The Spirits of Web of Things Past, Present, and Yet to Come

Matthias Kovatsch, Summer School on AI for Industry 4.0, 27 Jul 2020

Dr. Matthias Kovatsch

Principal Researcher

Education

- 2003 – 2008 Dipl.-Ing., FAU Erlangen-Nürnberg, Germany
- 2009 – 2014 Dr. sc., ETH Zurich, Switzerland

Work Experience

- 2006 – 2009 Working Student, Fraunhofer IIS, Germany
- 2011 ~ 2015 Visiting Researcher, RISE SICS, Sweden (multiple visits)
- 2014 – 2015 Visiting Researcher, Samsung Electronics, South Korea
- 2016 – 2018 Senior Research Scientist, Siemens AG, Germany
- 2019 – now Principal Researcher, Huawei Technologies, Germany

Roles

- Eclipse IoT Working Group Member (inactive)
- IETF IoT Directorate Member
- W3C Web of Things Interest Group & Working Group Co-Chair (inactive)
- OPC Foundation Field Level Communication Initiative Steering Committee Member

Projects

- Eclipse Thingweb (node-wot)
- Eclipse Californium
- Contiki Erbium
- Firefox Copper (deprecated)

The Spirits of Web of Things

Past

- Web Presences
- Putting Things to REST
- Constrained RESTful Environments

Present

- W3C Standardization
- Thing Description
- node-wot

Yet to Come

- More Bindings
- More Semantics
- Better Actions

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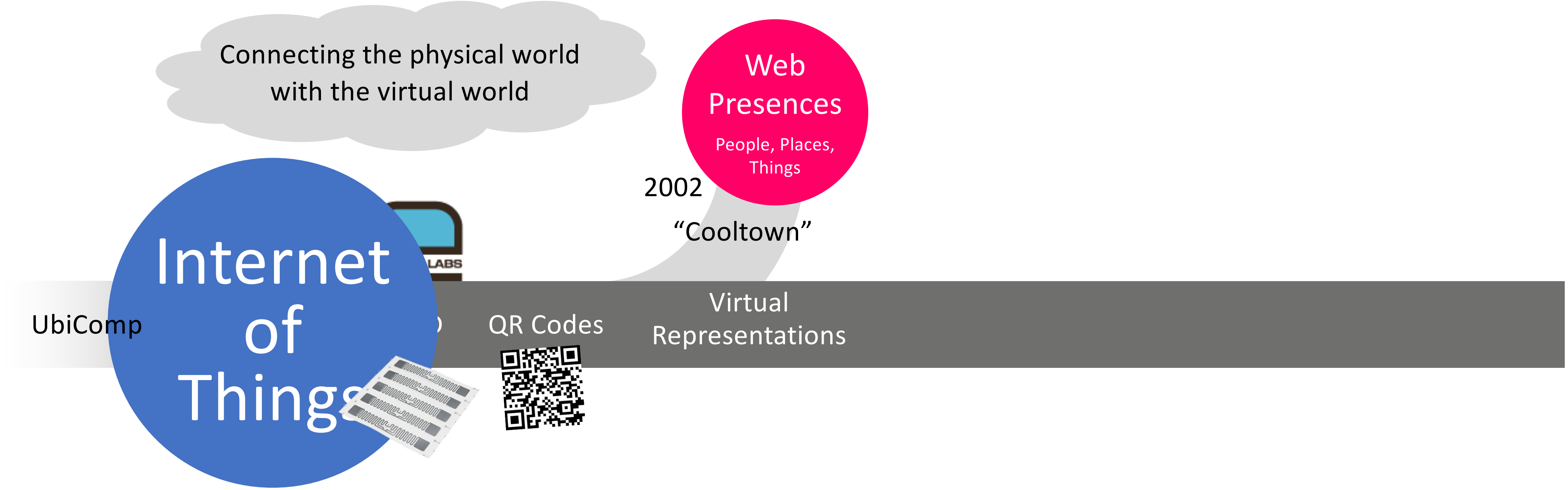
A Little History



Connecting the physical world with the virtual world

UbiComp

Internet of Things

QR Codes

2002

“Cooltown”

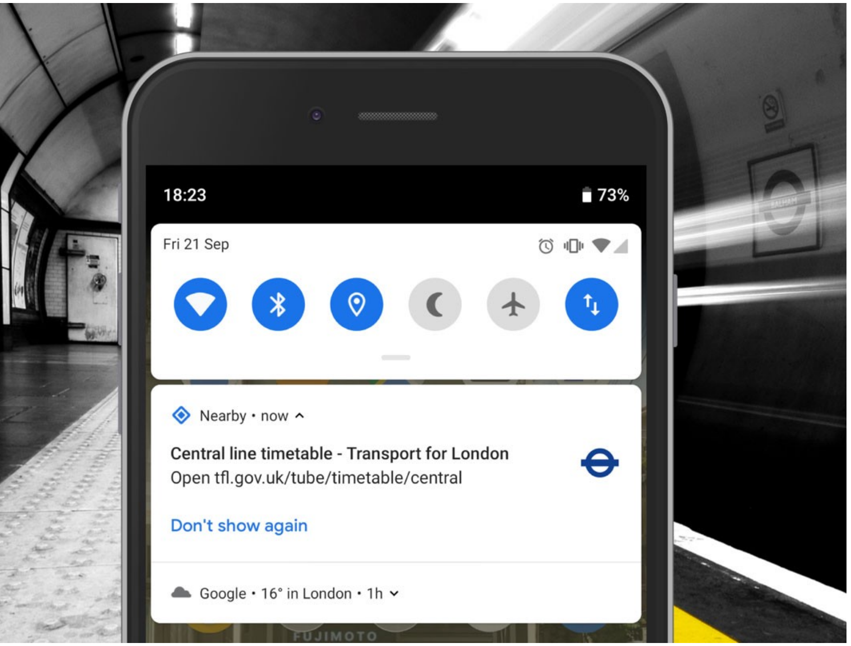
Web Presences

People, Places, Things

Virtual Representations

Web Presences for People, Places, Things

WoT Ideas from 2002 ... 2006


18:23
73%
Fri 21 Sep

Nearby • now

Central line timetable - Transport for London
Open tfl.gov.uk/tube/timetable/central

Don't show again

Google • 16° in London • 1h

Physical Web: URIs via BLE beacon

Kindberg et al. “People, places, things: Web presence for the real world.” Mobile Networks and Applications 7(5):365-76. Oct 2002
Rukzio et al. “Mobile Service Interaction with the Web of Things.” Proc. ICT 2006, Funchal, Madeira Island, Portugal, May 2006

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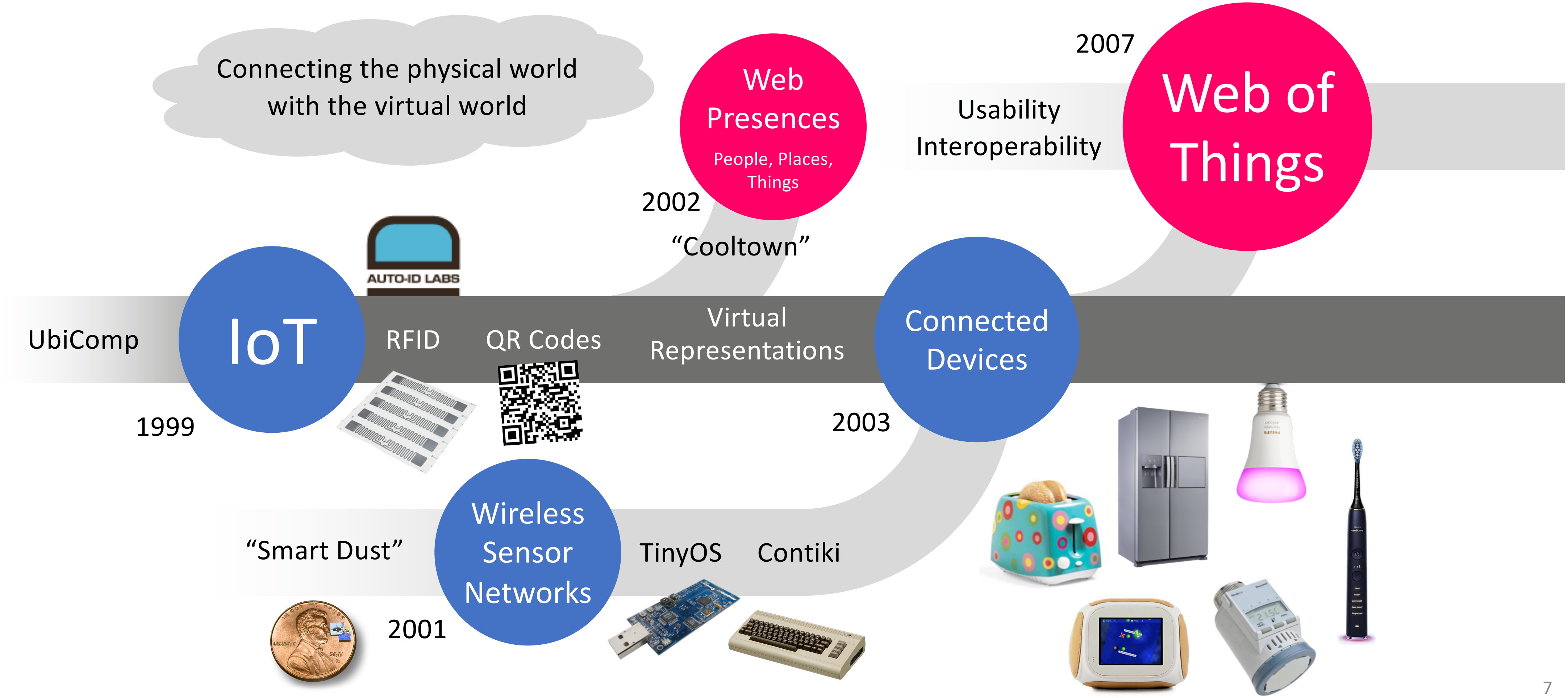


Connecting the physical world with the virtual world

UbiComp

IoT

1999

RFID

QR Codes

AUTO-ID LABS

"Smart Dust"

Wireless Sensor Networks

2001

TinyOS

Contiki

Virtual Representations

Web Presences

People, Places, Things

2002

"Cooltown"

