Stigmergic Multi-Agent Systems in the Semantic Web of Things

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5. Evaluation Plan
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1. Introduction

Semantic Web Agents

“At the doctor’s office, Lucy instructed her Semantic Web agent through her handheld Web browser. The agent promptly retrieved information about Mom’s prescribed treatment [...] It then began trying to find a match between available appointment times (supplied by the agents of individual providers through their Web sites) and Pete’s and Lucy’s busy schedules.” [1]

Agents were an integral part of the original vision of the Semantic Web!

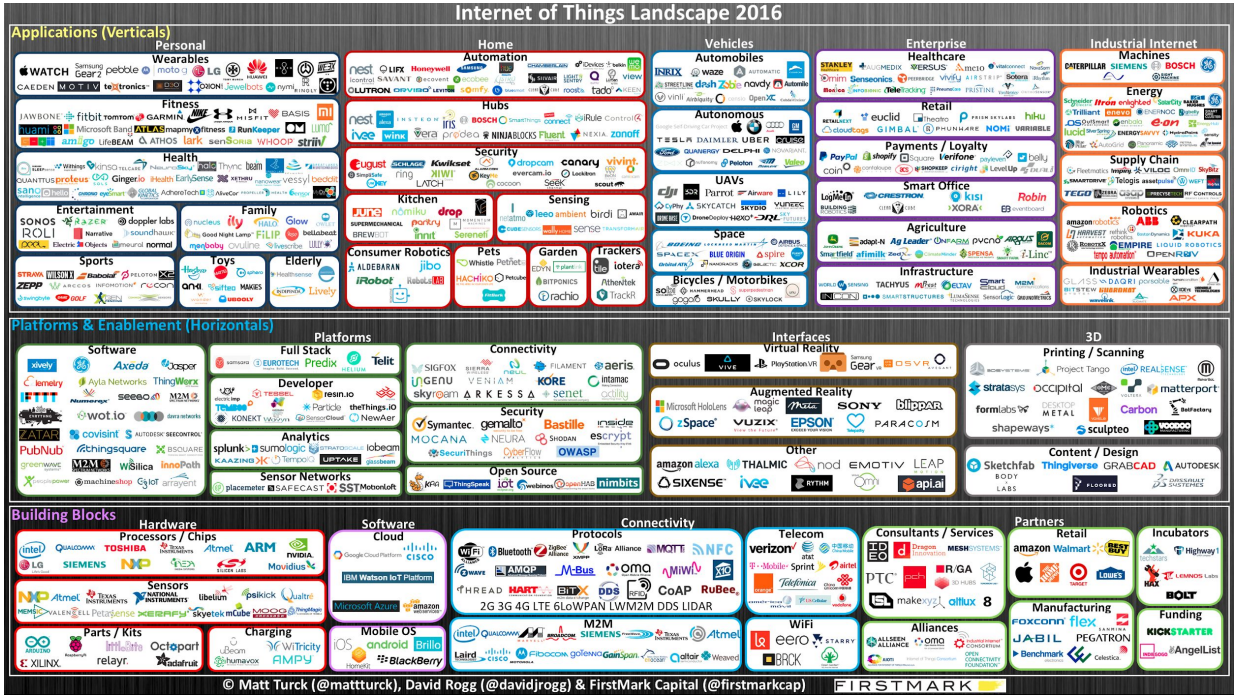
But: “Where are all the intelligent agents?” [2]

[1] Berners-Lee, T., Hendler, J., Lassila, O.: The semantic web. Scientific american 284(5), 34–43 (2001)

[2] Hendler, J.: Where are all the intelligent agents? IEEE Annals of the History of Computing 22(03), 2–3 (2007)

