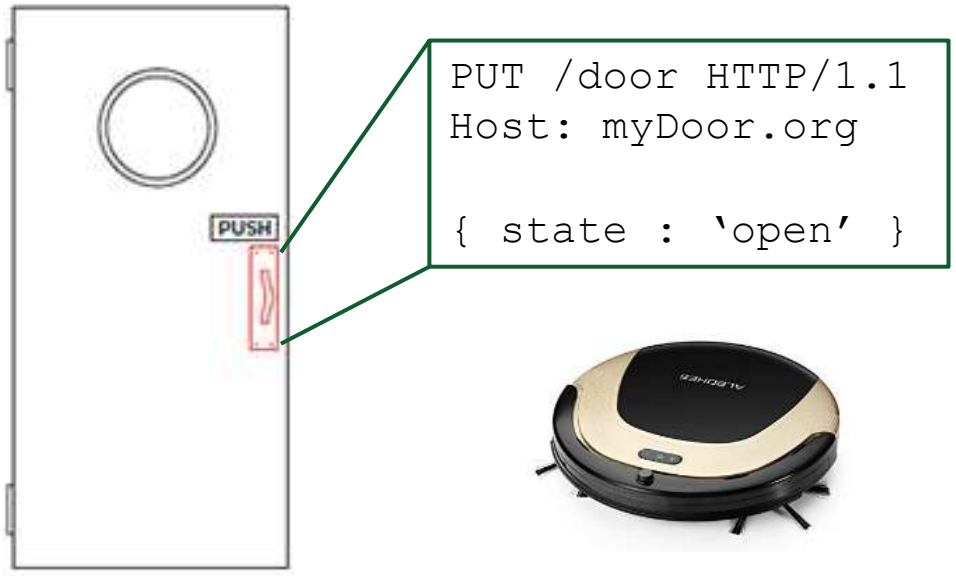
Affordance [Chemero & Turvey, 2007]

An affordance is a **behavior possibility** that is a relationship between a) an **ability** of an agent and b) a **situation** that includes agents and features of the environment.

Signifier

A perceivable cue or sign that can be interpreted meaningfully to **reveal information about an affordance**.





CHI 2022, New Orleans, US (Photo by Kenan Bektas)

Challenges: Efficient Interaction

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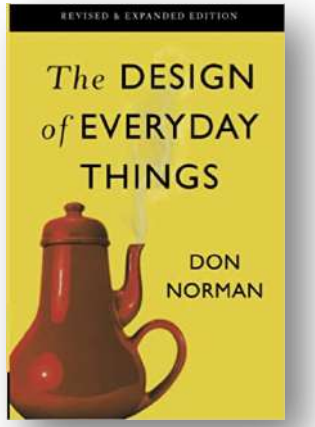

