The Web of Things and Semantic Interoperability

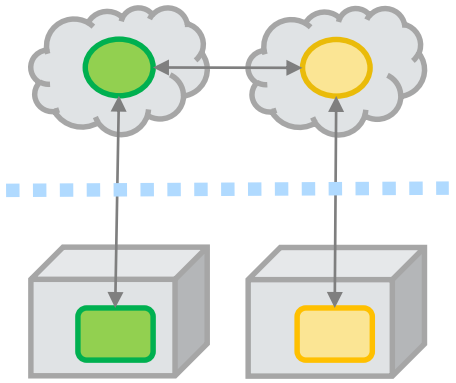
Michael McCool, Principal Engineer, Intel

IETF100, November 14, 2017

IoT/Fog Evolution Towards an Ambient Ecosystem

Cloud Supported IoT Devices

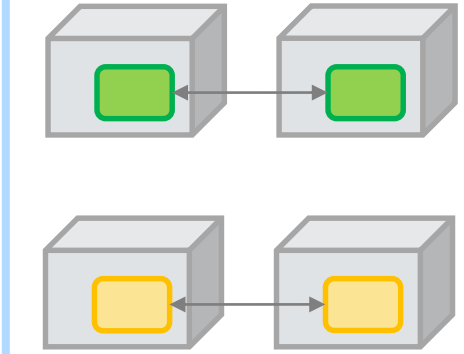
IoT devices connect to mostly independent cloud services



2016/2017

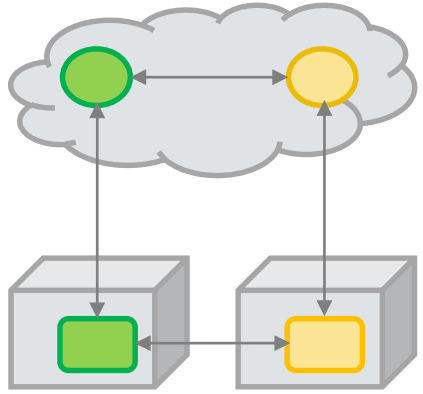
Locally Networked IoT Devices

IoT devices connect to others in isolated ecosystems



Fog Supported IoT Devices

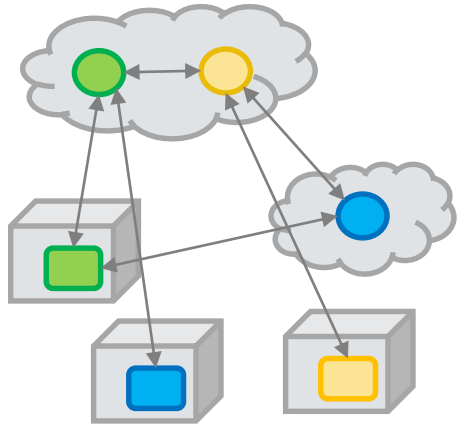
IoT devices can discover and connect to local “fog services” that facilitate interop.



2018/2019

Ambient Service Ecosystem Computing

Services composed from dynamically discovered devices and services



2020/2021

Standards Stack

Integrate *complementary* standards that promote *interoperability*

- Ambient Services Standard: e.g. OpenFog
  - Defines platform for **federated edge and cloud services**
  - Common services for discovery, security, monetization, updates, etc.
- ***Metadata Standard: e.g. W3C Web of Things***
  - Enables cross-ecosystem service discovery and composition
  - **Supports semantic interoperability** which **enhances usability**
- IoT Device Standards: e.g. OCF, MQTT, LwM2M, AWS IoT, etc.
  - Define standard local interfaces for devices and services

The Web of Things and IoT Interoperability

Web of Things supports IoT interoperability

…to enable an open “IoT service ecosystem” to develop

…by making use of well-developed web ecosystem

…without adding to the confusion of “too many standards”

Agenda:

→ *What? Why? How? Now!*

What?

What is interoperability?

Interoperability: What is it?

Two entities can be interfaced “directly”

- Web browser can access a web server and render content from it
  - Despite my never having visited that site before
- I can plug my laptop into the wall to charge
- I can replace lightbulbs in my apartment
- I can buy bolts and nuts and expect them to work together

For the IoT:

- I want to use devices (and data from those devices) from different manufacturers in the same system

Levels of Interoperability

Semantic: *Be able to decode the meaning of data.*

- Convert to a representation that has tagged elements with identifiers, properties, and relationships using elements rooted in shared contexts, vocabularies, and ontologies.

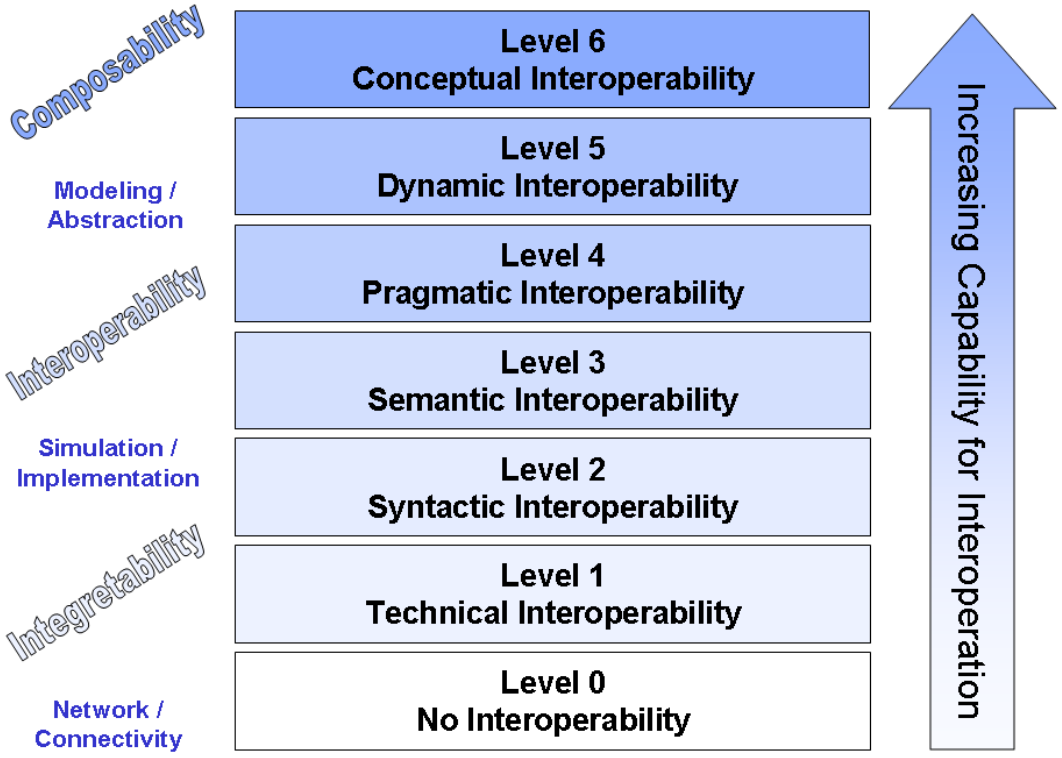
Structural: *Be able to decode the organization of data.*

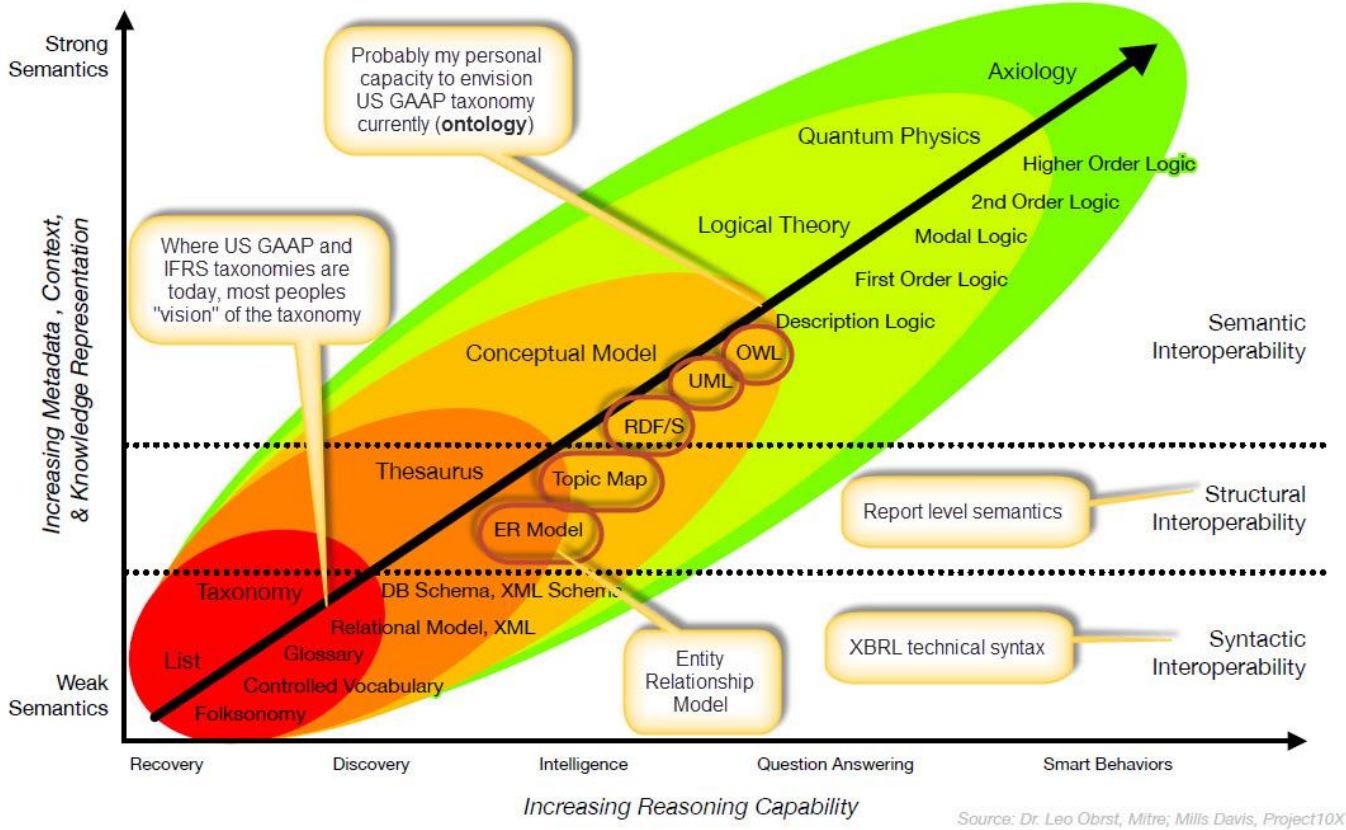
- Convert data into a set of common primitive types (numbers, characters, etc) structured with a set of organizational patterns (lists, sets, arrays, links, objects, tables, etc).