Connected Devices

2003

Usability

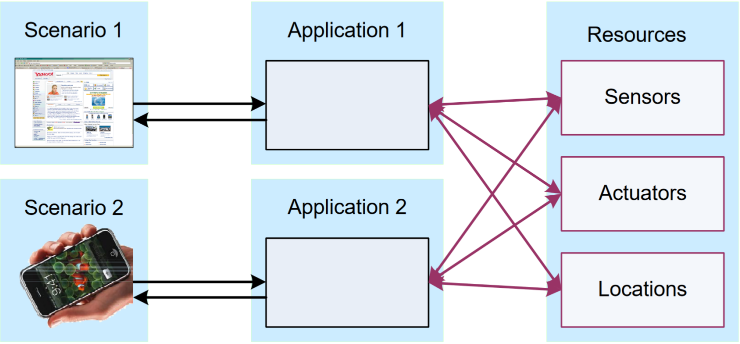
Interoperability

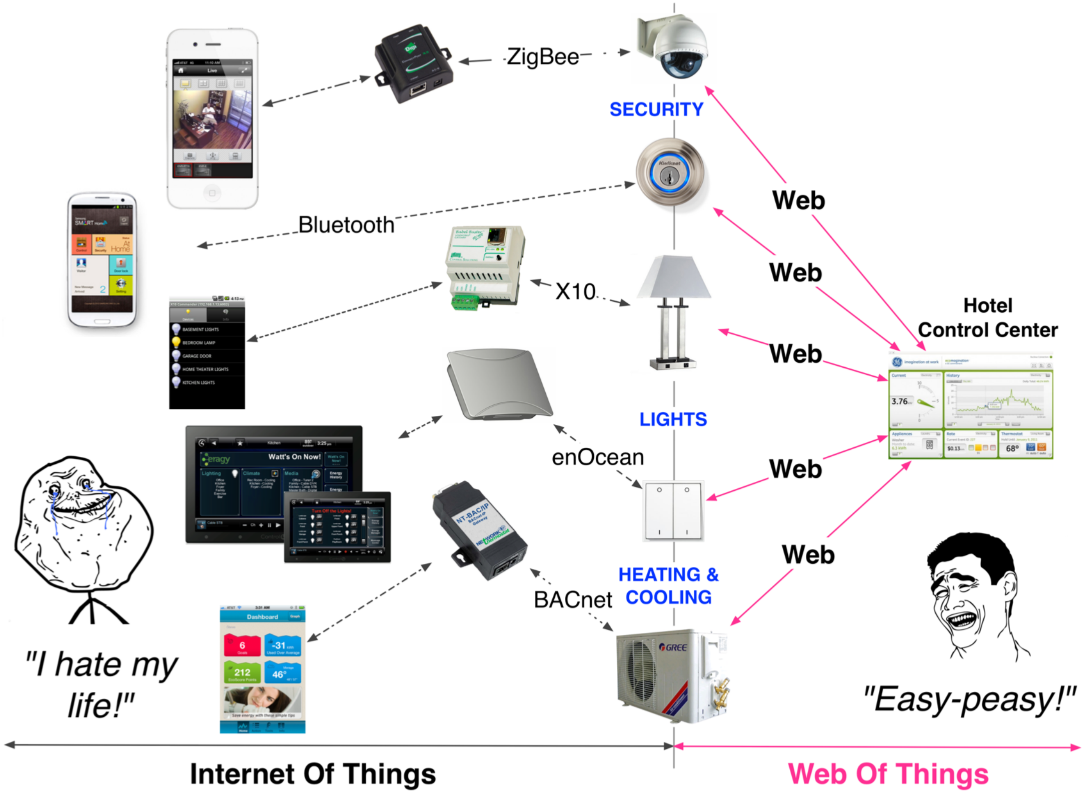
2007

Web of Things

Putting Things to REST – Towards WoT

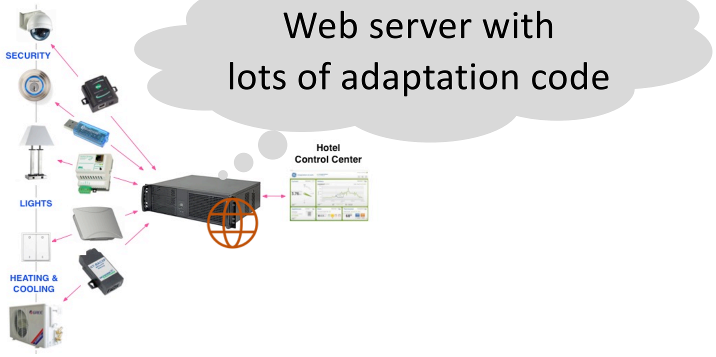
- Use Representational State Transfer, the architectural style of the Web, to communicate with Things
- Web resources allow loose coupling between devices and applications
- HTTP enables interoperability and libraries available for most platforms



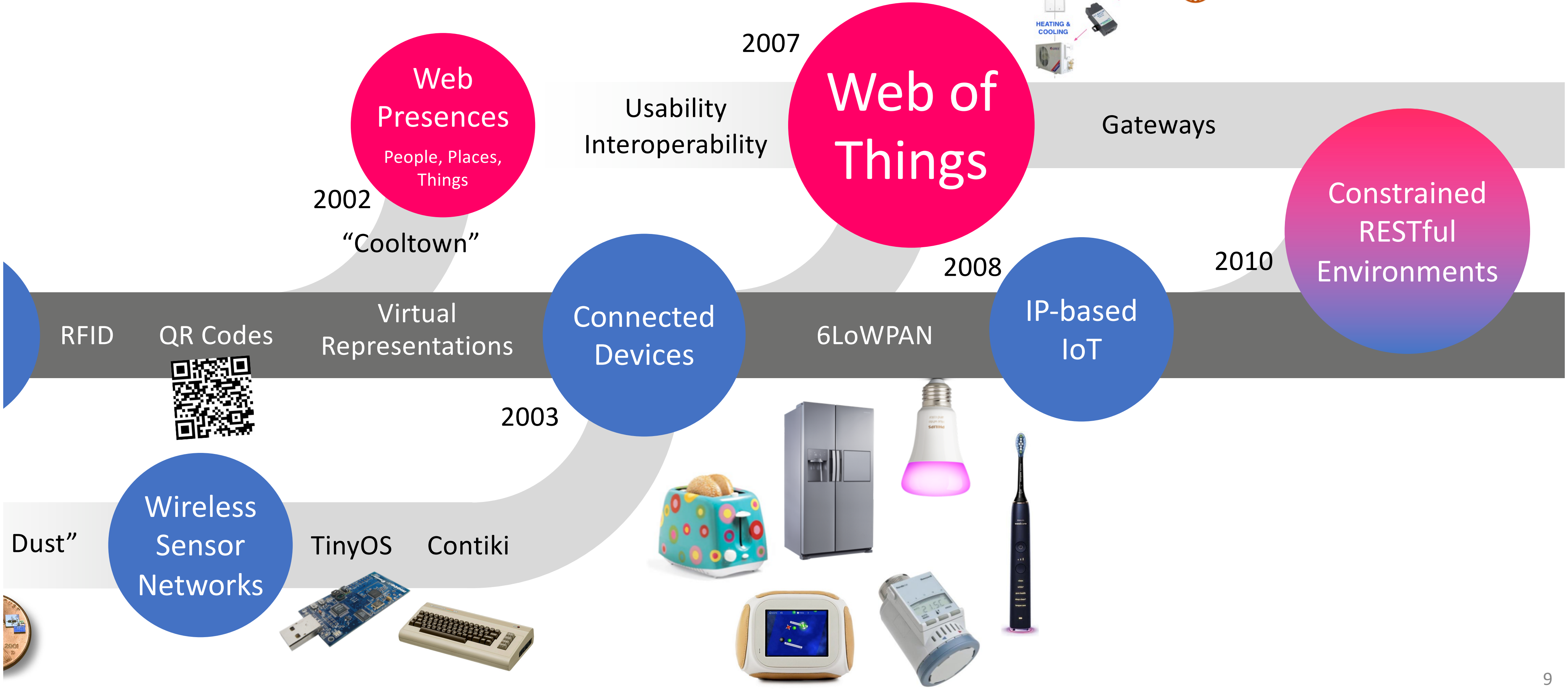


Wilde. Putting Things to REST. UCB iSchool Report 2007-015. Nov 2007
Guinard,Trifa. Building the Web of Things. Manning Publications. Jun 2016

A Little History



Web server with
lots of adaptation code



2002

Web Presences

People, Places, Things

“Cooltown”

Usability
Interoperability

2007

Web of Things

Gateways

2010

Constrained RESTful Environments

RFID

QR Codes

Virtual Representations

2003

Connected Devices

6LoWPAN

2008

IP-based IoT

Dust”

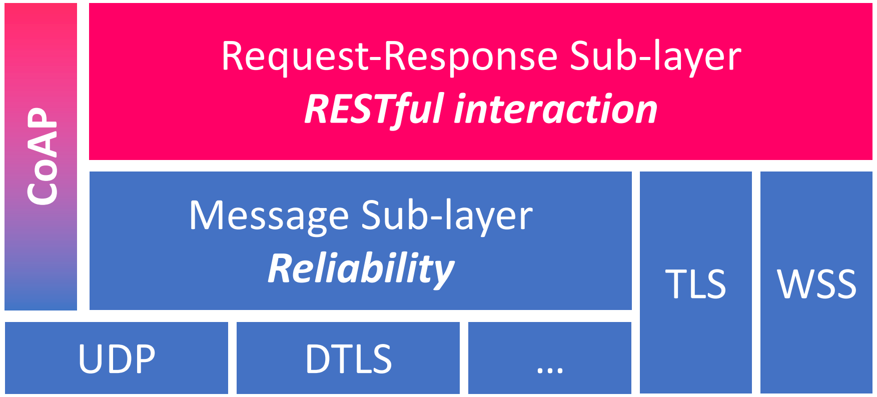
Wireless Sensor Networks

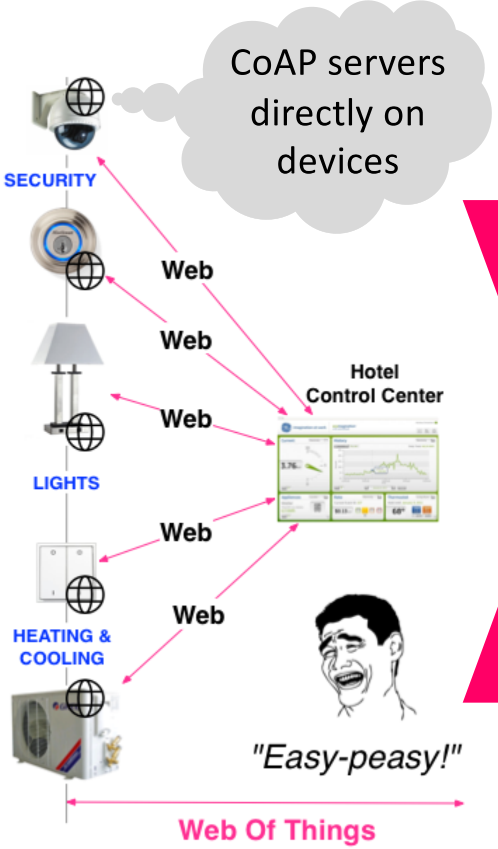
TinyOS

Contiki

Constrained Application Protocol (CoAP)

- New Web protocol for low-power networks and resource-constrained devices
- Designed from scratch following the REST architectural style
- Transparent mapping to HTTP
- Additional features for IoT applications





OPEN CONNECTIVITY FOUNDATION®

zigbee

dotdot

LightweightM2M
specified at oma

Fairhair Alliance

Shelby, Hartke, Bormann. “The Constrained Application Protocol (CoAP).” RFC 7252. Jun 2014

Why the Web?

- Internet of Things
  - Domain expertise
  - Embedded developers
  - Optimized protocols and formats
    - Silos with high integration costs

in Profiles
336,951

- World Wide Web
  - Interoperability and usability
  - Web developers
  - HTTP, JSON, scripting
    - Application mashups

in Profiles
4,450,002

- Web of Things
  - Take patterns that worked for the Web
  - Adapt and apply them to the IoT

Expedia
PayPal
Nemea Appart'hotel - Biot
45 Rue Henri Poincare - Accès 17, (Avenue Roumanille), Biot, Alpes-Maritimes, 06410, Frankreich, 069-945 192 395
Gehe zu: Überblick | Zimmerauswahl | Informationen zum Hotel
Zurück zu Suchergebnissen
Mo, 25. Januar 2016 - Do, 28. Januar 2016, 3 Nächte, 1 Zimmer, 1 Erwachsener
171 €
Preis für 3 Nächte
inkl. Steuern und Gebühren
Jetzt buchen
Bestpreisgarantie
Profilbild [1/21]
Gut
3,5 / 5
Von 70 Bewertungen
tripadvisor
AccuWeather
facebook
Teilen

But this an **AI** Summer School?!