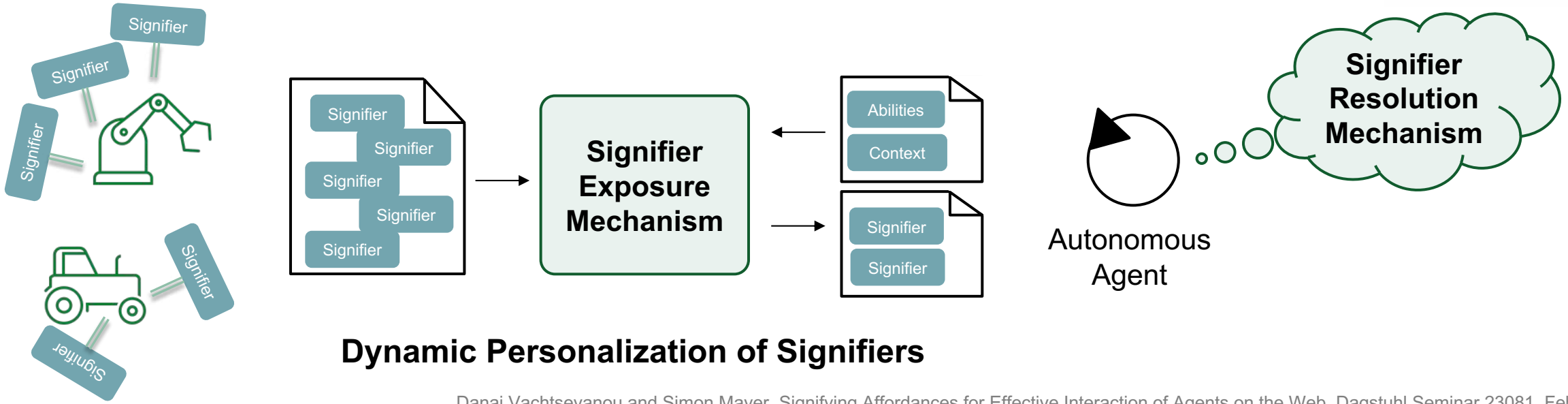

Dynamic Personalization of Signifiers

Danai Vachtsevanou and Simon Mayer. Signifying Affordances for Effective Interaction of Agents on the Web, Dagstuhl Seminar 23081, Feb. 2023.
Danai Vachtsevanou, Andrei Ciortea, Simon Mayer, and Jérémy Lemée. Signifiers as a First-class Abstraction in Hypermedia Multi-Agent Systems. AAMAS 2023.

Challenges: Efficient Interaction

AAMAS 2023

Signifiers as a First-class Abstraction in Hypermedia Multi-Agent Systems

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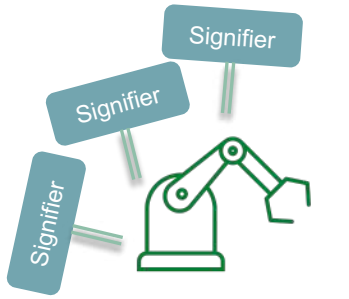
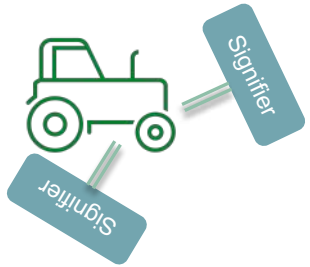
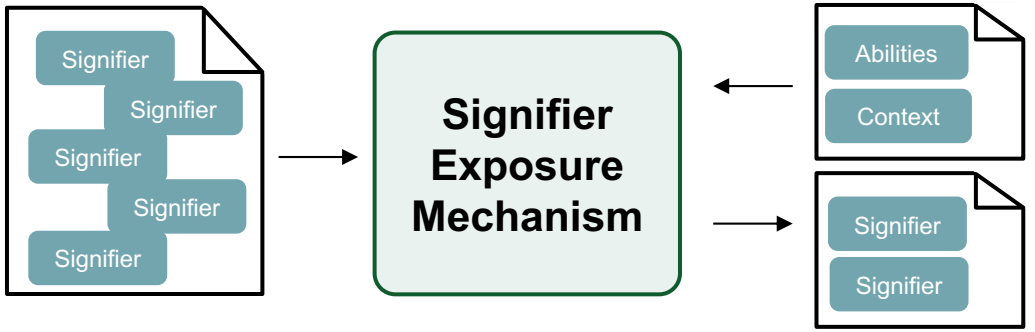
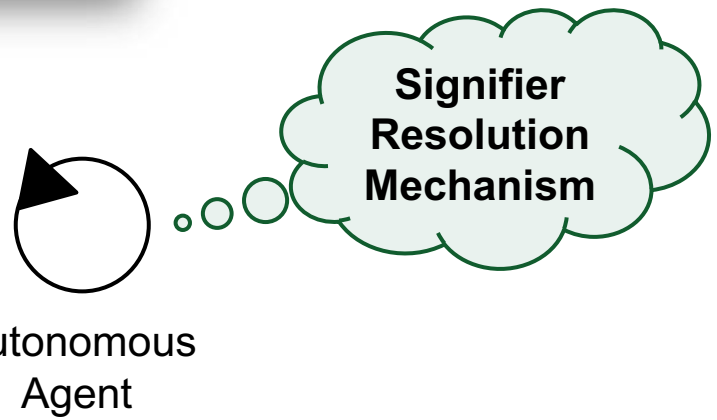
ABSTRACT

Hypermedia APIs enable the design of reusable hypermedia clients that discover and exploit affordances on the Web. However, the their reasoning and decision-making abilities by discovering and exploiting affordances of Web resources towards achieving their goals [8]. The prime mechanism for affordance discovery and ex-









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Challenges: Accountable Interaction

Accountability is the underpinning of **regulation**, which balances **autonomy**

– induced by law, agreements, contracts, etc.