Internet of Things

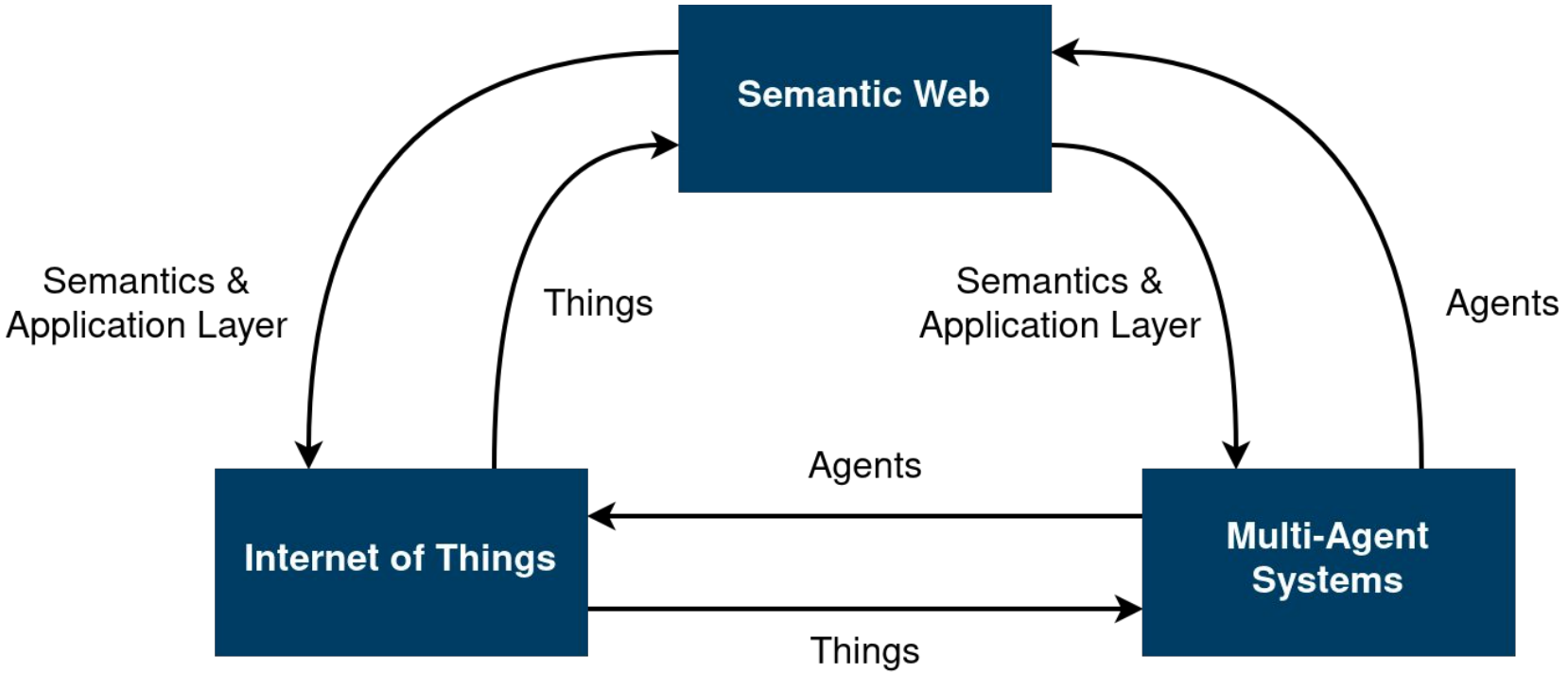
The Internet of Things is very fragmented and suffers from a lack of interoperability [3]!



https://mattturck.com/2016-iot-landscape/

[3] Bröring, A., Schmid, S., Schindhelm, C. K., Khelil, A., Käbisch, S., Kramer, D., ... & Teniente, E. (2017). Enabling IoT ecosystems through platform interoperability. IEEE software, 34(1), 54-61.

Those fields could profit from each other!



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2. State of the Art

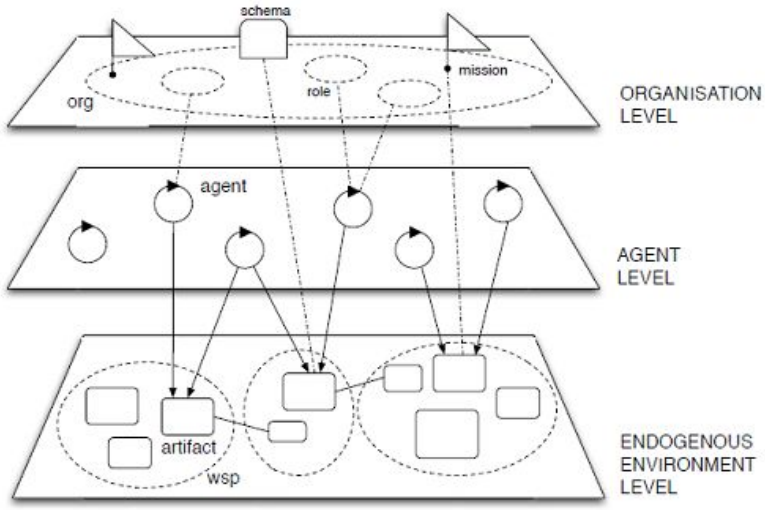
Multi-Agent Systems

Agent-Oriented Programming

JaCaMo is the quasi-standard to program so called Belief-Desire-Intention-Agents (BDI Agents).