Spirit of the Past: Digitalization

- All these technologies form the foundation to enable AI
  - Connected devices are required to collect the data for data-driven machine learning
  - Proper protocols and APIs are required to enable automated control and optimization
  - Developers are provided to carry out the digitalization at scale
- Digitalization allows to monitor and quantify processes in real-time
- “Industry 4.0” describes the digitalization of industries

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- More Semantics
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W3C Standardization Activity

W3C WoT Community Group (CG)

No charter needed

- Started summer 2013
- ~300 participants
- Free discussion (no membership needed)

- **W3C WoT Workshop, Berlin, 2014**
- Identify stakeholders for standards work

- Believe in benefits of Web technology for IoT
- Web standards are horizontal and neutral

W3C Standardization Activity

W3C WoT Interest Group (IG)

https://w3c.github.io/wot/charters/wot-ig-2019.html

- Started spring 2015
- ~200 participants
- Informal work, outreach

- Exploration of new building blocks
- “PlugFests” validation with running code
- “OpenDays” with also external speakers
- Liaisons and collaborations
  with other organizations and SDOs

W3C WoT Working Group (WG)

https://www.w3.org/2020/01/wot-wg-charter.html

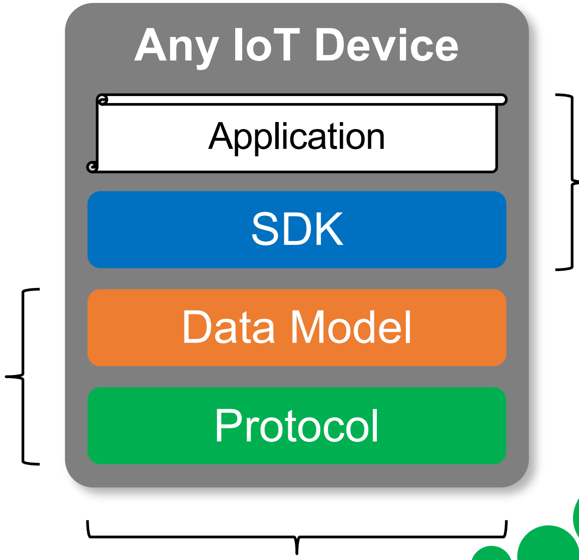
- Started end of 2016
- ~100 participants
- Normative work

- Work on deliverables
- W3C Patent Policy for royalty-free standards
- Only W3C Members and Invited Experts

Describe Existing IoT Ecosystems

Provide **semantic metadata** that uniformly describes how to interact with Things

Form an implicit interaction model, which is usually not well documented



Every SDK and library is different, so that application development is expensive

Define a **common runtime** similar to the Web browser to implement Thing behavior

Capture each protocol once in a uniform template that describes how to **configure protocol stacks** (e.g., CoAP or MQTT) to send the message expected by the Thing

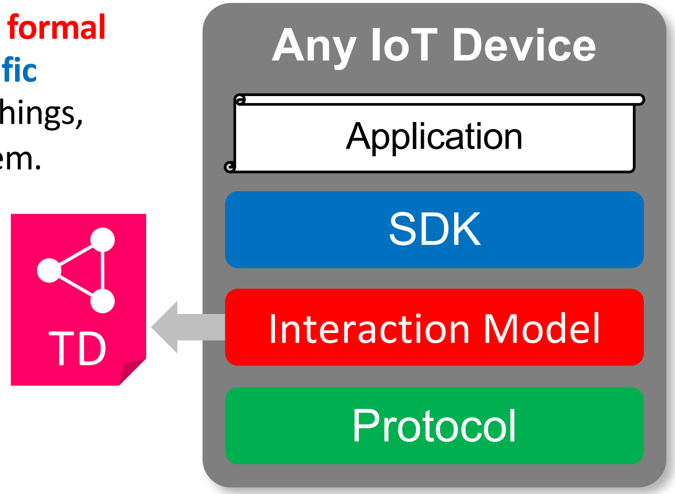
The IoT has a plethora of protocols,
often dialects due to custom options
for protocols such as HTTP, CoAP, MQTT, etc.

Describe Existing IoT Ecosystems

WoT Thing Description (TD)

JSON-LD representation format to describe Thing **instances** with metadata. Uses **formal interaction model** and **domain-specific vocabularies** to uniformly describe Things, their capabilities, and how to use them.

Define a **common runtime** similar to the Web browser to implement Thing behavior



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An ***index.html*** for Things

Properties

Actions

Events

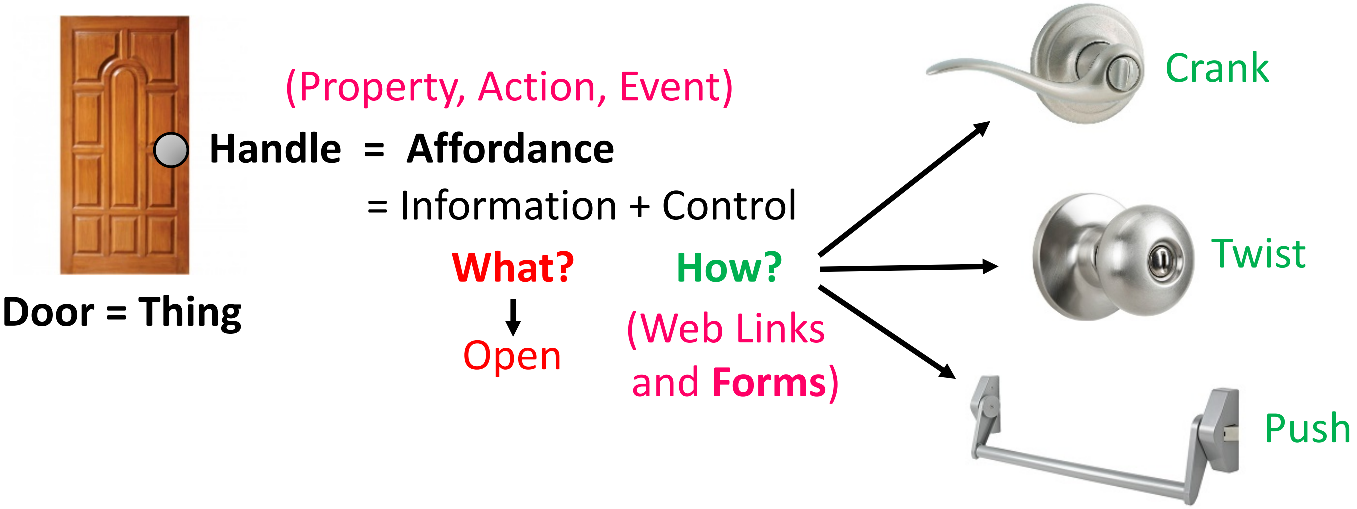
"Interaction Affordances"

The IoT has a plethora of protocols, often dialects due to custom options

Capture each protocol once in a uniform template that describes how to **configure protocol stacks** (e.g., CoAP or MQTT) to send the message expected by the Thing

Affordances

- “Affordance refers to the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used.”
  – Donald Norman on everyday things
- “… the simultaneous presentation of information and controls such that the information becomes the affordance through which the user obtains choices and selects actions.”
  – Roy Fielding on hypermedia



(Property, Action, Event)

Handle = Affordance

= Information + Control

What? ↓ Open

How? (Web Links and **Forms**)