Autonomy as a relational notion

An entity X is autonomous from Y about G, where [Castelfranchi, 1993; Castelfranchi & Falcone, 2003]:

– X: the main entity whose autonomy is considered/evaluated

– G: a function/action/goal that must be realized or maintained by the main entity and on which the autonomy is evaluated

– Y: the secondary entity (human, artificial agent, environment, organization, etc.) with respect to whom X should be considered autonomous given the specified function/action/goal G

"X is autonomous from (any) Y to achieve goal G"

"X depends on Y to achieve goal G"
(and knows Y can help achieve goal G)

"X is permitted/prohibitted/obliged by organization Y to achieve goal G"

C. Castelfranchi. *Guarantees for Autonomy in Cognitive Agent Architecture*, ECAI, 1993.
C. Castelfranchi, R. Falcone. *From Automaticity to Autonomy: The Frontier of Artificial Agents*. In: Hexmoor H., Castelfranchi C., Falcone R. (eds) Agent Autonomy. Multiagent Systems, Artificial Societies, and Simulated Organizations (International Book Series), vol 7, 2003.

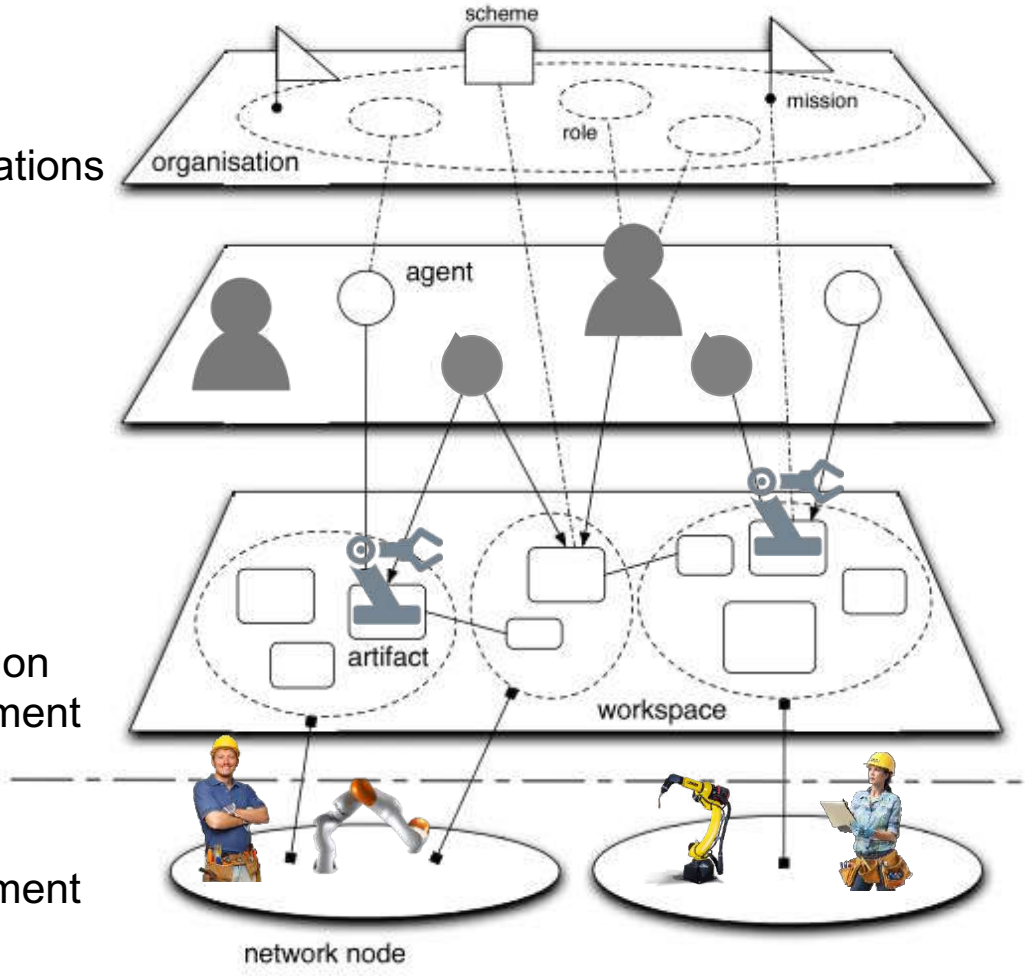
Challenges: Accountable Interaction

Organizations

Agents

Application Environment

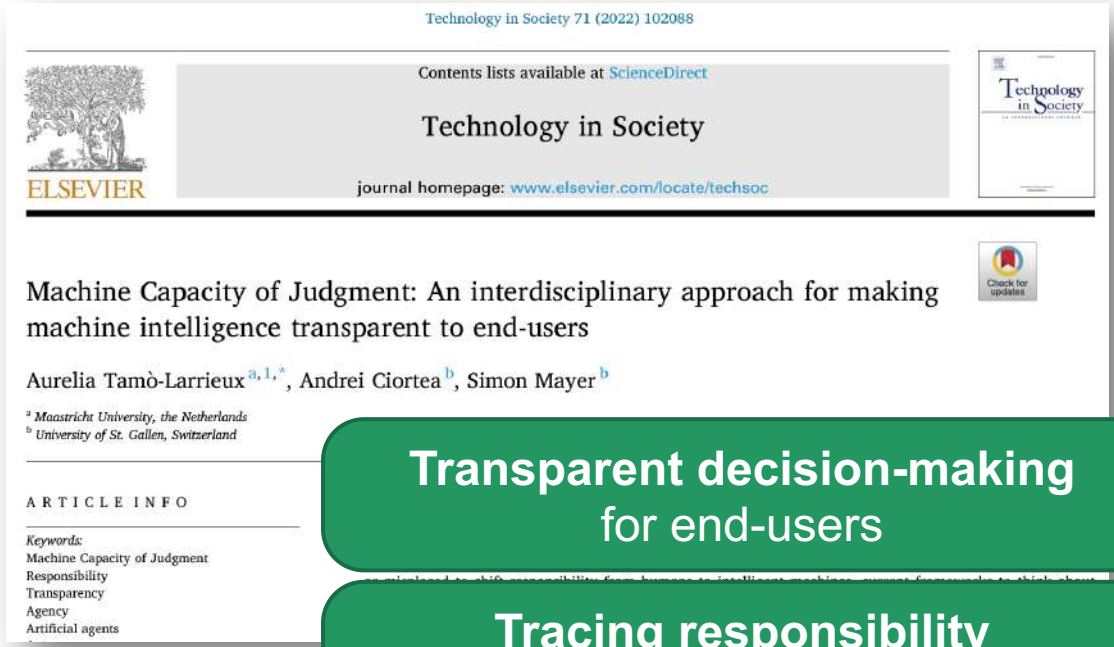
External Environment



JaCaMo Meta-Model [Boissier et al., 2013]

Autonomy from:

- other agents (**indepedence** vs. **interdependence**)
- organizations (**deontic autonomy**)
- the environment (**freedom** from the environment)



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ELSEVIER

Machine Capacity of Judgment: An interdisciplinary approach for making machine intelligence transparent to end-users

Aurelia Tamò-Larrieux [a,1,*], Andrei Ciortea [b], Simon Mayer [b]

[a] Maastricht University, the Netherlands
[b] University of St. Gallen, Switzerland

ARTICLE INFO

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Responsibility
Transparency
Agency
Artificial agents

Transparent decision-making
for end-users

Tracing responsibility
at Web-scale

O. Boissier, R.H. Bordini, J.F. Hübner, A. Ricci, and A. Santi, Multi-agent oriented programming with JaCaMo, Science of Computer Programming, Volume 78, Issue 6, 2013.

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Conclusions

It is both timely and necessary to create **thorough conceptual** and **technological bridges** between MAS and Web research.

Exciting research opportunities for designing **usable**, **transparent**, and **accountable** MAS for the Web.

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Thank you!

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https://freepik.com