- Jason: A language for specifying agents' beliefs, desires and intentions
- Cartago: for programming artifacts in the environment
- Moise: for creation and management of agent organizations

But: By default all agents and artifacts run on the same host [4]!



http://jacamo.sourceforge.net/?page_id=40 (modified)

[4] Boissier, O., Bordini, R.H., Hübner, J.F., Ricci, A., Santi, A.: Multi-agent oriented programming with jacamo. Science of Computer Programming 78(6), 747–761 (2013)

Multi-Agent Systems

Foundation for Intelligent Physical Agents

FIPA is a set of standards (e. g. implemented by JaCaMo Jade Infrastructure) for agent communication over multiple protocols (HTTP, SMTP, etc.) [5].

HTTP, SMTP, etc.?

FIPA is an RPC-style protocol that uses HTTP only as a communication layer. It is thus not properly aligned to the application layer of the Web which is a resource-oriented (RESTful) one.

Applications in the Web that are not aligned with REST suffer from several disadvantages like limited scalability, tight coupling, caching, etc. [6]!

[5] O'Brien, P.D., Nicol, R.C.: Fipa - towards a standard for software agents. BT Technology Journal 16(3), 51–59 (1998)

[6] Ciortea, A., Mayer, S., Gandon, F., Boissier, O., Ricci, A., Zimmermann, A.: A decade in hindsight: the missing bridge between multi-agent systems and the world wide web. In: Proceedings of the International Conference on Autonomous Agents and Multiagent Systems (2019)

Multi-Agent Systems

Hypermedia Agents

Hypermedia should be used in Multi-Agent Systems to discover new agents and artifacts (and how to interact with them) at runtime [7].

HATEOAS

Hypermedia as the Engine of Application State is an important (if not the most important) constraint of REST and helps systems to a better scalability and evolvability [7]!

But:

Heavy focus on HATEOAS, other REST constraints (client-server principle, stateless communication) are neglected!

[7] Ciortea, A., Boissier, O., Ricci, A.: Engineering world-wide multi-agent systems with hypermedia. In: International Workshop on Engineering Multi-Agent Systems. pp. 285–301. Springer (2018)

Stigmergic Multi-Agent Systems

Stigmergy

A communication paradigm that - inspired by the behaviour of social insects - allows agents only to communicate with their environment, not with each other [8]. It can be used as a coordination mechanism for agents - and aligns very well with REST.

Simple Reflex Agents

A very simple agent architecture [9], however in combination with stigmergy many of those agents would probably still be capable of doing a lot of useful things on the Web in a self-organizing way.

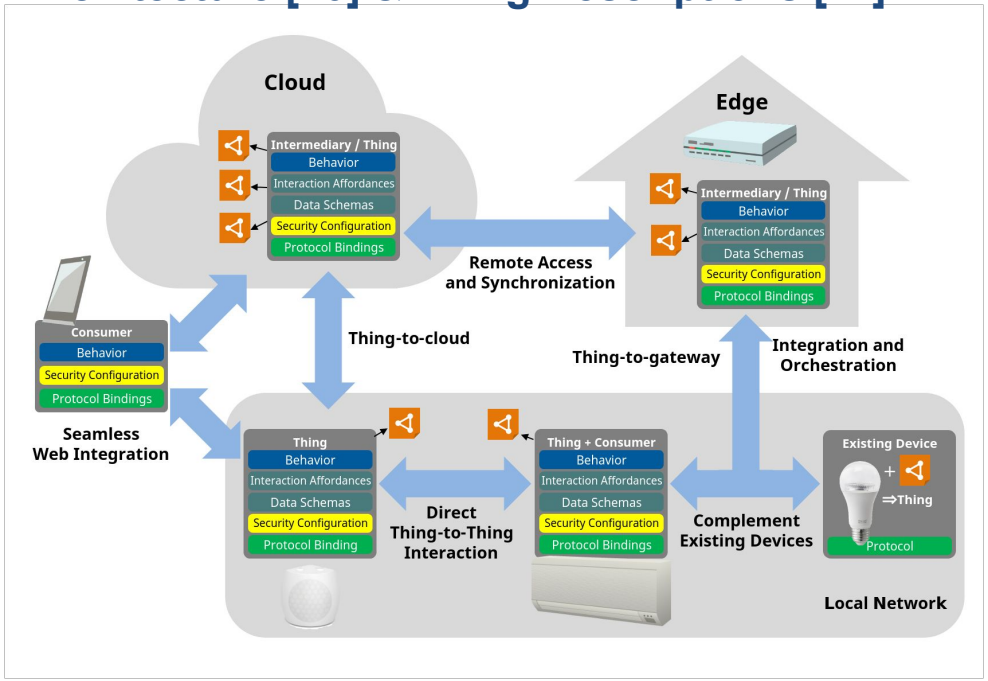
Mehmet Karatay (https://commons.wikimedia.org/wiki/File:Safari_ants.jpg) CC BY-SA 3.0