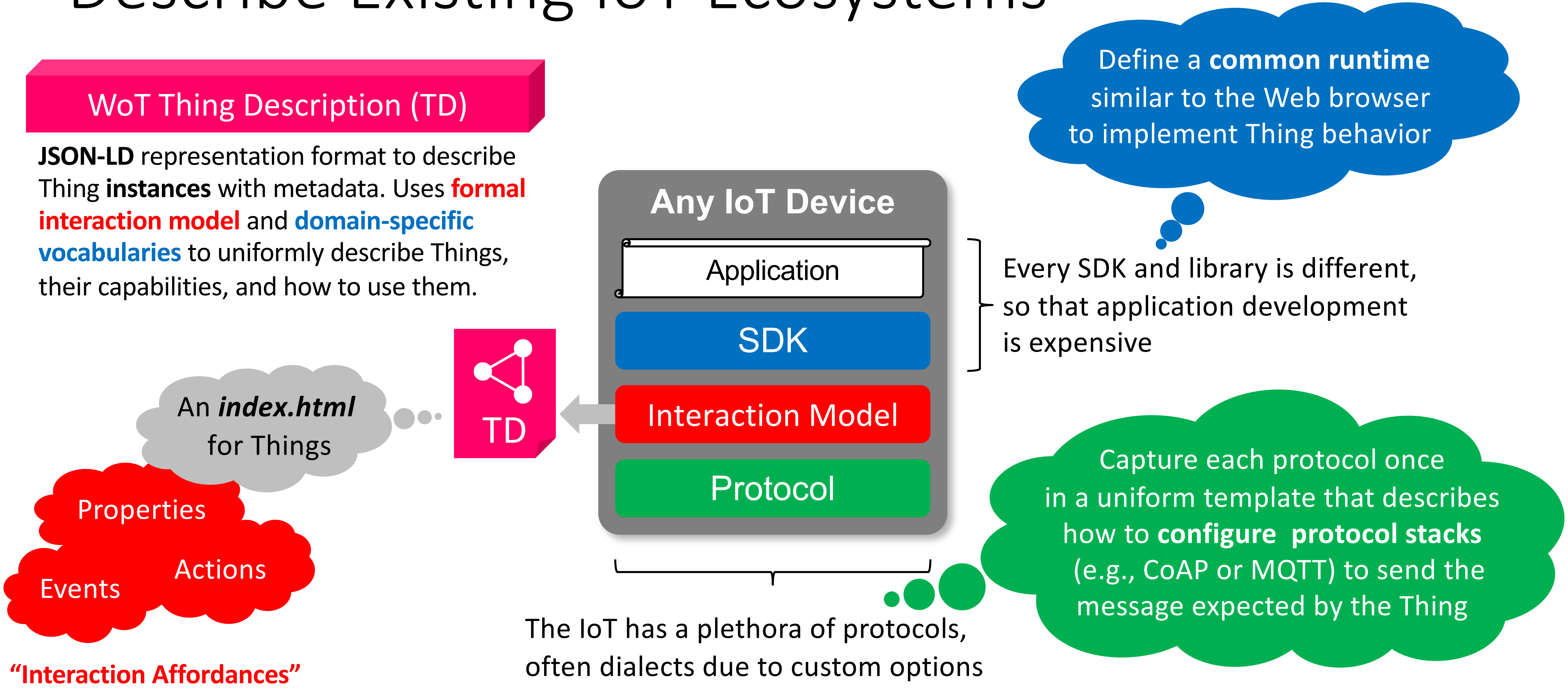
Door = Thing

Crank

Twist

Push

Describe Existing IoT Ecosystems



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Any IoT Device

Application

SDK

Interaction Model

Protocol

Every SDK and library is different, so that application development is expensive

TD

An ***index.html*** for Things

Properties

Actions

Events

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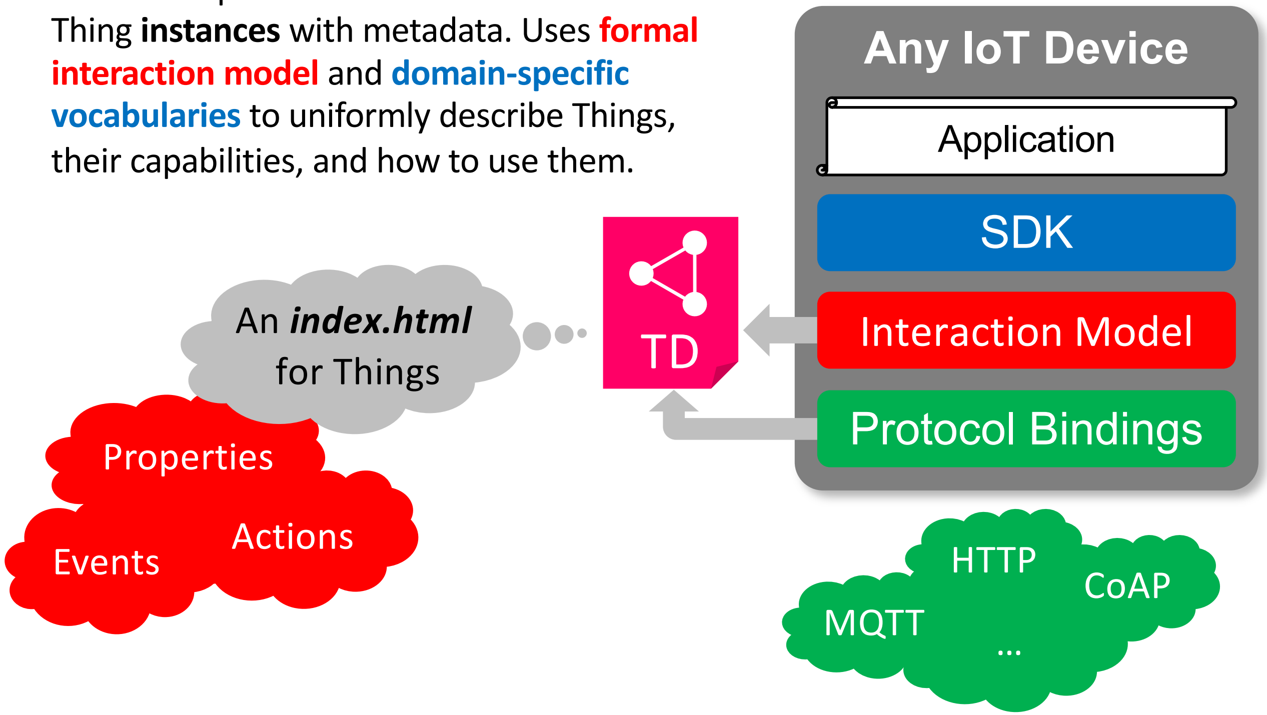

Every SDK and library is different, so that application development is expensive

WoT Binding Templates

Capture how the **formal Interaction Model** is mapped to concrete protocol operations (e.g., CoAP) and platform features (e.g., OCF). The templates are done once per ecosystem and require a vocabulary for each base protocol (e.g., HTTP in RDF).

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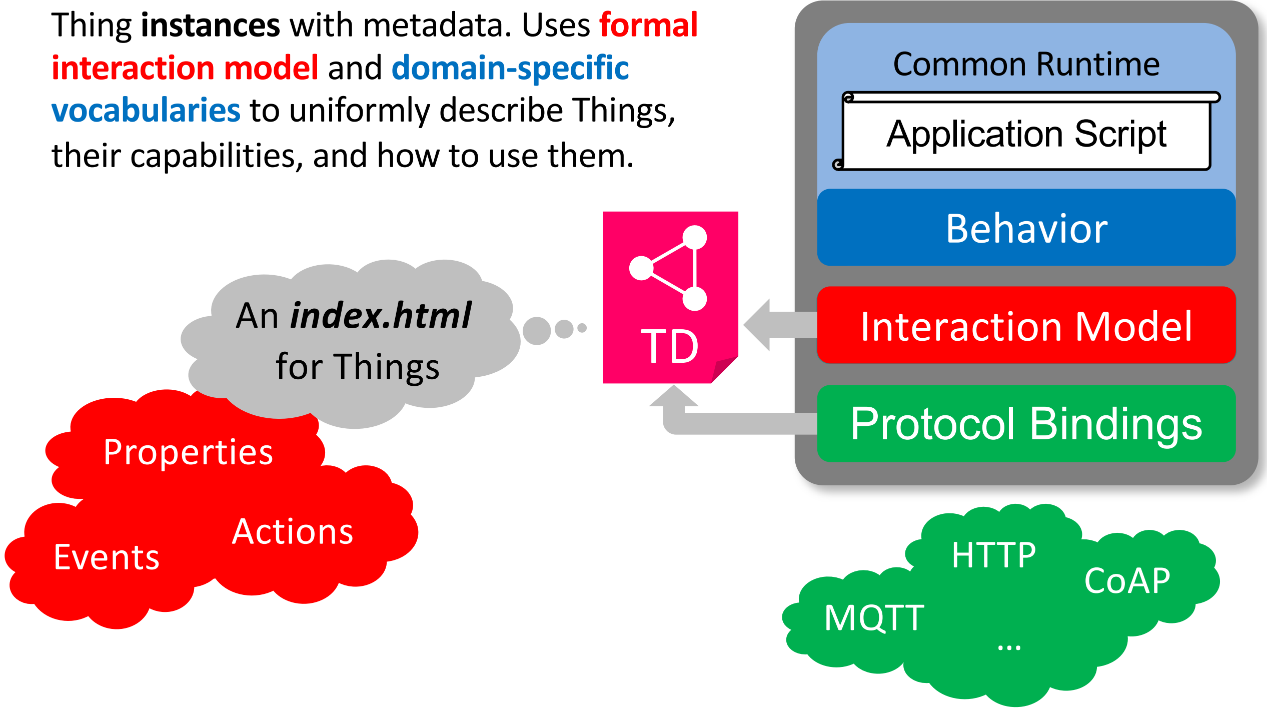

WoT Scripting API

Common **JavaScript** object API for an IoT runtime system **similar to the Web browser**. Enable **portable scripts** that implement the behavior of Things and Consume across different vendors, devices, and environments.
Behavior must also be identifiable through **domain-specific vocabulary terms**.

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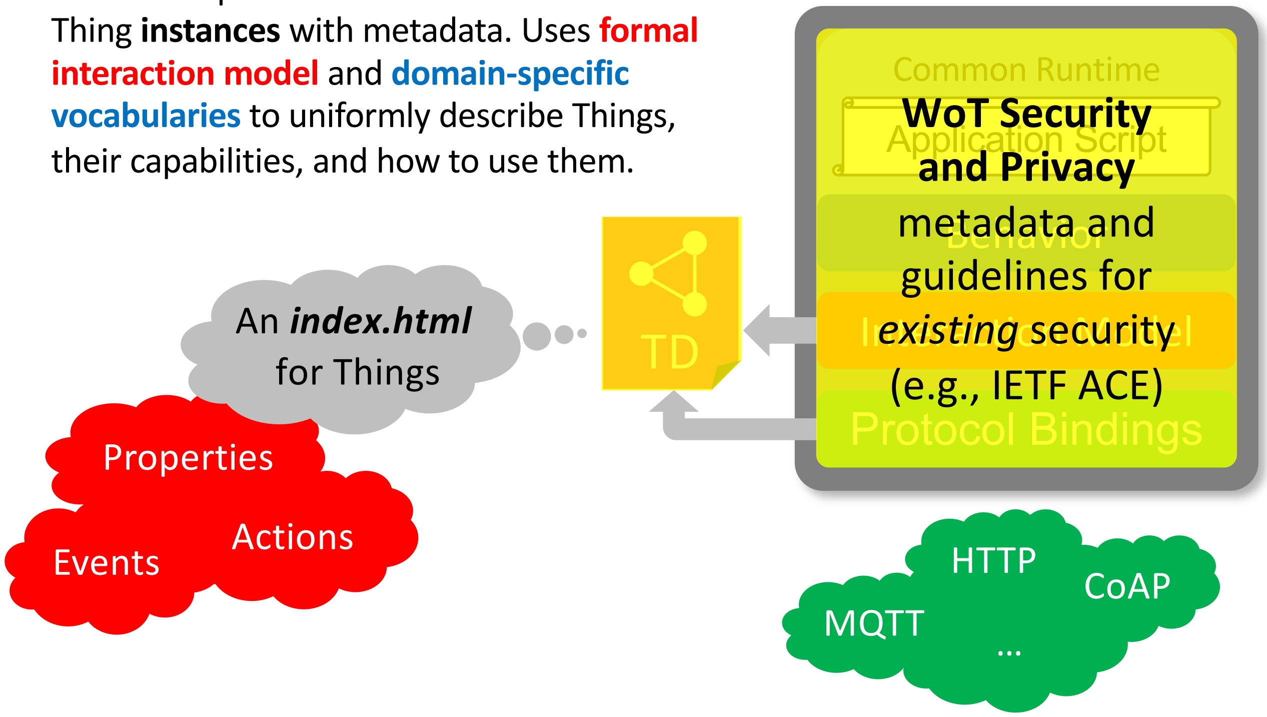

WoT Security and Privacy metadata and guidelines for *existing* security (e.g., IETF ACE)