Syntactic: *Be able to decode the encoding of data.*

- Convert data in a consistent way between a serialized (transmissible, storable) representation (eg a sequence of bytes) and an internal data structure (eg a parse tree).

Other Definitions…





Conceptual Interoperability

IoT Structural and Syntactic Interoperability

For the IoT, "data" can also include actions and events mediated by communications exchanges (eg the "application protocol").

There is potentially structure *between* such exchanges as well as *within* the exchange payloads…

- However, the REST and HATEOAS patterns try to make each exchange meaningful in itself.
- We also need to consider security: onboarding, negotiation of identity, origins, certificates, trust, etc. also constrain interactions

Within the payload of a given communication:

- Syntactic and structural interoperability can be accomplished today by using prescriptive standards designed for this purpose, such as JSON or XML.
- In these technologies, the structure is given explicitly by the syntax, although we can also constrain it with metadata (DTDs, etc).

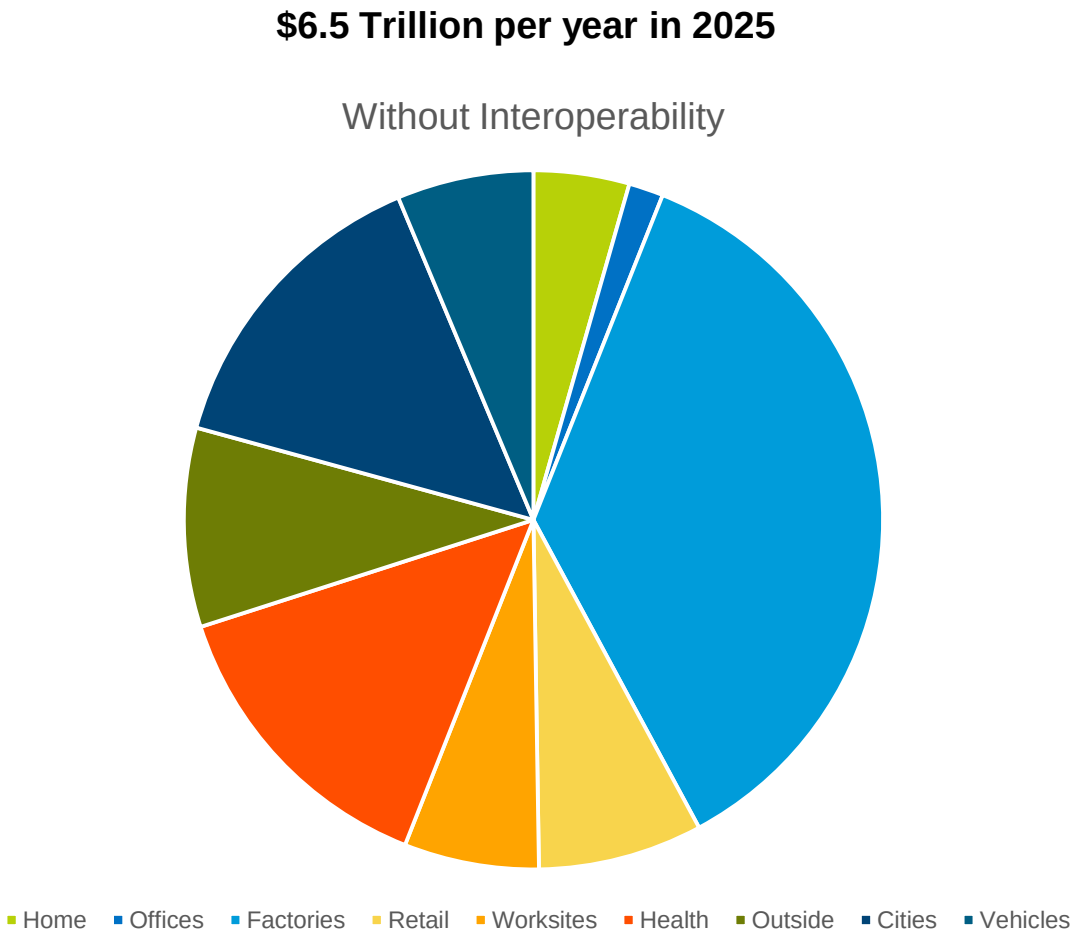
Why?

Why do we want interoperability?

Business Value of Interoperability

"Interoperability between IoT systems is critically important to capturing maximum value; on average, interoperability is required for 40% of potential value across IoT applications and by nearly 60% in some settings." [+$4.1B TAM by 2025]

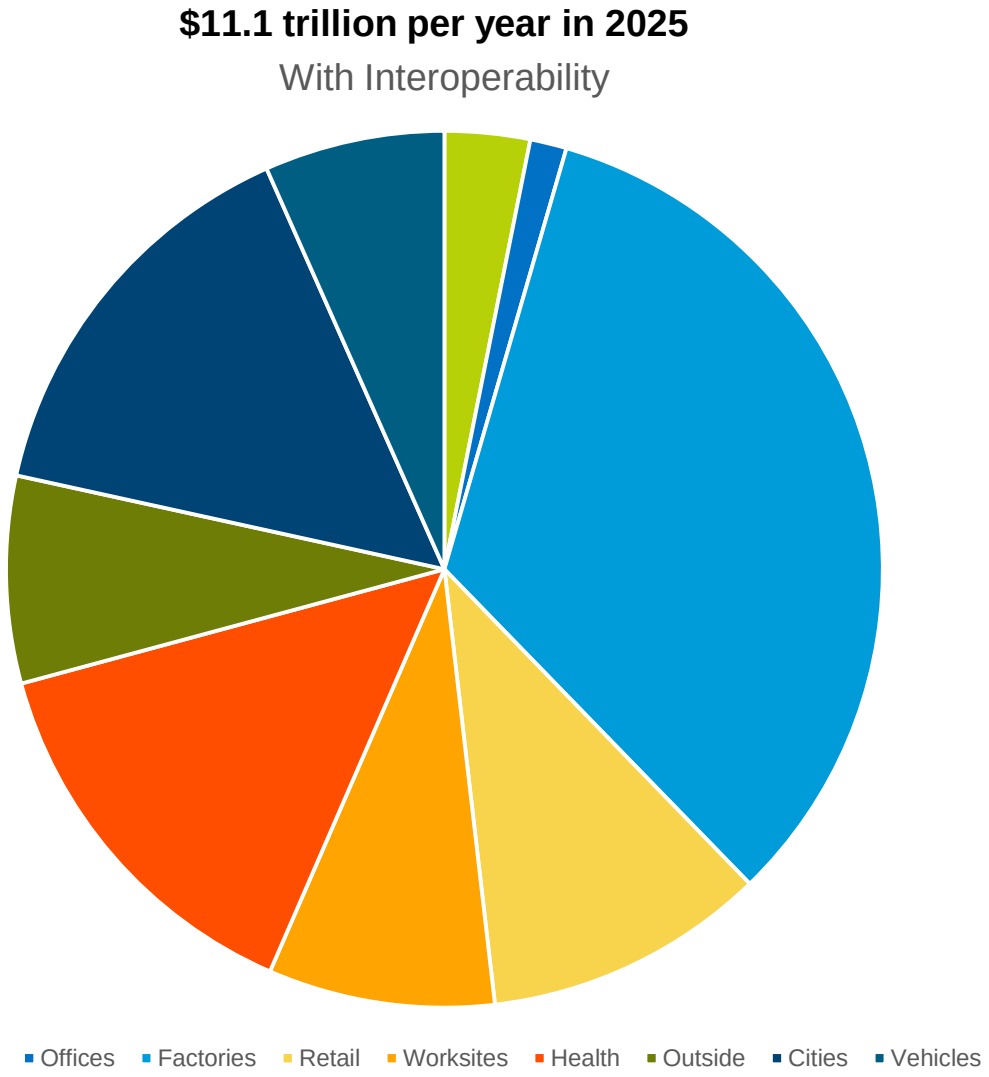
McKinsey & Company, *The Internet of Things: Mapping the Value Beyond the Hype*, 2015



Business Value of Interoperability

"Interoperability between IoT systems is critically important to capturing maximum value; on average, interoperability is required for 40% of potential value across IoT applications and by nearly 60% in some settings." [+$4.1B TAM by 2025]

McKinsey & Company, *The Internet of Things: Mapping the Value Beyond the Hype*, 2015

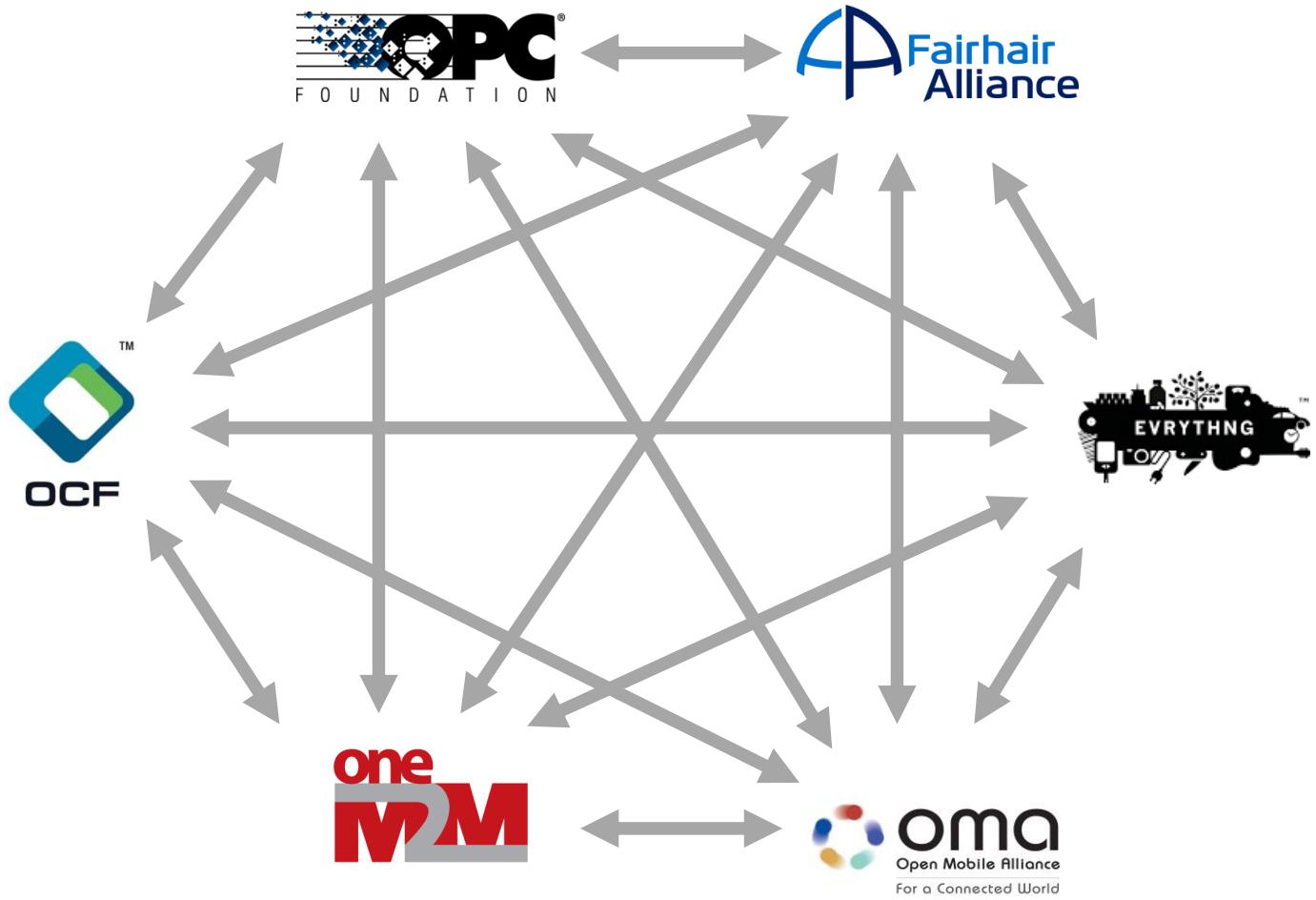


Interoperability Enables IoT Scaling

- *Interoperability* is the key to scaling the IoT ecosystem
  - Maximize number of devices and services that can interoperate