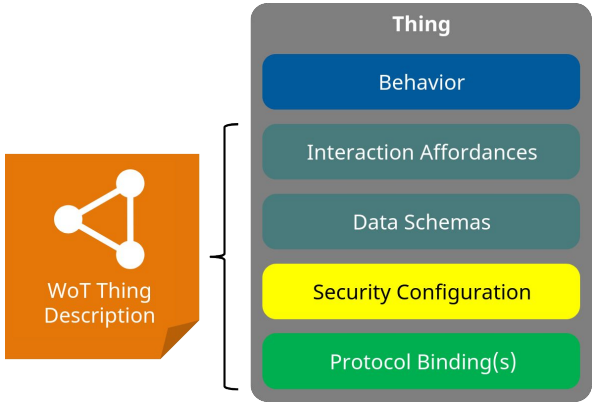
[8] Valckenaers, P., Kollingbaum, M., Van Brussel, H., et al.: Multi-agent coordination and control using stigmergy. Computers in industry 53(1), 75–96 (2004)

[9] Russell, S., Norvig, P.: Artificial intelligence: a modern approach (2002)

Web of Things

Architecture [10] & Thing Descriptions [11]





[10] Kovatsch, M., Matsukura, R., Lagally, M., Kawaguchi, T., Toumura, K., Kajimoto, K. (2020). Web of Things (WoT) Architecture. *W3C Recommendation*, *W3C*.

[11] Kovatsch, M., McCool, M., Käbisch, S., Kamiya, T., Charpenay, V. (2020) Web of Things (WoT) Thing description. W3C recommendation, W3C.

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3. Problem Statement and Research Questions

Problem Statement

We propose that

- the Semantic Web is a well-suited integration mechanism for Web Agents, Multi-Agents Systems and the Web of Things.
- it is not sufficient to just build interfaces between existing Multi-Agent Systems frameworks, Internet of Things platforms and the Semantic Web.
- instead: Both fields (MAS & IoT) should be integrated tightly into the application architecture of the Semantic Web to be more useful.

Research Questions

1. How can Multi-Agent Systems in the Semantic Web solve a given problem as fast as a classical Multi-Agent implementation while strictly adhering to the REST constraints?
2. What extensions to WoT Thing Descriptions and what constraints for the design of WoT Thing Descriptions help Multi-Agent Systems in the Semantic Web to solve a given problem faster?

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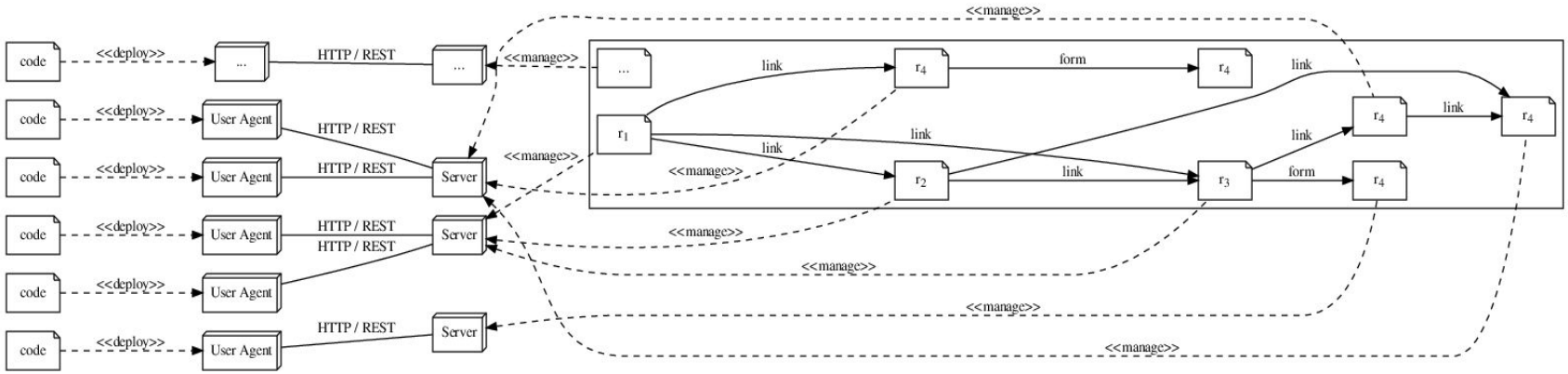
4. Approaches