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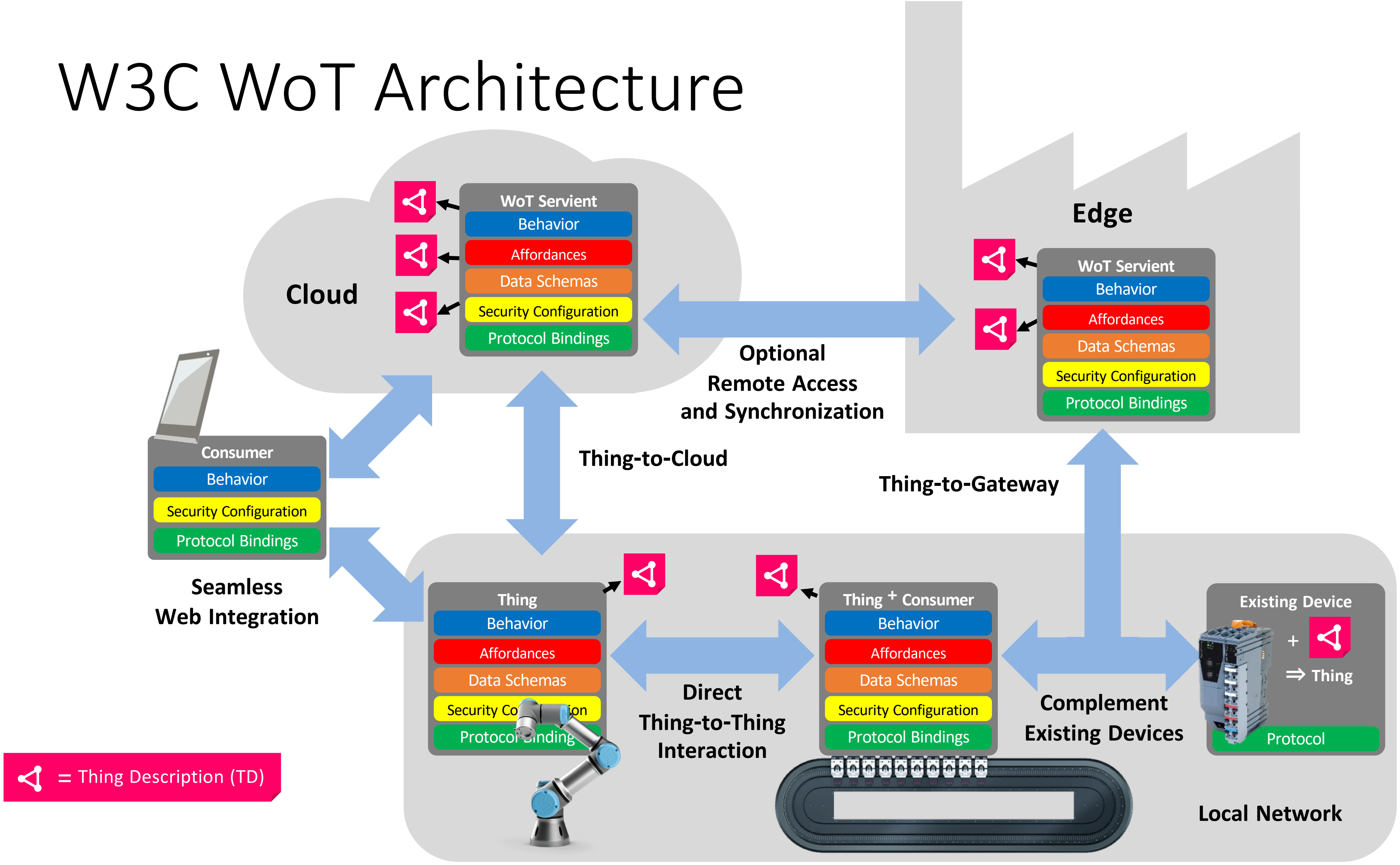
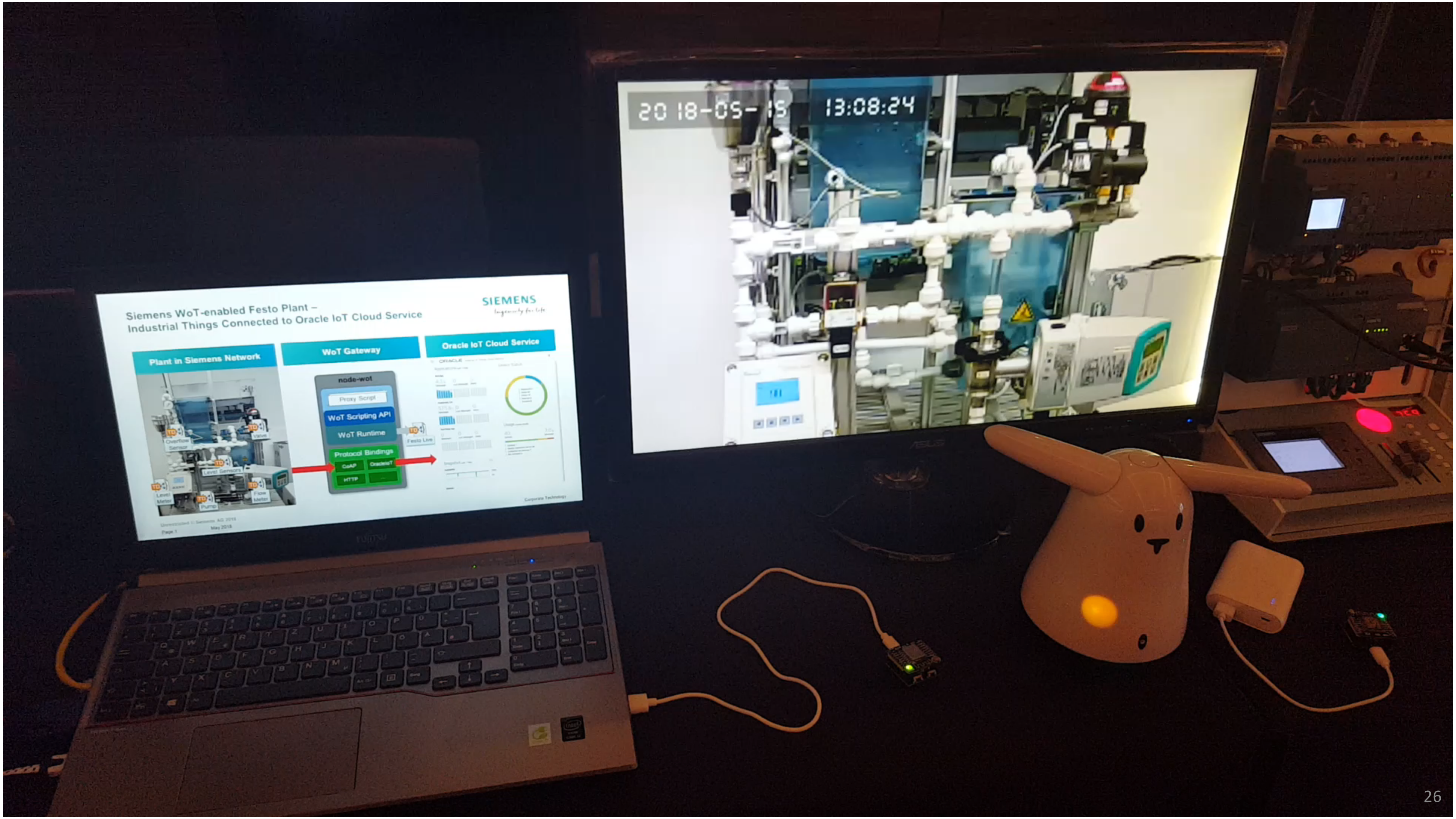
W3C WoT Architecture



SAMSUNG


Siemens WoT-enabled Festo Plant –
Industrial Things Connected to Oracle IoT Cloud Service
SIEMENS
Plant in Siemens Network
WoT Gateway
Oracle IoT Cloud Service
node-wot
Proxy Script
WoT Scripting API
WoT Runtime
Protocol Bindings
CoAP
OracleIoT
HTTP
...
Festo Live
Overflow Sensor
Valve
Level Sensors
Level Meter
Pump
Flow Meter
Corporate Technology
2018-05-15
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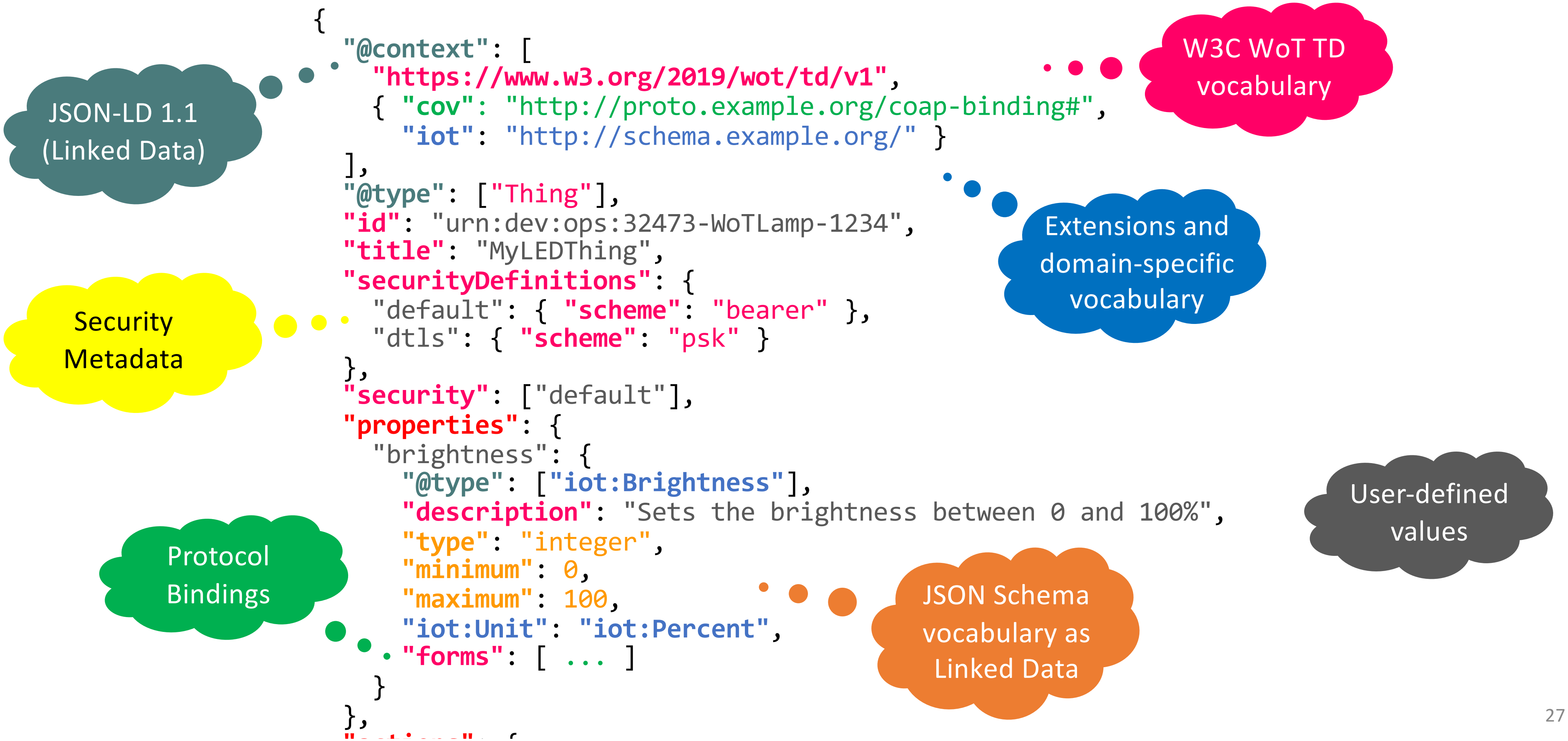
W3C WoT Thing Description



```
{
  "@context": [
    "https://www.w3.org/2019/wot/td/v1",
    { "cov": "http://proto.example.org/coap-binding#",
      "iot": "http://schema.example.org/" }
  ],
  "@type": ["Thing"],
  "id": "urn:dev:ops:32473-WoTLamp-1234",
  "title": "MyLEDThing",
  "securityDefinitions": {
    "default": { "scheme": "bearer" },
    "dtls": { "scheme": "psk" }
  },
  "security": ["default"],
  "properties": {
    "brightness": {
      "@type": ["iot:Brightness"],
      "description": "Sets the brightness between 0 and 100%",
      "type": "integer",
      "minimum": 0,
      "maximum": 100,
      "iot:Unit": "iot:Percent",
      "forms": [ ... ]
    }
  },
  "actions": {
```

JSON-LD 1.1 (Linked Data)

W3C WoT TD vocabulary

Extensions and domain-specific vocabulary

Security Metadata

User-defined values

Protocol Bindings

JSON Schema vocabulary as Linked Data

W3C WoT Thing Description

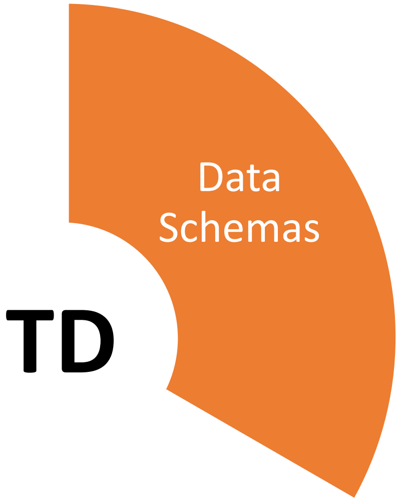
Like with HTML forms, the server/Thnig can tell the client/Consumer how to create a request