    → *Quadratic growth…*
  - Provide ecosystem that can compose devices and services flexibly

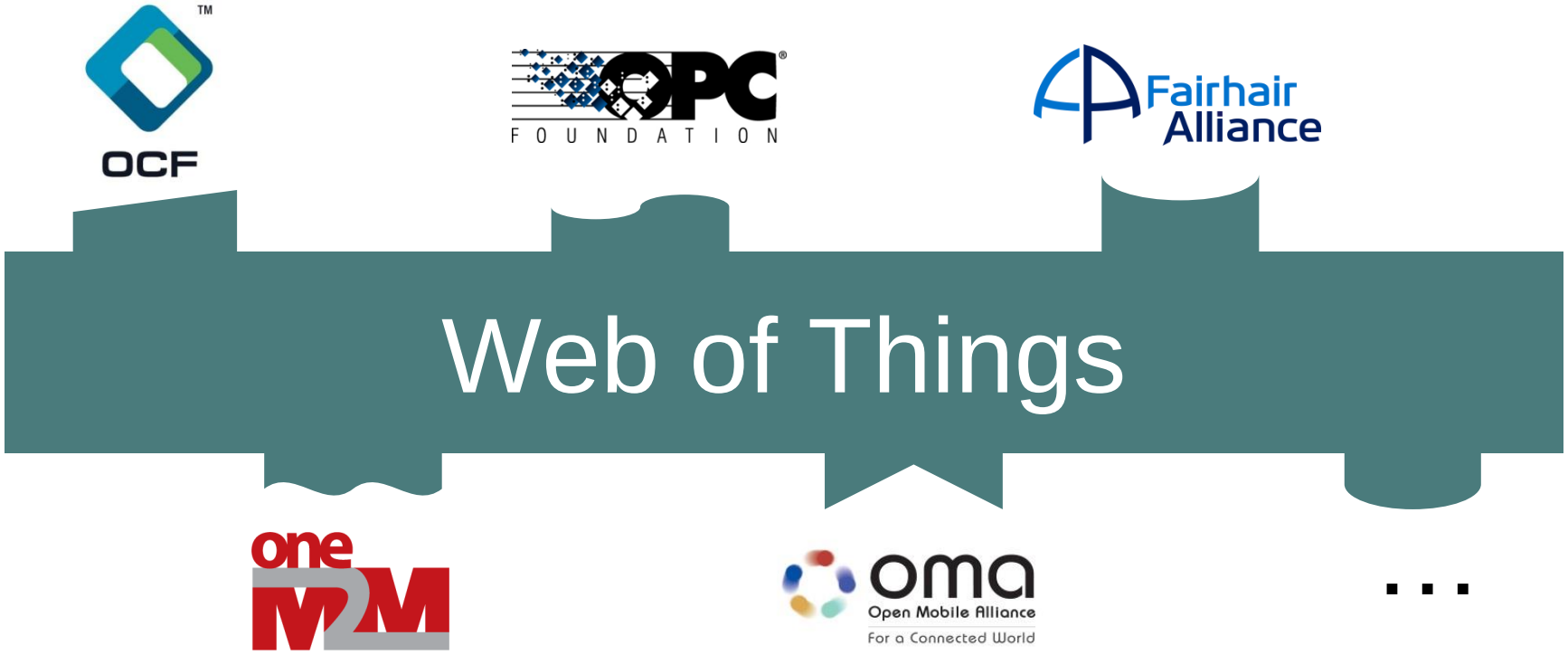
    → *Combinatoric growth!*



How?

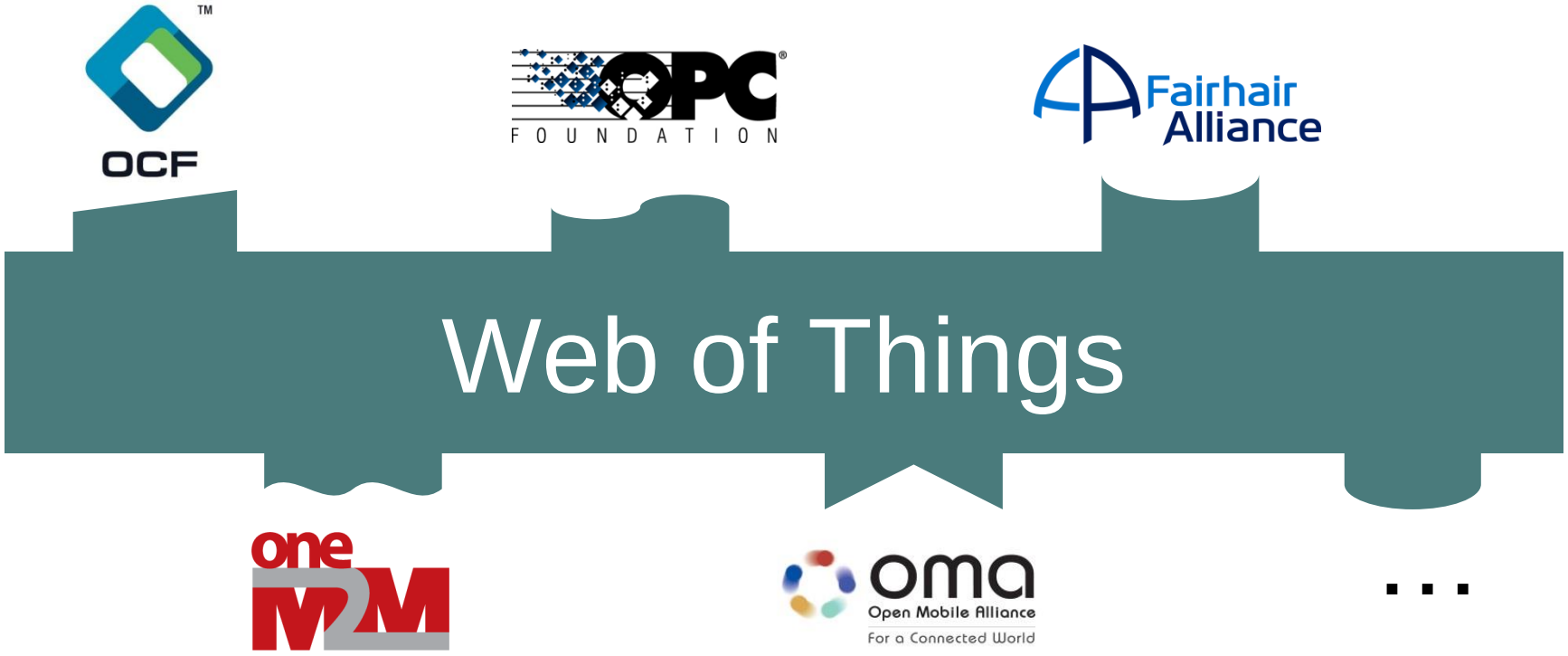
How to achieve interoperability?

W3C Mission for Web of Things



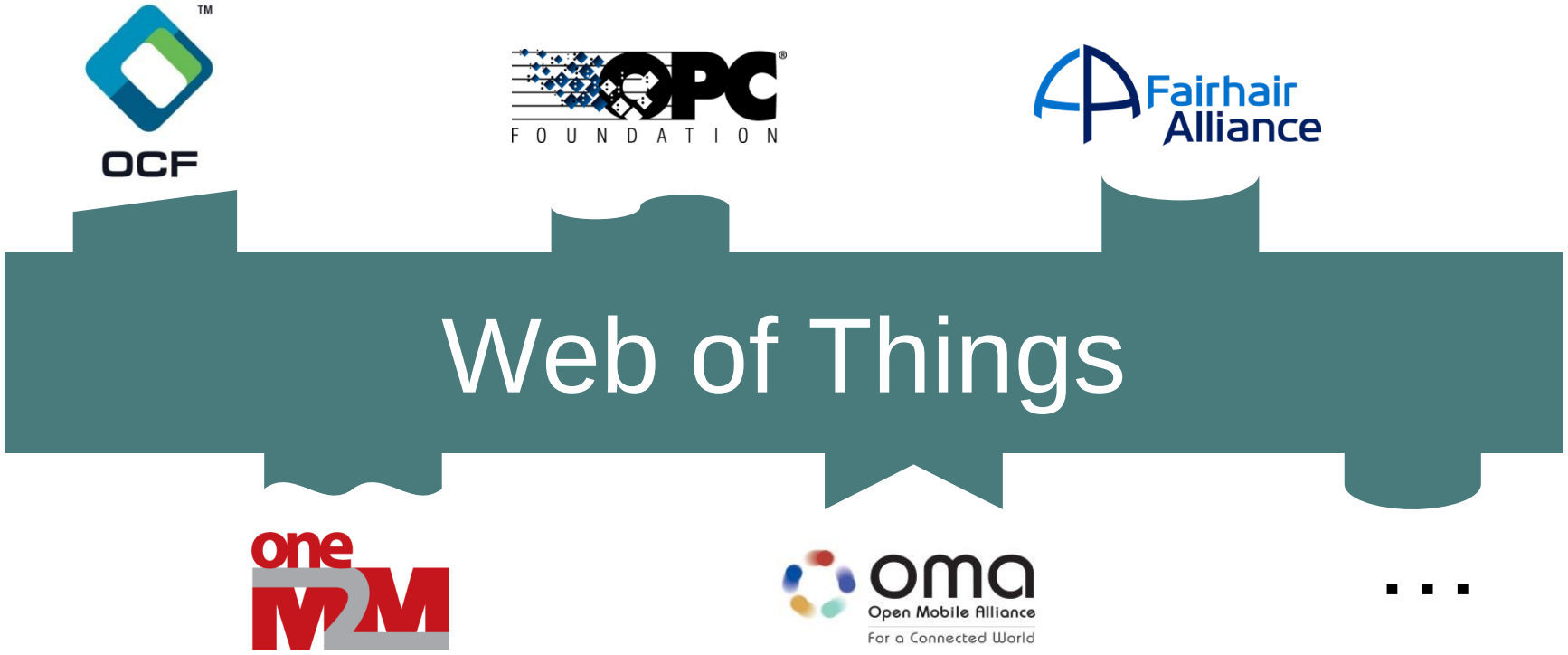
WoT provides a way to build systems that use devices from multiple IoT standards.