Artifacts and Things as Web Resources

- Agents: Proactive entities following their goal
- Artifacts: Reactive entities providing functions to the agents
- WoT Things: Abstractions of physical or virtual entities
- Web Resources: Digital, physical, or abstract thing identifiable by a URI

Agents ↔ Web User Agents

Artifacts ↔ WoT Things ↔ Web Resources



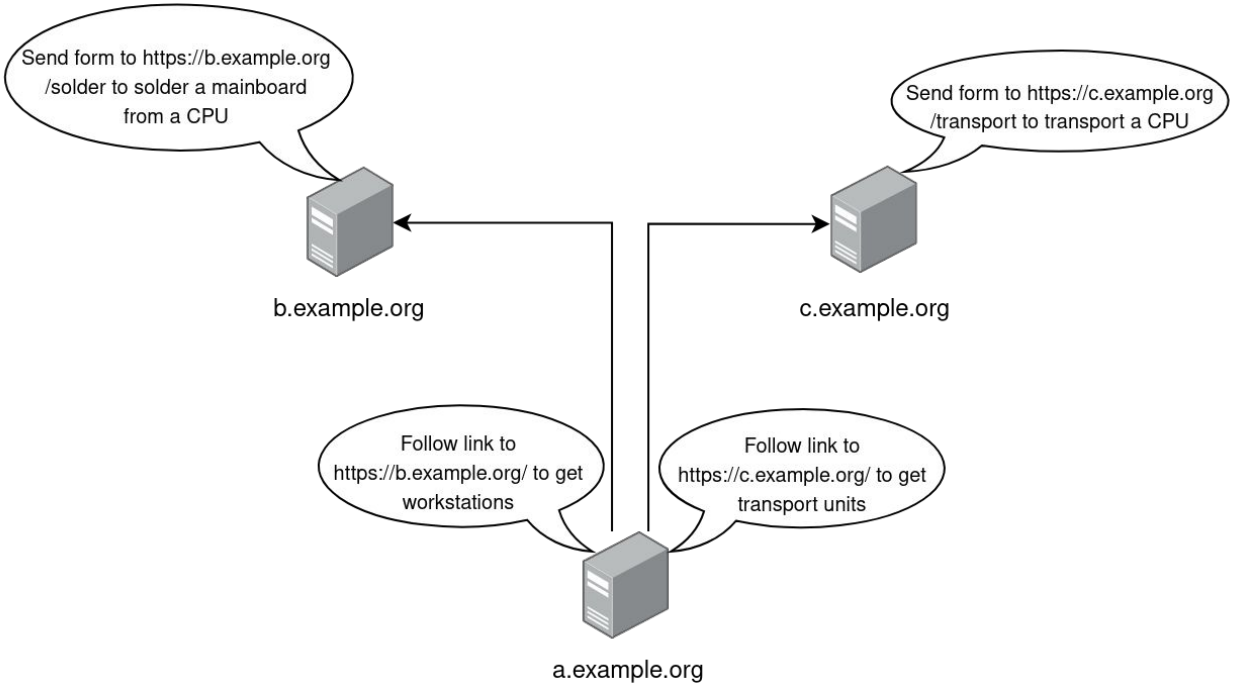
Aligning Stigmergy and REST

Stigmergy and REST fit together very well:

- Client-Server Architecture: Allowing agents to only directly communicate with artifacts brings a clear separation between clients (agents) and servers (artifacts). Clients can manipulate the state of the servers but not of each other (only indirectly by writing and reading something to resp. from a server).
- Statelessness: Stateless communication between agent and artifact is much easier to achieve than between agent and agent. Each artifact has a distinct resource state that is shared among all agents and thus communication with the artifact can be stateless. Communication between two agents in contrast will depend on the current context of the agents.
- ...