Basics to build the request

Deviation from defaults

```
...
"actions": {
  "fadeIn": {
    ...
    "forms": [
      { /// TD defaults: POST to invoke Action
        "href": "https://myled.example.com:8080/fadein",
        "mediaType": "application/json"
      },
      {
        "href": "coaps://myled.example.com:5684/on",
        "mediaType": "application/ocf+cbor",
        "cov:methodCode": 3, /// PUT instead of POST to invoke
        "cov:options": [{
          "cov:optionNumber": 2053, /// OCF-Content-Format-Version
          "cov:optionValue": "1.1.0"
        }]
      }
    ]
  },
  "fadeOut": {
    ...
    "forms": [
      {
        "href": "https://myled.example.com:8080/fadeout",
        "mediaType": "application/json"
```

Combining Existing Standards



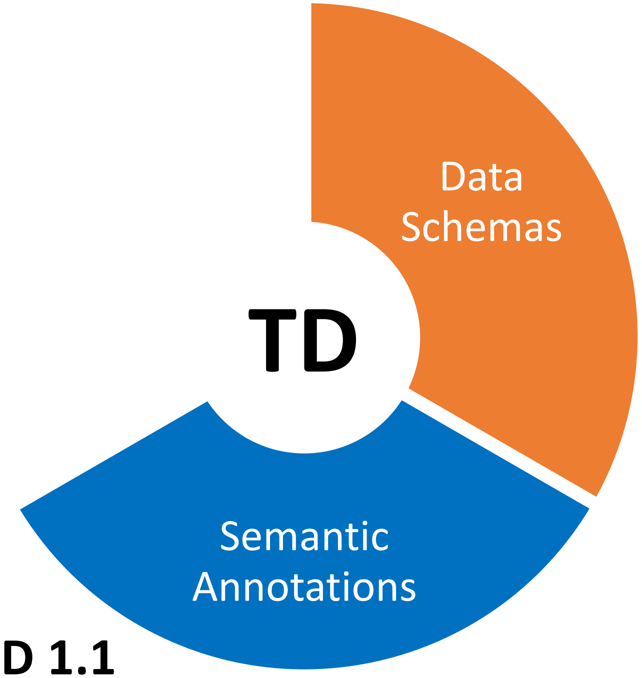
JSON Schema

Description of existing data formats

Validation of payloads through available implementations

Already in use by industry, e.g., OpenAPI (microservices), Open Connectivity Foundation

Combining Existing Standards



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JSON-LD 1.1

Semantic meaning through controlled vocabularies enables interoperability

Reasoning through ontologies makes TDs machine-understandable

Knowledge Graphs interlink TDs with all related information

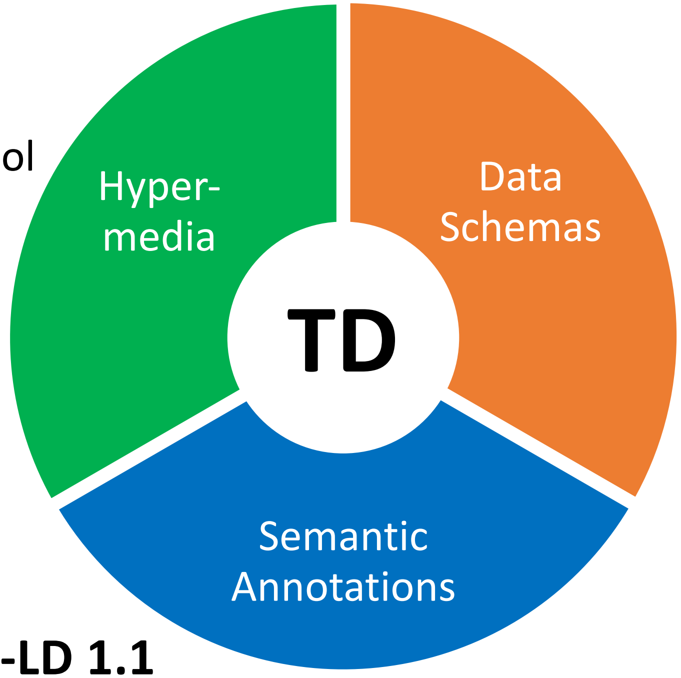
Combining Existing Standards

Web Links and Forms

Uniform REST interface describes how to interact given an IoT protocol such as HTTP and CoAP, but also MQTT, Modbus, UA Binary, etc.

URIs encode the IoT protocol and target address in a simple string

Media Types identify the payload format (e.g., `application/json`)



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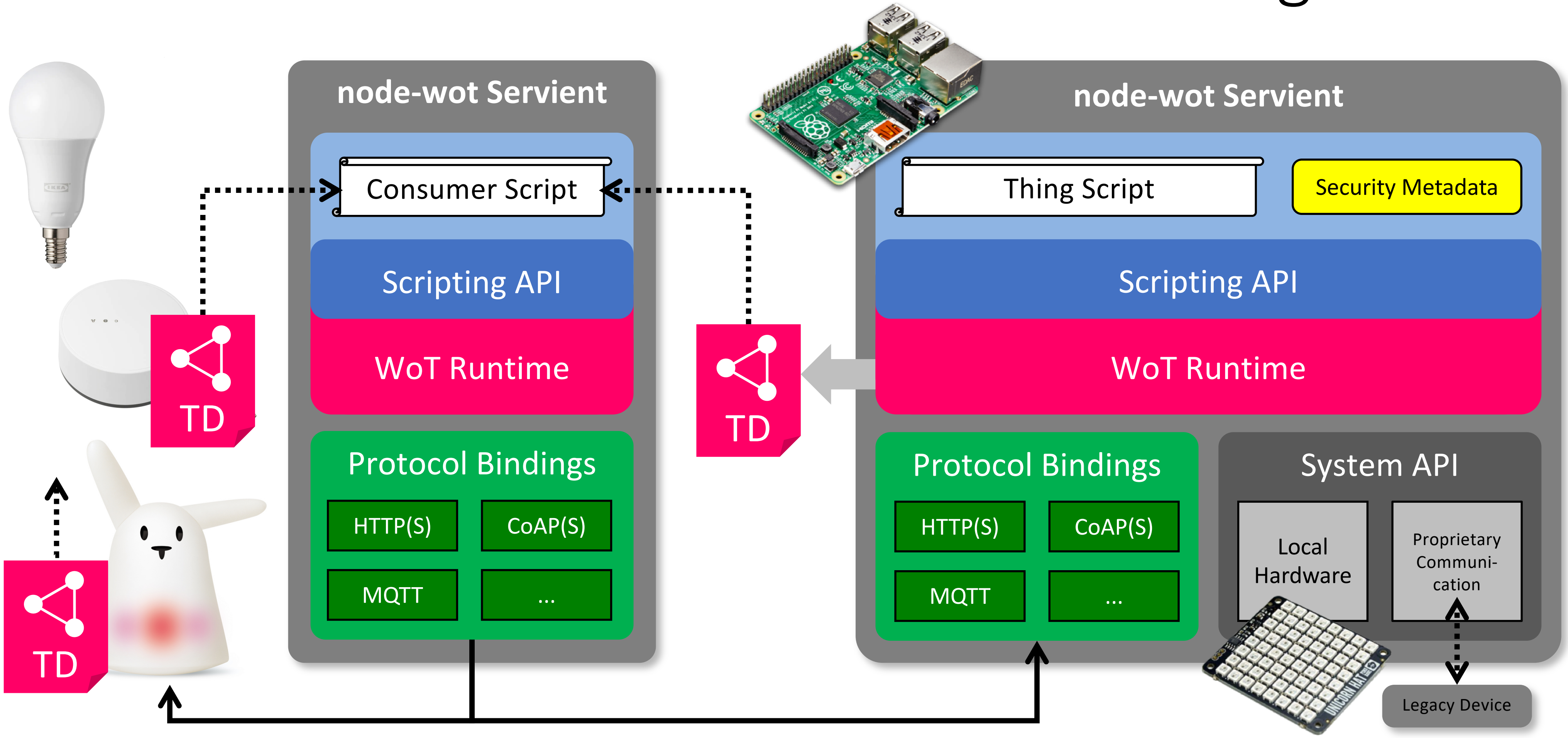
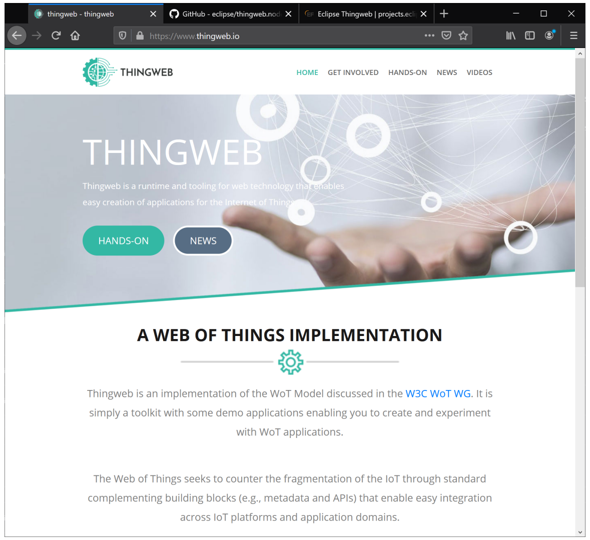
node-wot: Build Your Own Web of Things



Eclipse Thingweb: node-wot & more



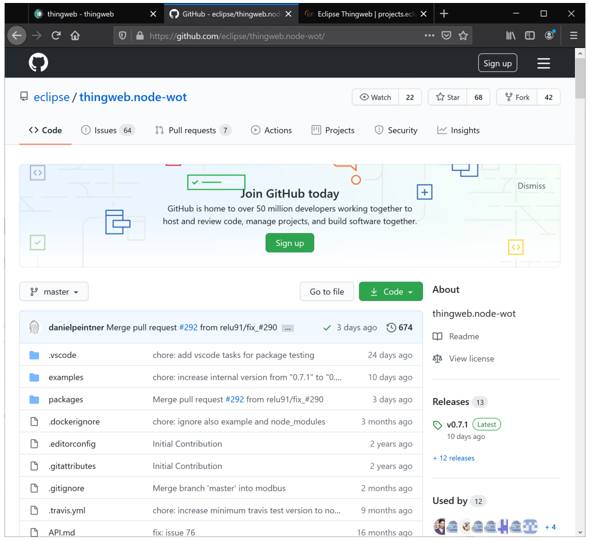
THINGWEB

Thingweb is a runtime and tooling for web technology that enables easy creation of applications for the Internet of Things

A WEB OF THINGS IMPLEMENTATION

Thingweb is an implementation of the WoT Model discussed in the W3C WoT WG. It is simply a toolkit with some demo applications enabling you to create and experiment with WoT applications.

The Web of Things seeks to counter the fragmentation of the IoT through standard complementing building blocks (e.g., metadata and APIs) that enable easy integration across IoT platforms and application domains.