W3C Mission for Web of Things



In other words, WoT's goal is to enable interoperability.

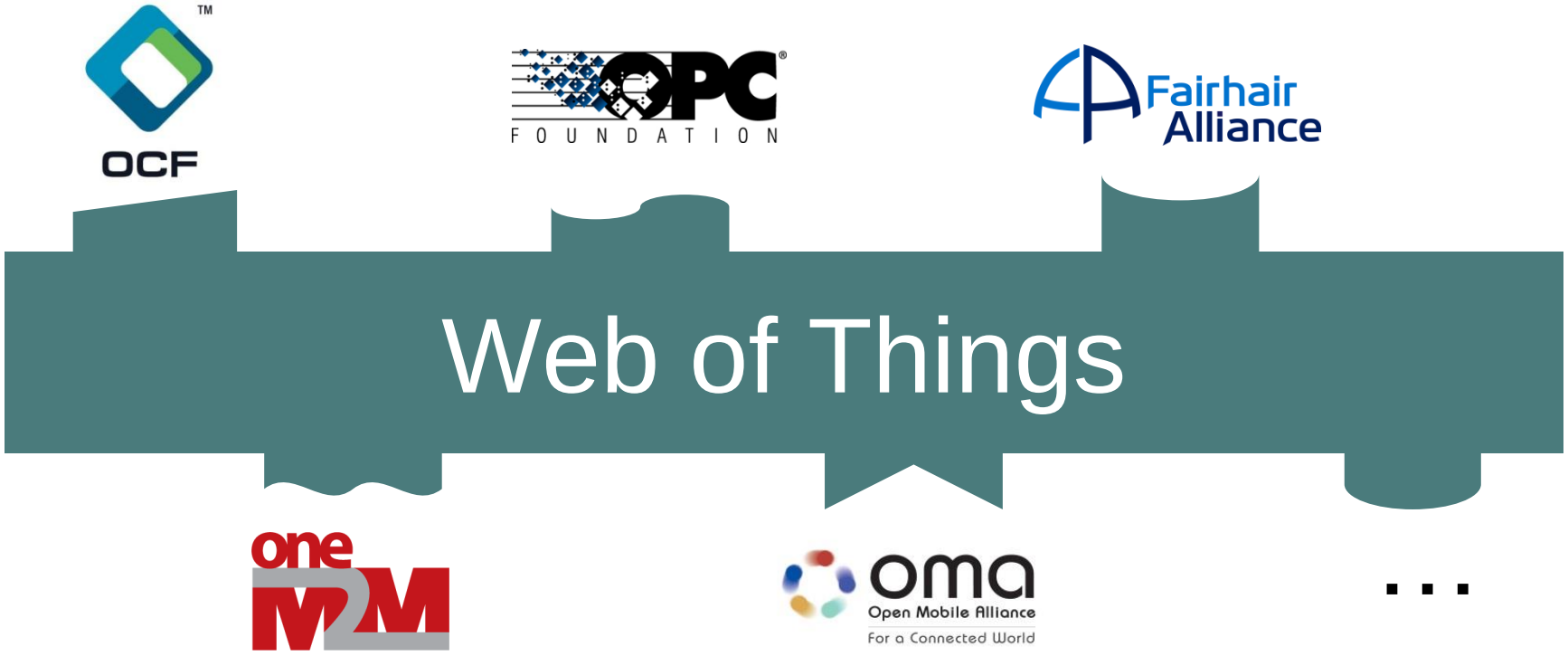
W3C Mission for Web of Things



But… how does the W3C WoT differ from other IoT standards?

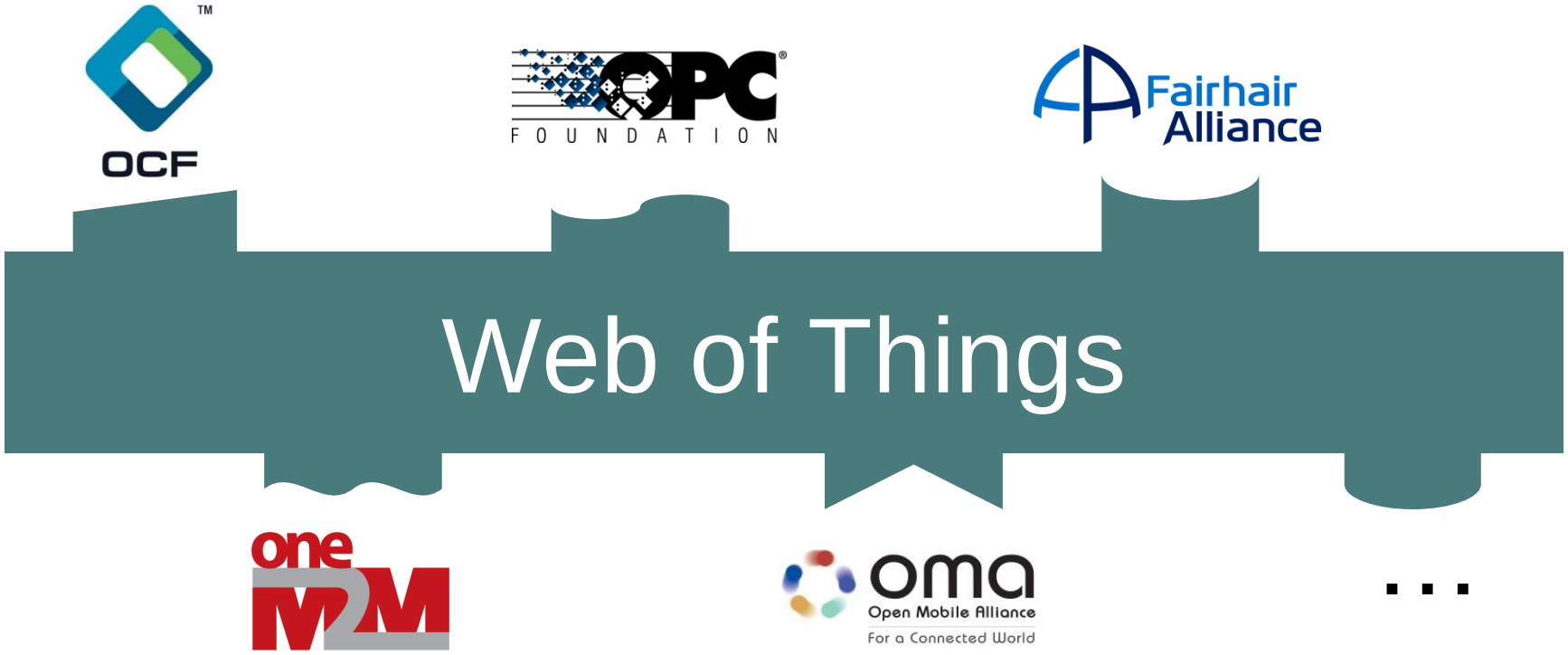
Most standards also have the goal of interoperability.

W3C Mission for Web of Things



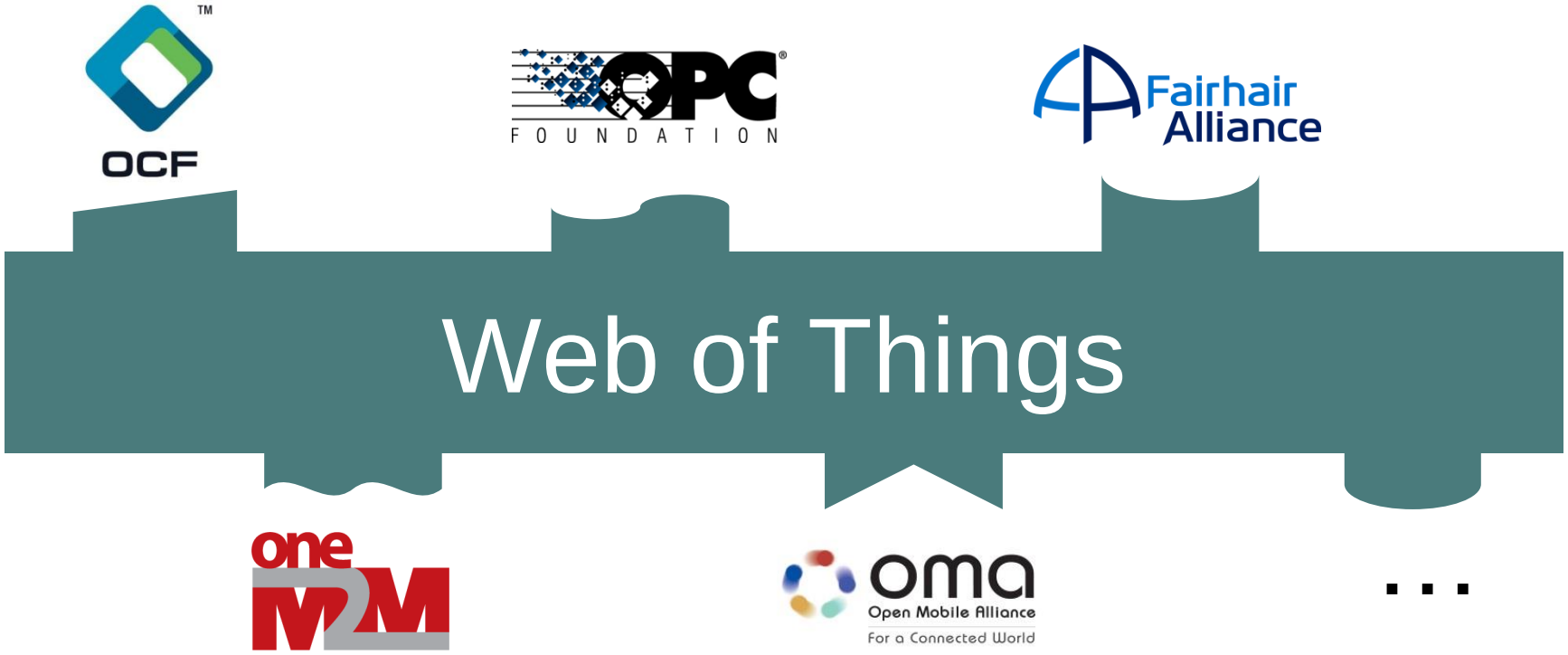
The difference is in how interoperability is achieved.