Hypermedia Affordances & Decentralized Planning

An offer to act by an artifact to an individual agent using Hyperlinks and -forms.



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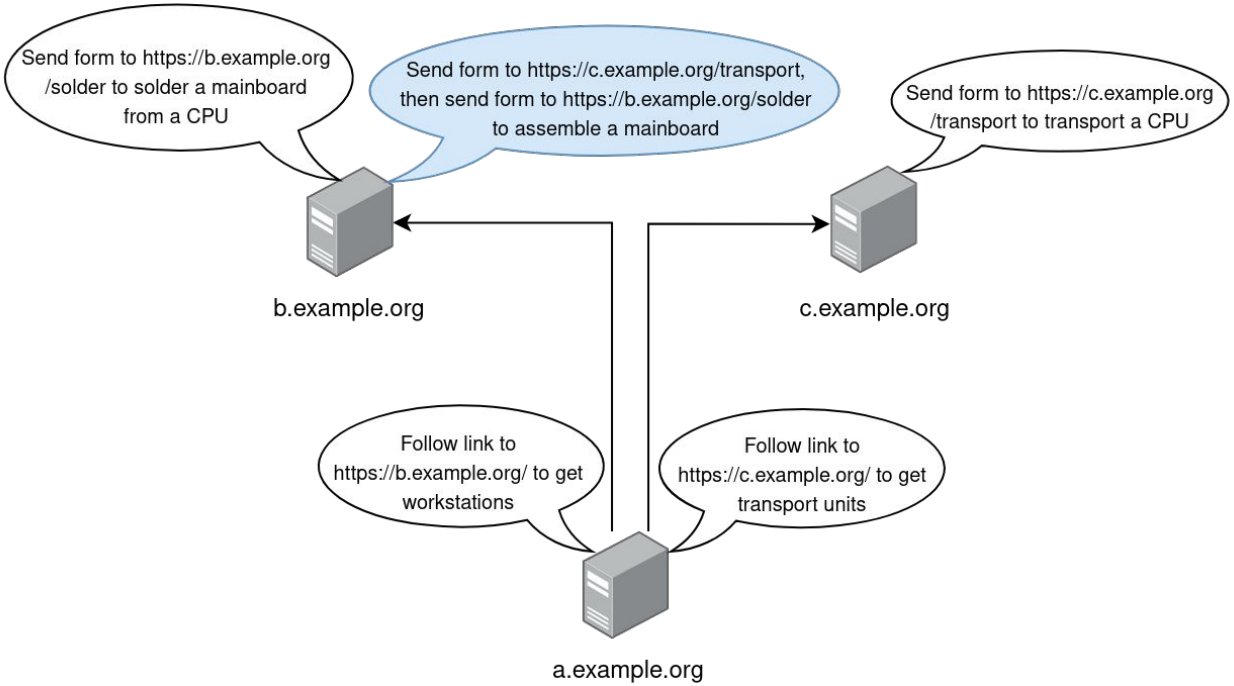

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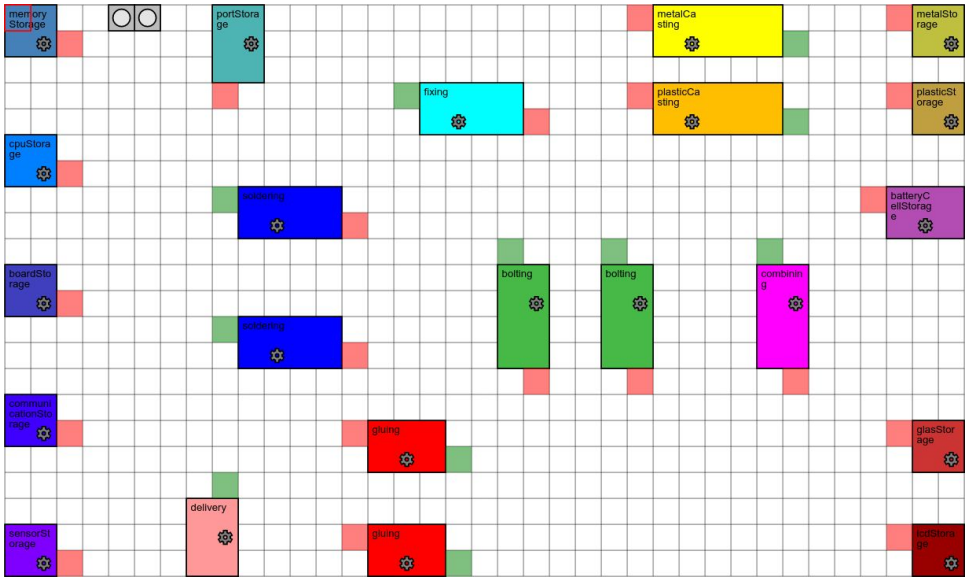
5. Evaluation Plan