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GitHub is home to over 50 million developers working together to host and review code, manage projects, and build software together.

danielpeintner Merge pull request #292 from relu91/fix_#290 … ✓ 3 days ago 674

.vscode	chore: add vscode tasks for package testing	24 days ago
examples	chore: increase internal version from "0.7.1" to "0.…	10 days ago
packages	Merge pull request #292 from relu91/fix_#290	3 days ago
.dockerignore	chore: ignore also example and node_modules	3 months ago
.editorconfig	Initial Contribution	2 years ago
.gitattributes	Initial Contribution	2 years ago
.gitignore	Merge branch 'master' into modbus	2 months ago
.travis.yml	chore: increase minimum travis test version to no…	9 months ago
API.md	fix: issue 76	16 months ago

About

thingweb.node-wot

Readme

View license

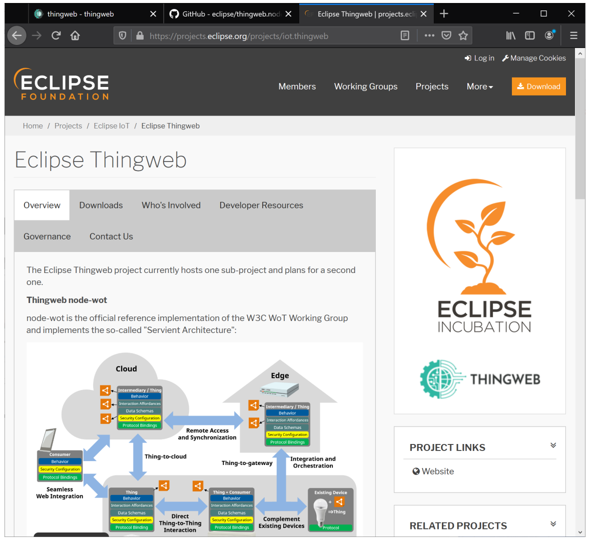
Releases 13

v0.7.1 Latest
10 days ago

+ 12 releases

Used by 12

+ 4



Eclipse Thingweb

The Eclipse Thingweb project currently hosts one sub-project and plans for a second one.

Thingweb node-wot

node-wot is the official reference implementation of the W3C WoT Working Group and implements the so-called "Servient Architecture":

https://www.thingweb.io/

https://github.com/eclipse/thingweb.node-wot/

https://projects.eclipse.org/projects/iot.thingweb

Spirit of the Present: Semantic Interoperability

- Independent digitalization led to various siloed ecosystems
  - Custom protocols and data models form implicit interaction models
  - High integration costs to access and harmonize data
  - Documentation usually for human readers only
- W3C WoT aims at breaking up the silos for interoperability in the IoT and at making interactions and data machine-understandable through semantic annotations

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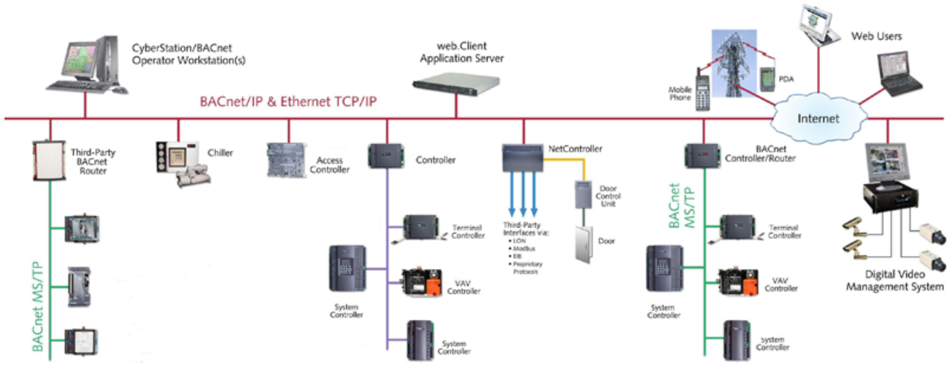
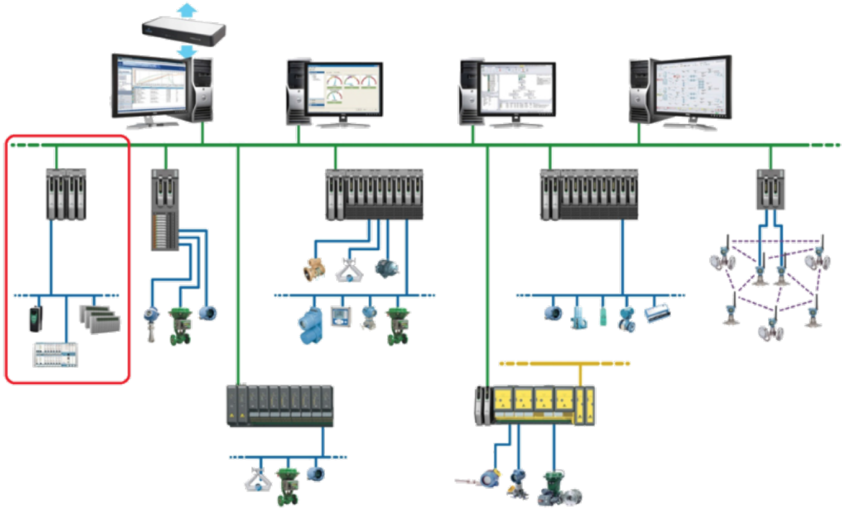
Industrial Protocol Bindings

Industrial IoT Ecosystems





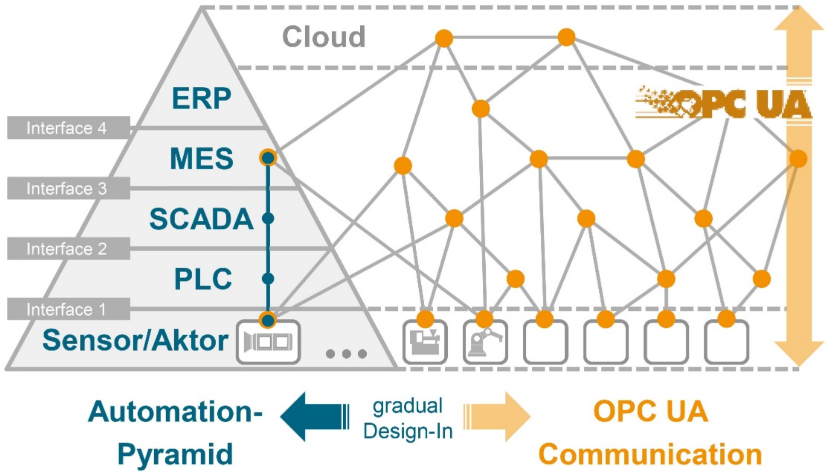
BACnet

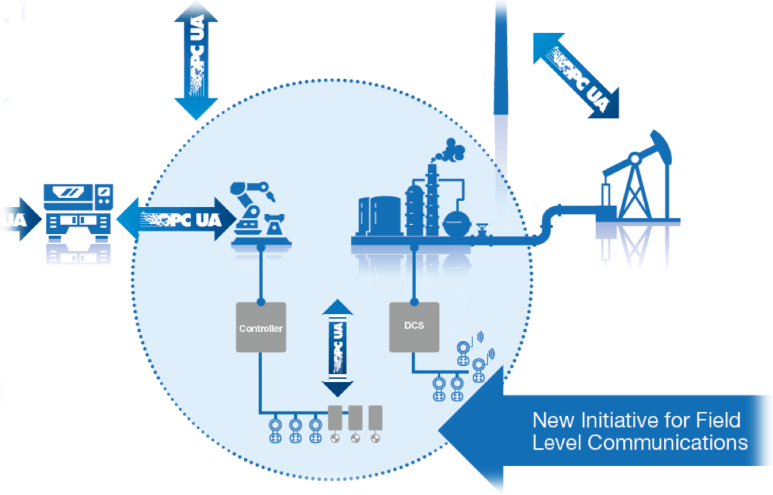
- Building automation
- Protocol with object-based information model

Modbus

- Energy systems, supervisory logic
- Simple protocol for addressing registers

Industrial IoT Ecosystems





OPC Unified Automation (UA)

- Factory and process automation
- Graph-based information model and communication protocols

→ For management/monitoring

OPC UA Field-Level Communications (FLC)

- Extension to cover field controllers and devices
- Integrates TSN, which is configured via NETCONF

→ For real-time applications

OPC UA Binding

- Mapping to Properties, Actions, and Events (with `opc:methodName` field in from)
  - Variable nodes → Properties
  - Method nodes → Actions (node attributes become TD fields)
  - Node alerts → Events
- DataSchema
  - OPC UA uses binary data types, hence JSON Schema must be further annotated
  - Would be binding-specific, ergo form field, but form metadata not available to ContentSerdes

  → `opc:dataType` annotation in DataSchema
- Form href URI (UA-Binary over TCP)
  - Adopt opc.tcp schema, but extend with ;-separated query similar to OPC UA tooling

  → `opc.tcp://localhost:5050/server-path?ns=1;s=mynode`
- Form contentType
  - UA-Binary has no registered mediatype (similar to URI schema, needs a push within OPCF)

  → `application/x.opcua`

Sciullo, Bhattacharjee, Matthias Kovatsch. "Bringing Deterministic Industrial Networking to the W3C Web of Things with TSN and OPC UA." Proc. IoT 2020. Malmö, Sweden. Sep 2020

NETCONF Binding

- Mapping to Properties, Actions, and Events (built on RESTCONF)
  - Leaf-nodes → Properties
  - RPCs → Actions
  - Notifications → Events
- DataSchema
  - Mostly works, as YANG is XML-based
  - Must add mechanism for XML node attributes (e.g.,)

  → `nc:container` and `nc:attribute` annotations – should become general XML mechanism
- Form href URI (XML messages over SSH transport)
  - Similar to RESTCONF URIs, but with support for datastores (RESTCONF has implicit rules)

  → `netconf://localhost:830/running/ietf-interfaces:interfaces/interface=eth0/type`
- Form contentType
  - Re-usable from RESTCONF

  → `application/yang-data+xml`

Sciullo, Bhattacharjee, Matthias Kovatsch. “Bringing Deterministic Industrial Networking to the W3C Web of Things with TSN and OPC UA.” Proc. IoT 2020. Malmö, Sweden. Sep 2020

Examples

OPC UA

```
"properties": {
  "Velocity": {
    "type": "number",
    "observable": true,
    "opc:dataType": "Double",
    "forms": [{
      "href": "opc.tcp://xts.local:5050/ns=1;\\
          s=GVL.OPC_Interface.MOVER[1].Input.Velocity",
      "contentType": "application/x.opcua-binary" }] },
  ... },
"actions": {
  "Execute": {
    "input": {
      "type": "boolean", "opc:dataType": "Boolean" },
    "output": {
      "type": "boolean", "opc:dataType": "Boolean" },
    "forms": [{
      "href": "opc.tcp://xts.local:5050/ns=1;\\
          s=GVL.OPC_Interface.XTS.Input.Execute",
      "contentType": "application/x.opcua-binary",
      "opc:method": "Call" }] } }
```