W3C Mission for Web of Things



Most standards ***prescribe*** how devices should operate.

W3C Mission for Web of Things



Most standards ***prescribe*** how devices should operate.
The WoT ***describes*** how devices operate.

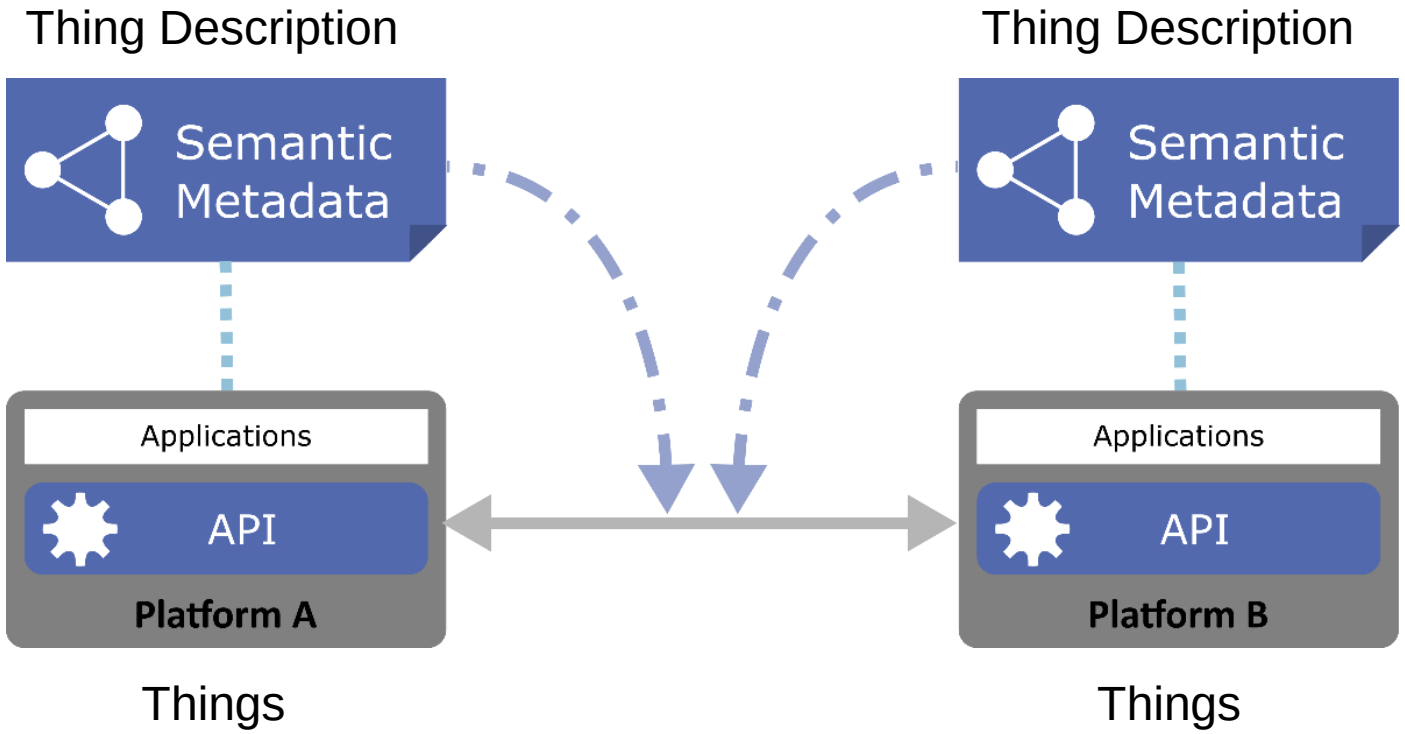
Web of Things: Standardised Metadata

Metadata simplifies application development

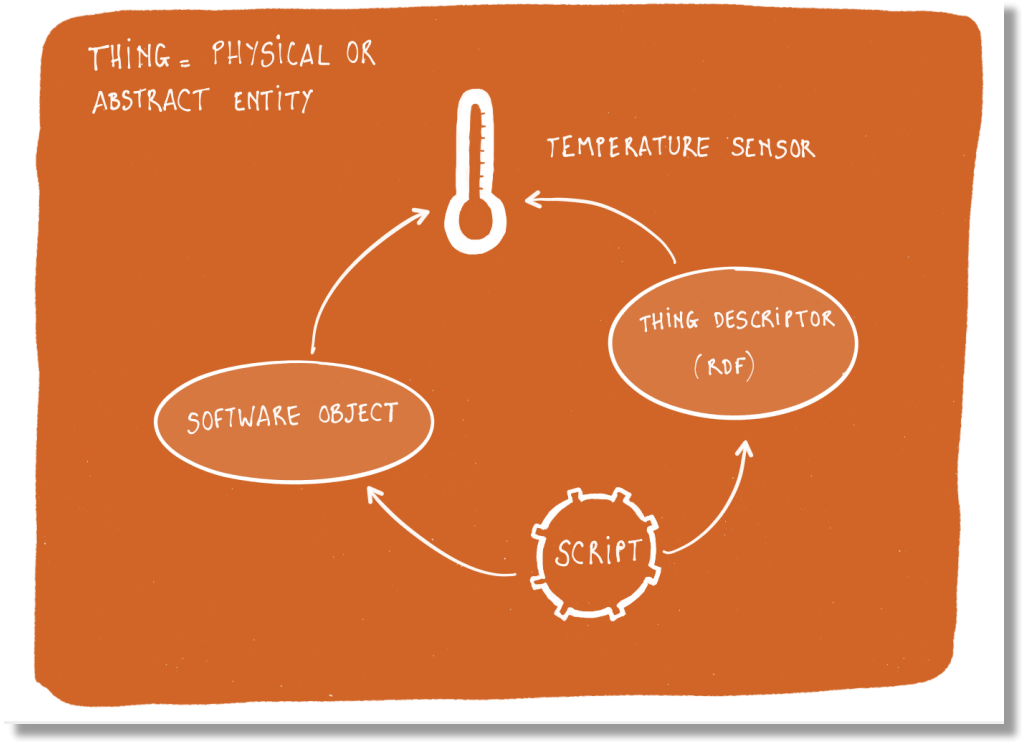
- Decouples underlying protocols
- Enables automated tooling

Metadata enables interoperability

- Describe the interfaces exposed to applications
- Describe the communication and security requirements for accessing things
- Describe the data models, semantics, and domain constraints



Web of Things: Thing Abstraction



Applications act on "Things"

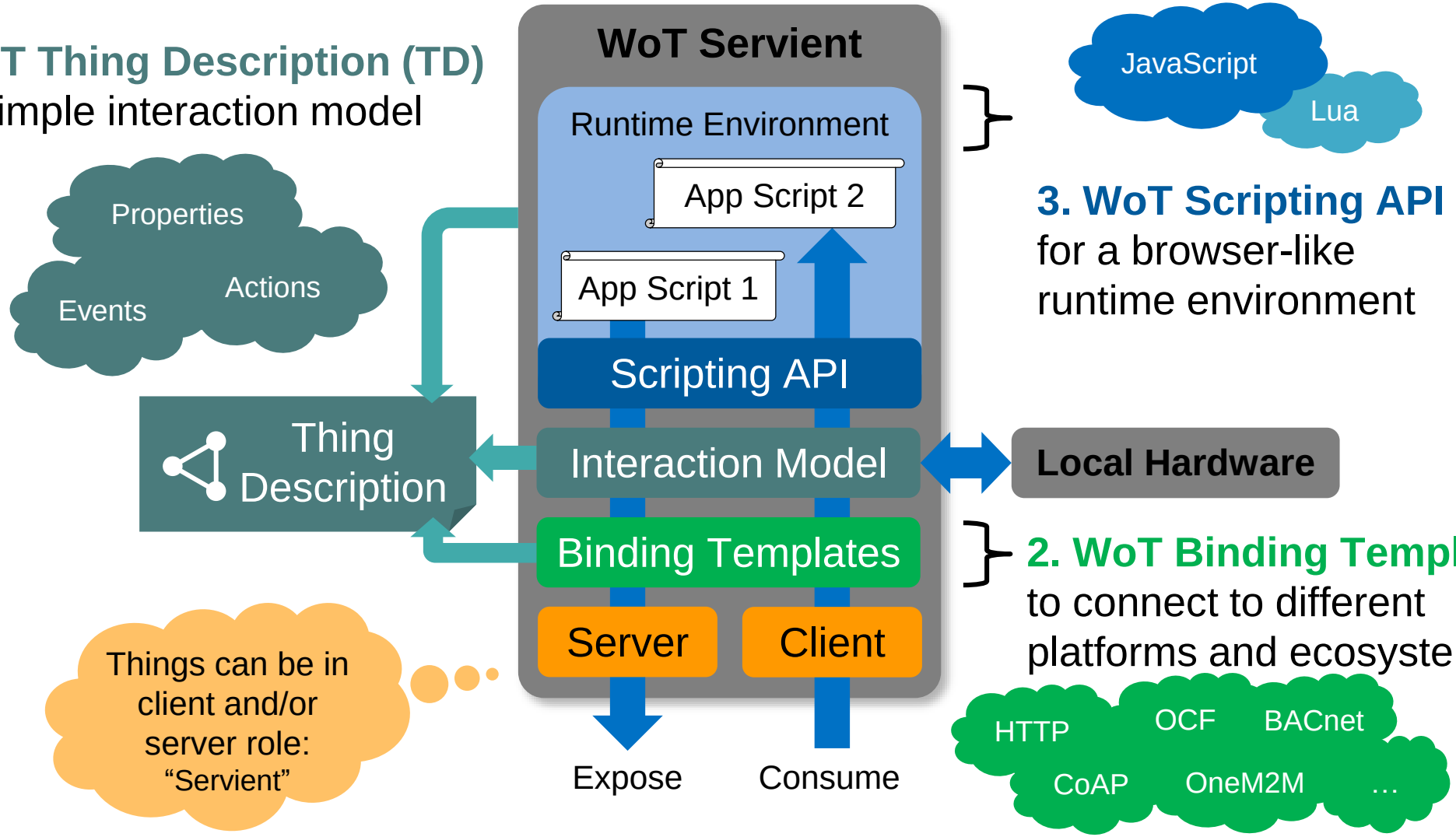
- Things are *software objects*
- Digital avatars representing physical or abstract entities (such as services)
- Have properties, support actions and events
- Can be local or remote

Metadata descriptions for every "Thing"

- Each Thing has a URI for its name
- URI provides access to its description
- Ontologies describe Things and their relationships
- Using W3C's Linked Data semantic framework

WoT: Deliverables/Architecture

1. WoT Thing Description (TD)
with simple interaction model



3. WoT Scripting API
for a browser-like runtime environment

2. WoT Binding Templates
to connect to different platforms and ecosystems

Thing Description Example

JSON-LD (Linked Data)