Modular Smartphone Manufacturing Scenario

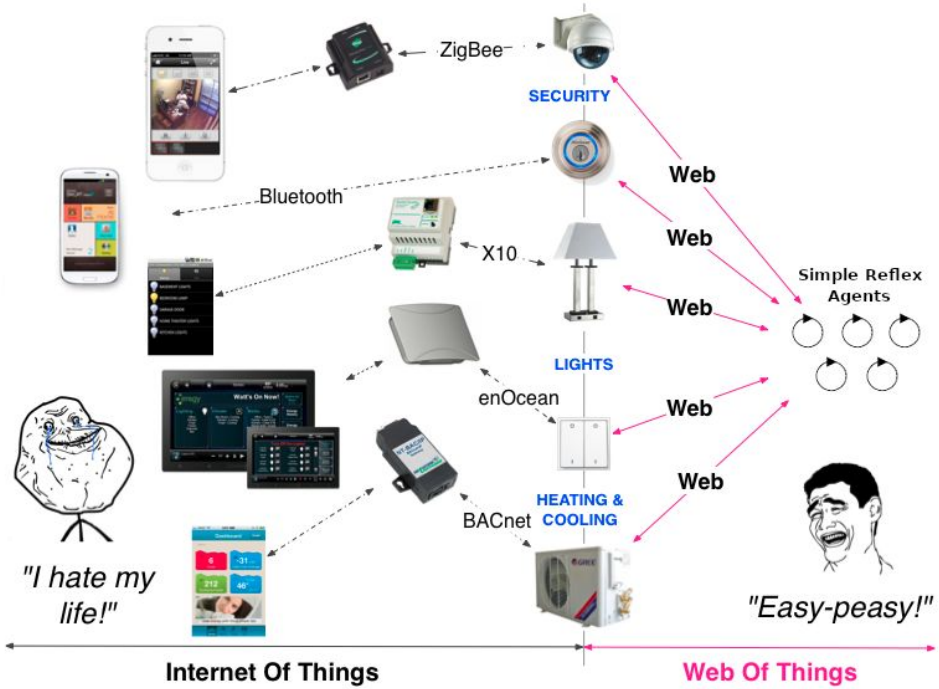
- A shop floor can assemble individualized modular smartphones from a lot of different parts.
- Parts are processed by different stations and transported between them using transporters.
- The environment will suffer from sporadic disturbances (e. g. machine breakdown).
- Task: Control the system to have a minimal time to completion!

Also see my demo at the Poster & Demo session!



Smart Home Scenario

- Multiple IoT devices in a smart home environment are addressable over smart sensor protocols (e. g. Bluetooth Low Energy, Zigbee).
- Agents can control those devices over a Semantic Web infrastructure and collaborate to achieve a certain goal (e. g. to minimize the overall energy consumption while fulfilling a certain task).



Building the Web of Things: book.webofthings.io (modified)
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6. Preliminary Results & Conclusion

Preliminary Results

We already have successfully shown that it is possible to use simple reflex agents in a Semantic Web environment to drive a simple manufacturing use case by using stigmergy [12].

Conclusion

We want to contribute to integrating the fields of Multi-Agent Systems, Internet of Things and the Semantic Web by investigating how to build a MAS that

- is tightly integrated into the application layer of the Semantic Web by using stigmergy and simple reflex agents.
- integrates Things from the IoT as artifacts and Web resources into this system.
- lets artifacts advertise their affordances through hypermedia enabling agent to take intelligent decisions.

[12] Schraudner, D., Charpenay, V.: An http/rdf-based agent infrastructure for manufacturing using stigmergy. In: European Semantic Web Conference. pp. 197–202. Springer (2020)