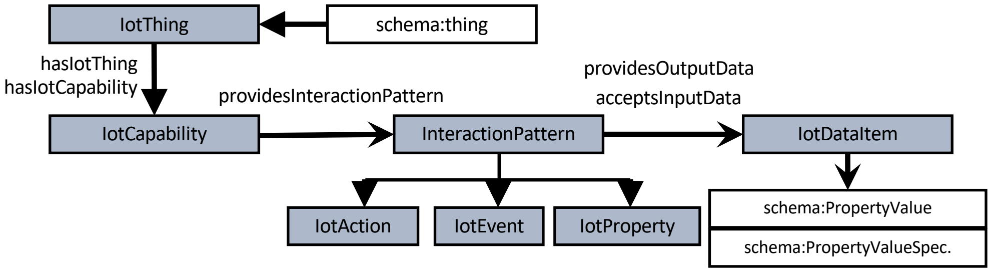
NETCONF

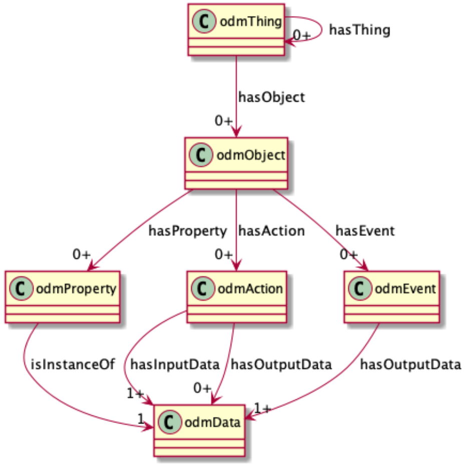
```
"properties": {
  "admin-control-list": {
    "type": "array",
    "items": {
      "type": "object",
      "properties": {
        "index": {
          "type": "number", "minimum": 0, "maximum": 127 },
        "time-interval": {
          "type": "number", "minimum": 0, "maximum": 4294967295 },
        "gate-state": {
          "type": "number", "minimum": 0, "maximum": 255 } } },
    "uriVariables": {
      "datastore": {
        "@type": "nc:Target",
        "type": "string",
        "enum": ["candidate", "running", "startup"] },
      "interface": {
        "type": "integer", "minimum": 0, "maximum": 7 } },
    "forms": [{
      "href": "netconf://172.17.0.2:830/{datastore}/huawei:tsn-configuration\\
          /interface={datastore}/gate-parameters/admin-control-list",
      "contentType": "application/yang-data+xml",
      "nc:curies": { "ht": "urn:ietf:params:xml:ns:yang:huawei-tsn" } }] },
  ...
```

From TDs to Knowledge Graphs

WoT Thing Description Is a Framework

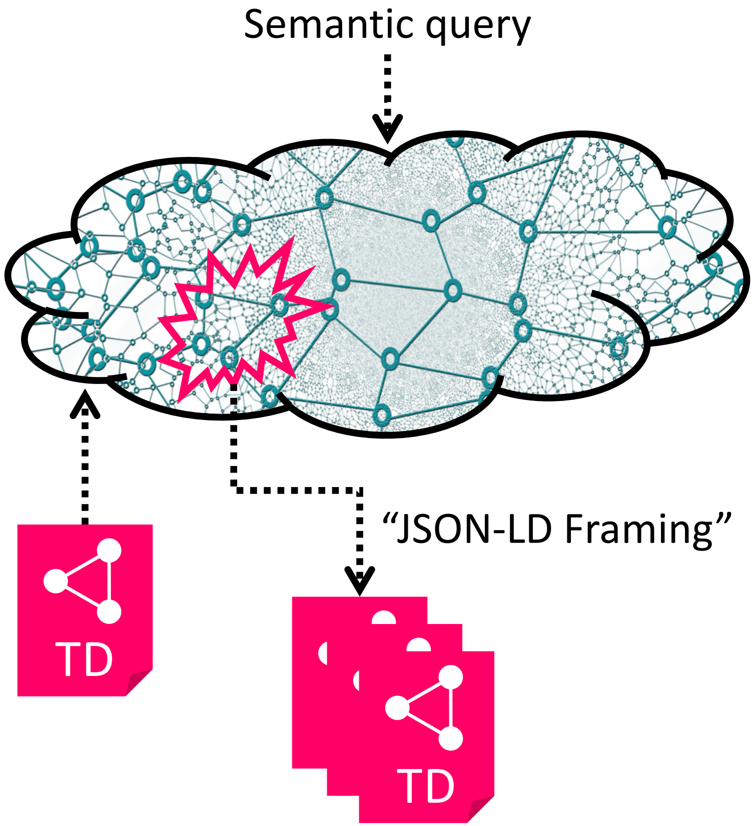
- Provisioning of domain-specific vocabularies and ontologies
  - schema.org IoT Extension
    - W3C Community Group
  - Bridging existing ontologies, e.g.,
    - SSN
    - eCl@ss
    - Building Topology Ontology
  - Converting existing models, e.g.,
    - OPC UA Companion Specifications
    - OneDM (ZigBee Cluster Lib etc.)





WoT Thing Description Is a Framework

- Management of TD information
  - Thing Directory to be standardized
    - Registration
    - Lookup
  - TDs are Linked Data (JSON-LD 1.1)
    - Thing Directory is a knowledge base
    - Enrich with any data, e.g., maintenance
    - Serialize context-aware TDs, e.g., for admin
  - TDs is a modern version of the I4.0 Asset Administration Shell
    - Describes the interface
    - Can store lifetime data
    - Has no baggage of executable code



Semantic query

“JSON-LD Framing”

Hypermedia-driven Actions

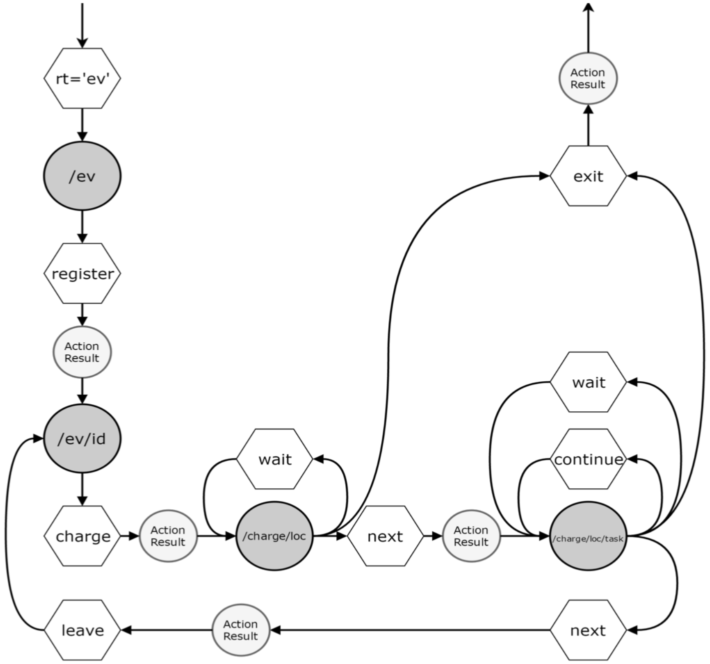
Actions in Thing Descriptions

```
...
"actions": {
  "fadeIn": {
    ...
  },
  "fadeOut": {
    ...
  },
  "toggle": {
    ...
  },
  "execute": {
    ...
  }
},
...
```

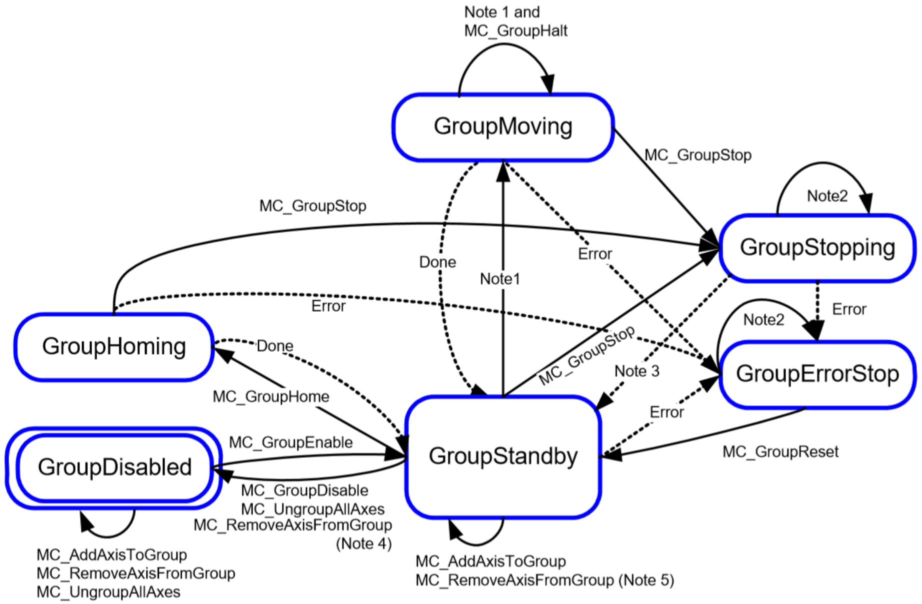
- All examples just show simple Actions that can be completed in a single step
- This has been sufficient for most use cases considered so far
- Often there is the implicit assumption that a Consumer needs to know in what order to interact with the different affordances to follow a process

What if only the Thing Knows the Process?

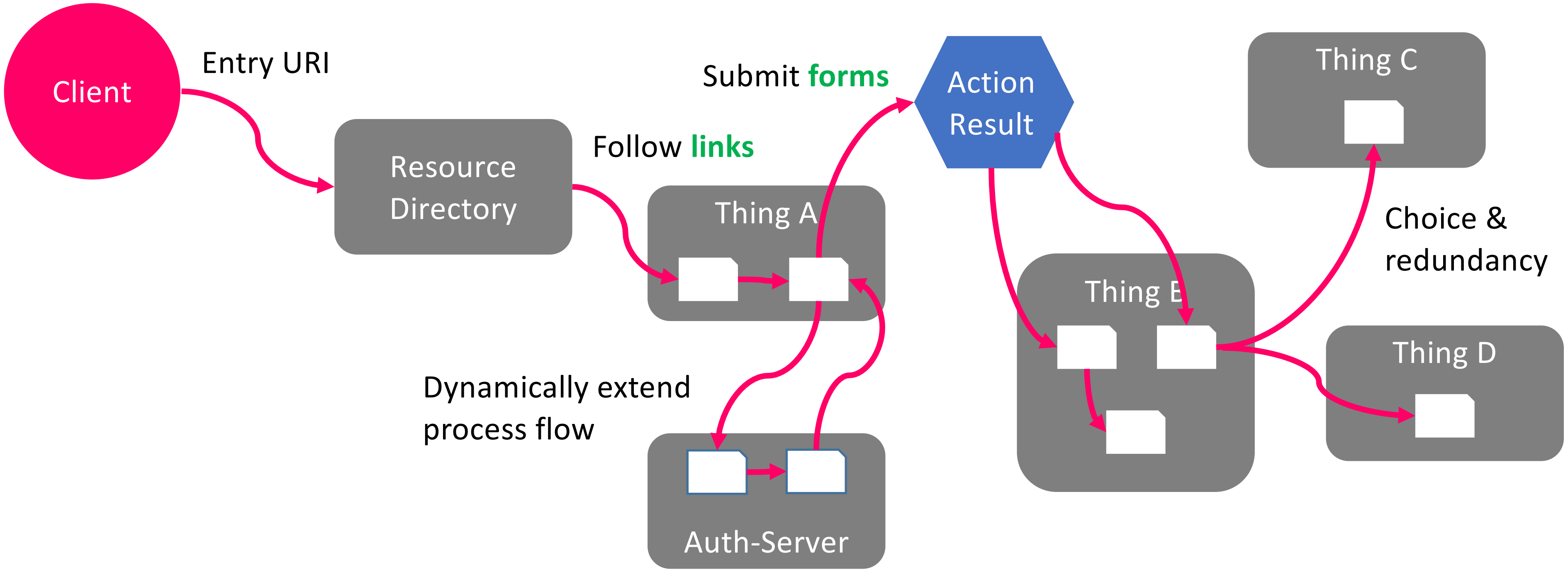
Electric Vehicle Charging



Robots (PLCopen)



Let Machines use Things Like We Browse the Web



Spirit of Yet to Come: *Up to You!*

- AI for Industry 4.0 requires industrial protocol bindings for W3C WoT
- W3C WoT only defines the framework and still requires WoT-oriented vocabularies and ontologies as JSON-LD context extension files
  → Industrial Knowledge Graphs can help
- W3C WoT currently only describes simple, single-step interactions,
  so that complex workflows and processes still need manual programming
  → Action responses with affordances and Hypermedia Agents can help

Contact

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(Note that this is a research view)