W3C WoT TD vocabulary

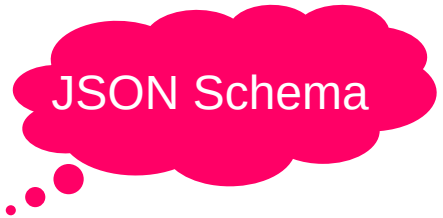
domain-specific vocabulary

```
{  "@context":["http://w3c.github.io/wot/w3c-wot-tdcontext.jsonld",
                "http://w3c.github.io/wot/w3c-wot-common-context.jsonld",
                {"iot":"http://iotschema.org/"},
                {"http":"http://www.w3.org/2011/http/"}],
   "base":"http://example.ocfgateway.net/api/oic",
   "@type":["Thing","Light","iot:LightControl", // Capabilities
            "iot:Actuator","iot:BinarySwitch"],
   "name":"Intel-OCF-Smart Home LED (2relay)",
   "interaction":[
       {"name":"Switch Status",
        "@type":["Property","OnOffState","iot:SwitchStatus"], // Interactions
        "link":[
            {"href":"/a/led2relay?di=79683ab5-8df1-4b7a-b110-c1b8fe251e7d",
             "mediatype":"application/json",
             "http:methodName":"http:post", // Methods (specific to protocol binding)
             "rel":"setProperty"},
            {"href":"/a/led2relay?di=79683ab5-8df1-4b7a-b110-c1b8fe251e7d",
             "mediatype":"application/json",
             "http:methodName":"http:get",
             "rel":"getProperty"}
         ],
          → Payload structure and semantics
        },
        → Other interactions: Properties, Events, and Actions
    ]
}
```

Thing Description Example: A Property

// Payload structure and semantics for a Property interaction

```
"inputData":{
    "type":"object",
    "fields":[
        {"name":"value",
         "value":{"@type":["iot:Toggle"],  // Data
                  "type":"boolean"}
        }
    ]},
"outputData":{
    "type":"object",
    "fields":[
        {"name":"value",
         "value":{"@type":["iot:Toggle"],
                  "type":"boolean"}
        }
    ]}
```



WoT Semantic Interoperability

Meaning is associated with data entities by annotating various metadata entities with vocabulary elements

Vocabulary elements can also have relationships with each other.

- A reasoner can be used to *infer* additional properties or relationships
- The vocabulary may be explicit or implicit

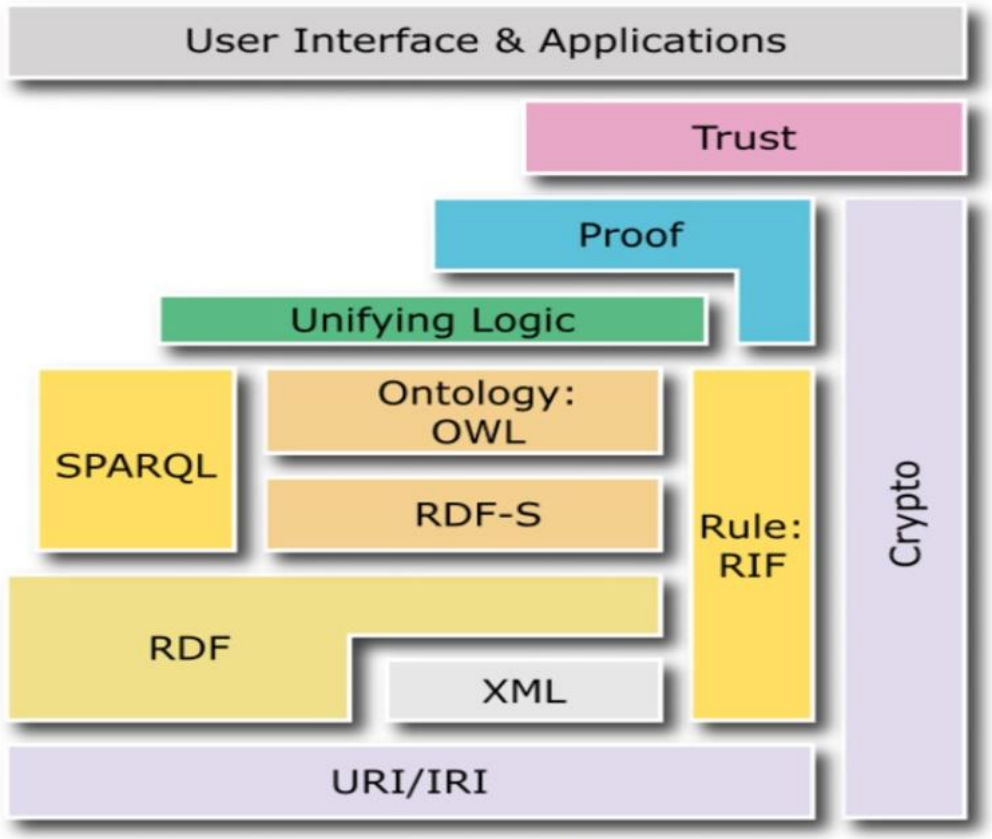
Semantic Web technologies like RDF and JSON-LD make the context and vocabulary *explicit*

- These technologies can also define relationships between vocabulary elements
- *Linked Data* gives each vocabulary element a unique URI and interprets connections between them as hyperlinks.

Linked Data and Semantic Interoperability

Well-defined semantics ensure that platforms share the same meaning for the data they exchange

- → Discovery based upon properties and relationships
  - → Search engines that can index the Web of Things
- → Verify consistency and interoperability
  - → Design service compositions based upon knowledge of which services are compatible
- → Reuse existing domain knowledge
  - → Using iot.schema.org, SSNO, SAREF, etc.



W3C has a rich suite of related standards

iotschema.org

- Project to develop *simple* and *common* IoT ontologies for semantic interoperability

Scope in the Standards Stack

Functional Layer	Documents	Governing body
Ontologies and Taxonomies	SAREF, SSN, IoT-Lite, Haystack, QUDT	Various
Semantic Interoperability	Simple schemas and common definitions	iot.schema.org community
Modeling and Description Language	Thing Description High Level API	OCF, W3C Web of Things WG
Device Definitions	Clusters, Resource types, Device Types	OCF, Zigbee Alliance (dotdot)
Transfer Protocols	CoAP, Zigbee	IETF, Zigbee
Networks and Transports	IPV6, TCP, UDP, Thread, ZIgbee	IETF, Thread, Zigbee

Principals: Michael Koster (Samsung/Smart Things), David Janes (IOTDB), Darko Anicic (Siemens), Dan Brickley (Google)

See: iotschema.org site, discussion doc, and meeting minutes

IoT Service Semantics as Capability Bundles

Bundle theory, originated by the 18th century Scottish philosopher David Hume, is the ontological theory about objecthood in which an object consists only of a collection (bundle) of properties, relations or tropes.

As opposed to substance theory…

"Things" considered as

- Bundles of Capabilities
- Capabilities support specific sets of properties, actions, and events
- Services support sets of Capabilities

→ This is a more flexible model than just having definitions of particular Services or Things

→ Ideally we want a way to *model* novel devices, not just *select* them from a list

→ Capabilities allow us to model a novel device by selecting (and perhaps parameterizing) a set of capabilities

Now!

Proof of Concept Work…

Proof of Concept Development Goals

- ***Understand*** *the relationships of different technologies and standards*
- ***Identify*** *technology and standards gaps*
- ***Overcome*** *specific technical obstacles and gaps*
- ***Demonstrate*** *the business value of new technologies or standards*
- ***Test*** *integration patterns for multiple technologies and standards*
- ***Advance*** *engagements with key ecosystem players*

Stages

1. **Metadata Bridging** (value: increase adoption and applicability)

   → Support *all* existing IoT devices from *multiple* ecosystems

   - Rather than trying to bridge data peer-to-peer, bridge *metadata*
   - Supports end-to-end security since data translation can be pushed to secure endpoints

2. **Semantic Voice Control** (value: demonstrate utility, engage key ecosystem player)

   → Support *any* IoT device with adaptive semantic voice controls

3. **Fog Integration** (value: develop support for ubiquitous localized services)

   → Deploy using local compute resources for proxies, translators, and acceleration

4. **Service-Oriented Development System** (value: support ecosystem development)

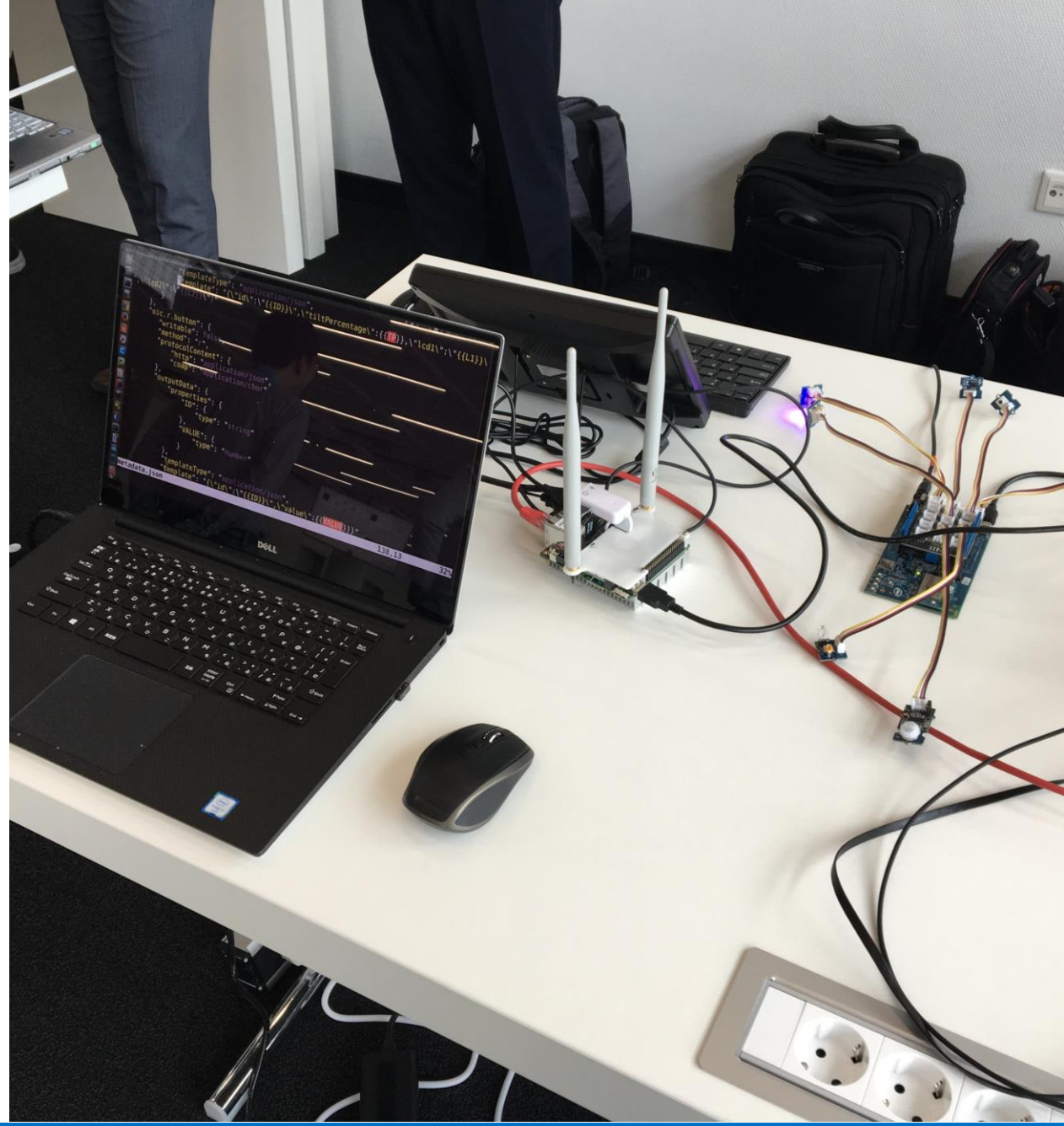
   → Support development and deployment of code for services, not (just) devices

1. Metadata Bridging

Goal: Maximize number of devices accessible

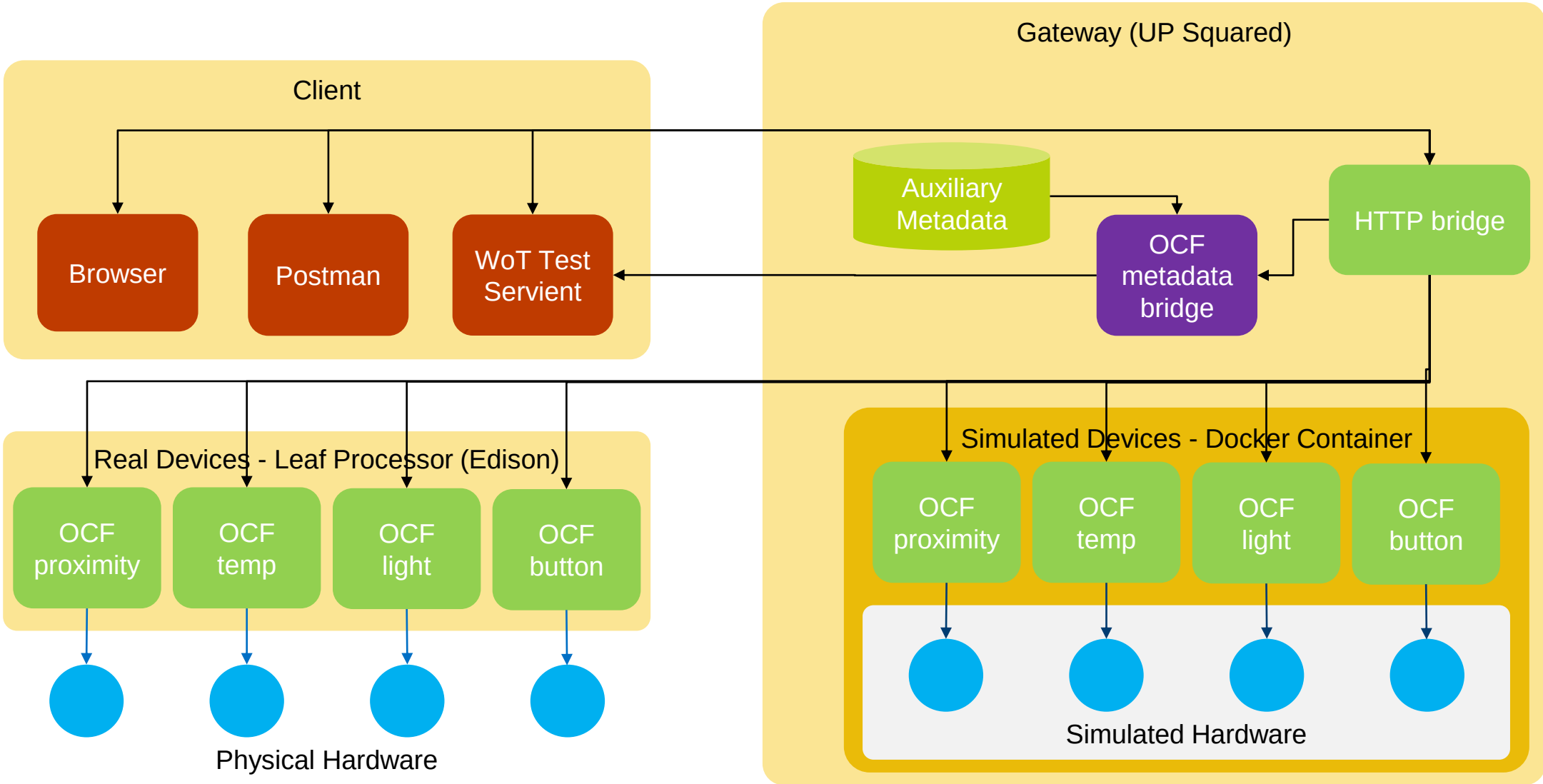
- Translate all metadata into common format (WoT TD)
- Infer and add extra information not available in native metadata
- Make IoT devices available to any system that can process WoT TDs
- Does *not* need specific changes to target IoT devices.

→ *Prototype built using OCF Smart Home Demo as test target.*



1. Metadata Bridging

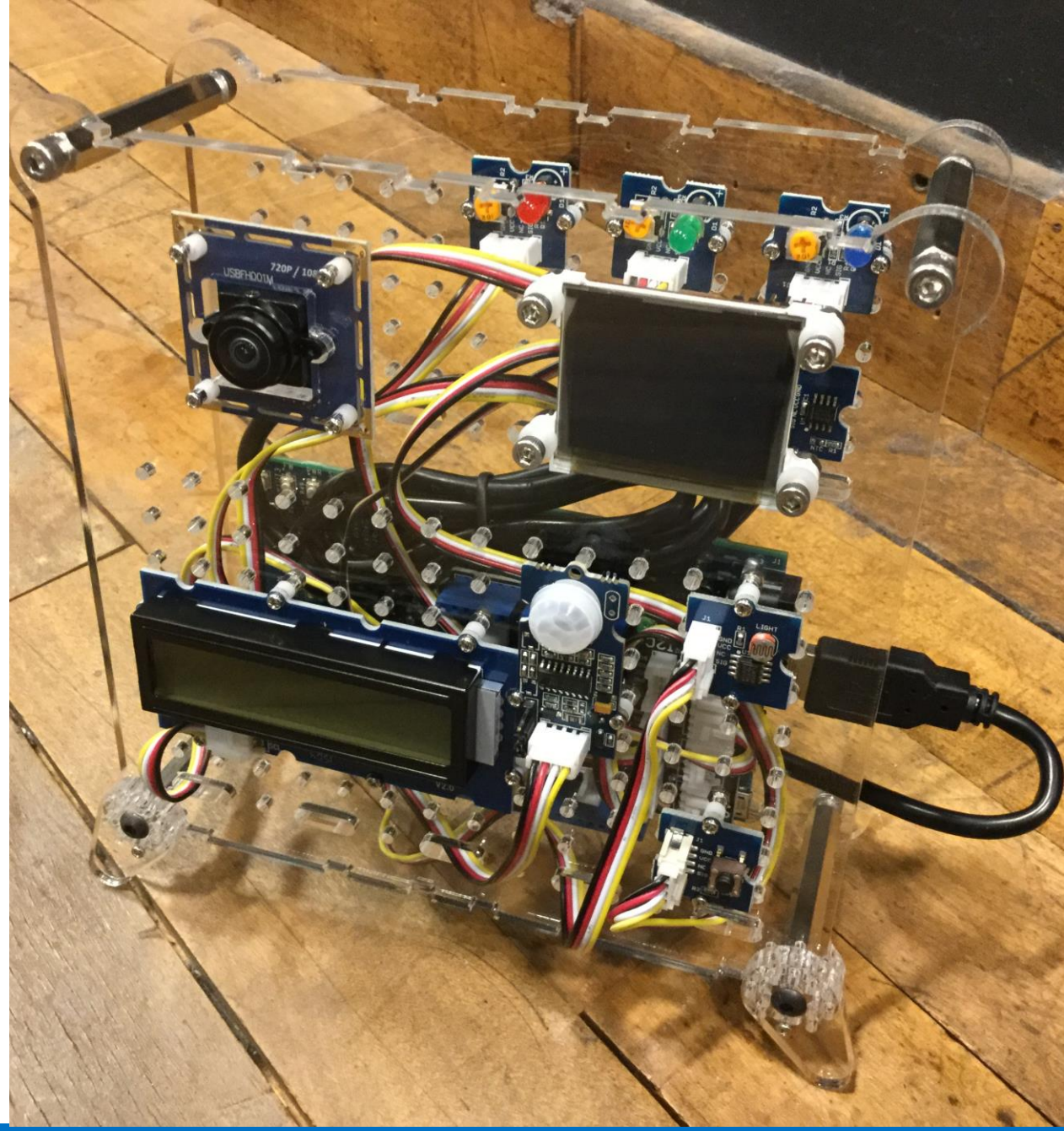
Goal: Translate OCF metadata and make it available to via WoT Thing Description



1.5 Metadata Bridging

Goal: Improve and expand system architecture

- Support NAT traversal
- Support Thing Directories
- Translate native metadata more completely
- [Support devices from multiple standards]
- Support secure transport and authentication

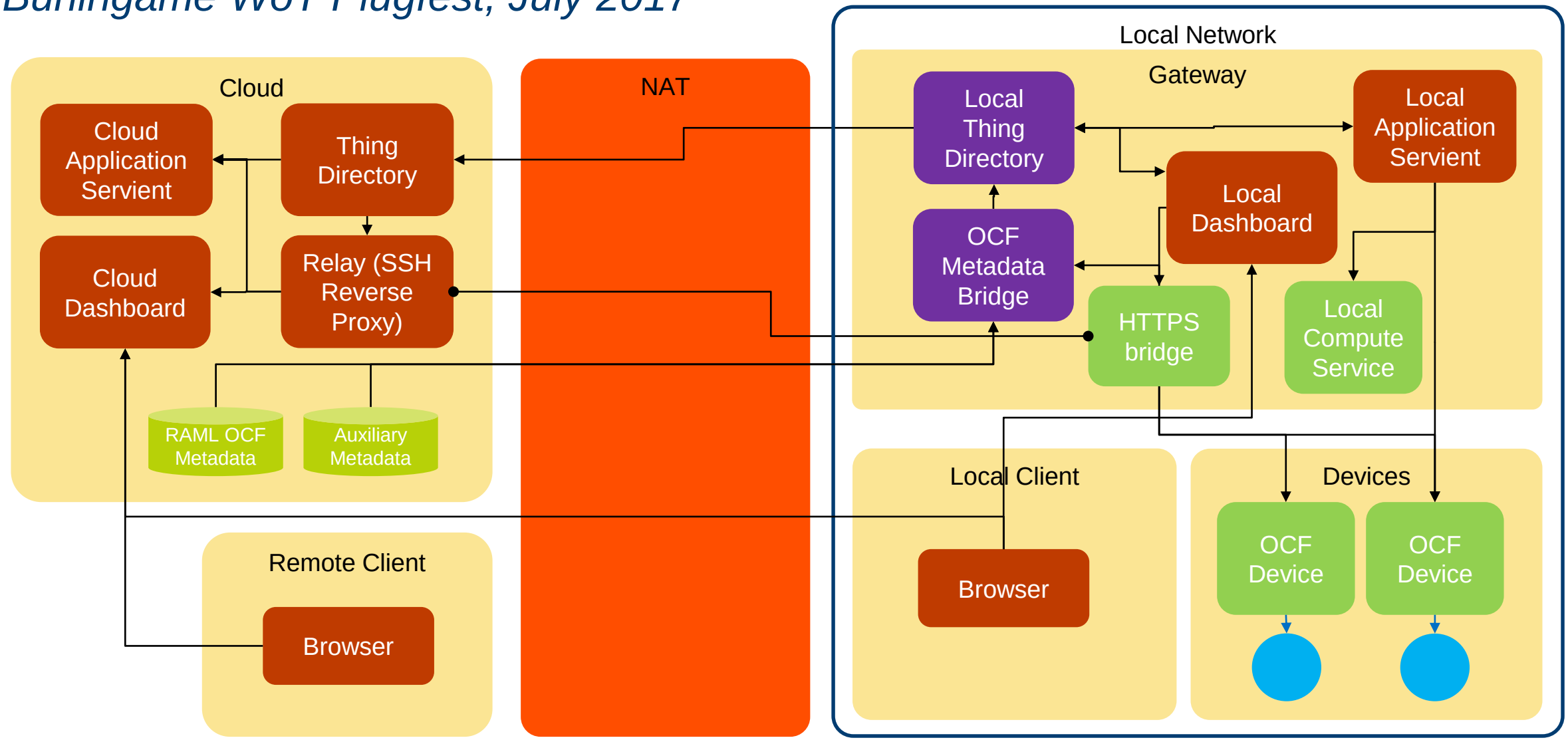



ThinkPad

1.5 Metadata Bridging

Burlingame WoT Plugfest, July 2017

Add: Ingest official OCF data models, traverse NAT, use Thing Directory, …



Metadata Bridge

Metadata generator updated to include:

- Semantic Annotation
  - WoT tdcontext, common context; iotschema.org,
  - HTTP methodName, rel
  - Capabilities (on Things), Interactions, Data
- Protocol Bindings
  - inputData, outputData

```
{   "@context":["http://w3c.github.io/wot/w3c-wot-tdcontext.jsonld",
                "http://w3c.github.io/wot/w3c-wot-common-context.jsonld",
                {"iot":"http://iotschema.org/"}, // Prefix definitions for semantic terms
                {"http":"http://www.w3.org/2011/http/"}],
    "base":"http://example.ocfgateway.net/api/oic",
    "@type":["Thing","Light","iot:LightControl", // Capabilities
             "iot:Actuator","iot:BinarySwitch"],
    "name":"Intel-OCF-Smart Home LED (2relay)",
    "interaction":[
        {"name":"Switch Status",
         "@type":["Property","OnOffState","iot:SwitchStatus"], // Interactions
         "link":[
             {"href":"/a/led2relay?di=79683ab5-8df1-4b7a-b110-c1b8fe251e7d",
              "mediatype":"application/json",
              "http:methodName":"http:post", // Methods (specific to protocol binding)
              "rel":"setProperty"},
             {"href":"/a/led2relay?di=79683ab5-8df1-4b7a-b110-c1b8fe251e7d",
              "mediatype":"application/json",
              "http:methodName":"http:get",
              "rel":"getProperty"}
         ],
          → Payload structure and semantics
         },
         → Other interactions: Properties, Events, and Actions
    ]
}
```

Metadata Bridge

Metadata generator updated to include:

- Semantic Annotation
  - WoT tdcontext, common context; iotschema.org,
  - HTTP methodName, rel
  - Capabilities (on Things), Interactions, Data
- Protocol Bindings
  - inputData, outputData

```
// Payload structure and semantics for a Property interaction

"inputData":{
    "type":"object",
    "fields":[
        {
            "name":"value",
            "value":{
                "@type":["iot:Toggle"],  // Data
                "type":"boolean"
            }
        }
    ]
},
"outputData":{
    "type":"object",
    "fields":[
        {
            "name":"value",
            "value":{
                "@type":["iot:Toggle"],
                "type":"boolean"
            }
        }
    ]
}
```

Semantic Annotation: Issues

- Missing Terminology:
  - TemperatureSensor? IlluminanceSensor?
- Inconsistent Terminology:
  - SwitchStatus/Toggle; Light Colour/Current Color; Temperature/TemperatureData

→ Most of these are due to maturity in IoT ontology development

→ Not a blocking issue…

→ Semantic tooling can bridge multiple ontologies

→ New and more precise ontologies can be used as they become available

→ … and as we learn how to write good ones and what the requirements are

Technical Details – System and Network

- SSH Tunnel Reverse Proxy
  - SSH Tunneling is used for NAT traversal, to give local Things a globally accessible access point and URL.
  - Base address in Thing Description needs to be modified depending on whether it is entered into a global or a local Thing Directory
- OCF Metadata Bridge and Thing Directory Cache
  - Global Thing Directory exists in cloud but it is inefficient for local devices to go through cloud to talk to other, local devices on the same subnet
  - In addition to translating metadata and registering TDs, the gateway also runs a local Thing Directory that stores versions of TDs with local links (via a local base address).

To Do: Security Features

- Use Cases from Plugfest
  - Additional lower-level “patterns” or “system configurations”
  - Can also present current set of system configurations in WoT-Sec doc (sec 5)
- Authenticated, Encrypted, Authorized universally available endpoints
  - Authorization: HTTPS + Oauth 2 (global), Web Tokens (local)
  - Payment: Interledger
- Document POCs
  - Intel: HTTPS; SSH tunnel for NAT traversal; OAuth; COAPS locally
  - Issues: local certs for HTTPS? Lets Encrypt/certbot does not work; cert renewal (need certbot…). Look into “HTTPS Local” (W3C CG).

2. Semantic Voice Control

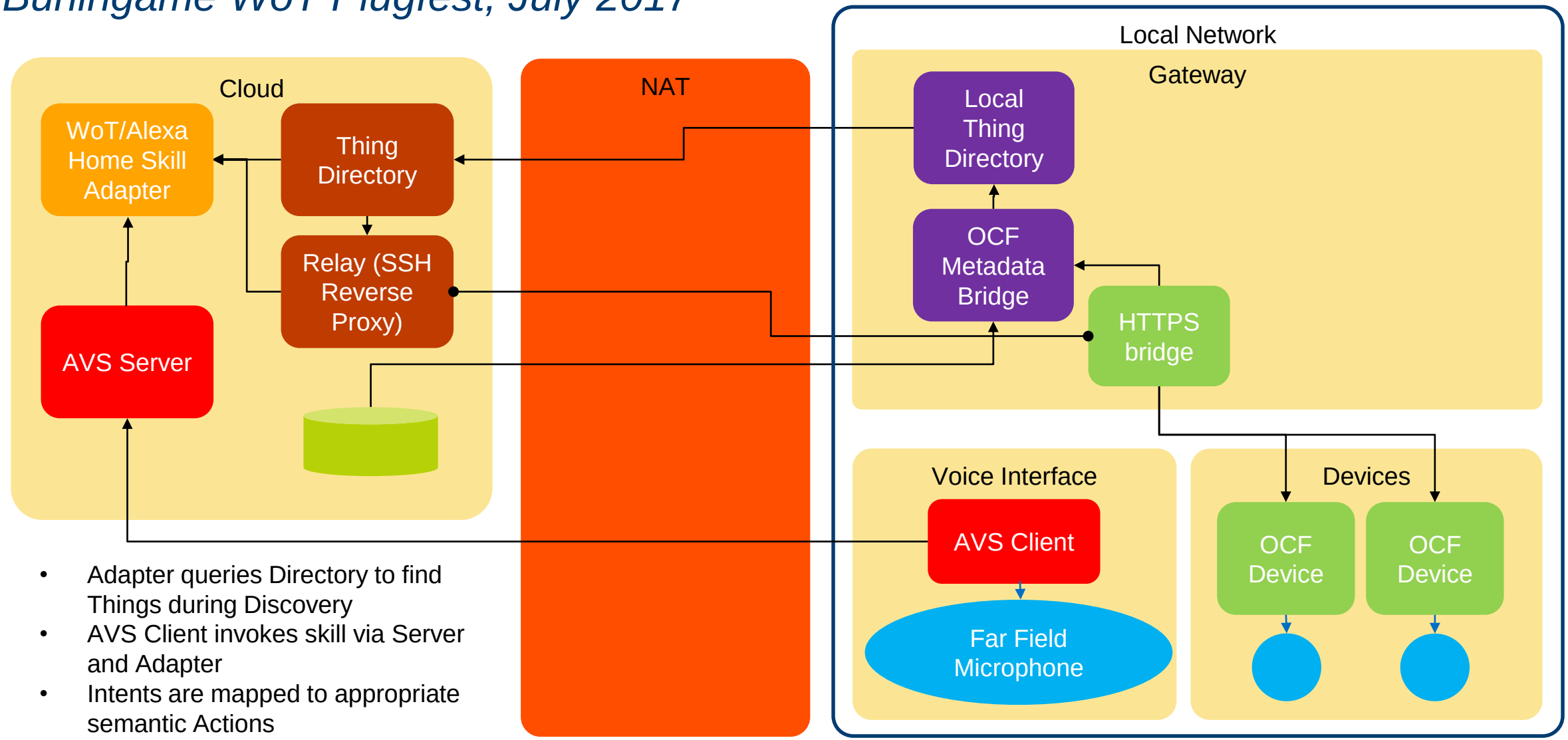
Goal: Enable *automatic* voice control of *any* WoT-enabled device

- Demonstrate use of semantic markup of Thing Description
  - Using iot.schema.org, SSNO ontologies, and semantic inferencing tools
- Generate adaptive AVS Alexa skill, bridging with Alexa Home Skill
- Layer with WoT metadata bridges to control devices from multiple ecosystems (including OCF)

2. Semantic Voice Control

Burlingame WoT Plugfest, July 2017

Goal: Provide generic voice interface using WoT Thing Descriptions



- Adapter queries Directory to find Things during Discovery
- AVS Client invokes skill via Server and Adapter
- Intents are mapped to appropriate semantic Actions

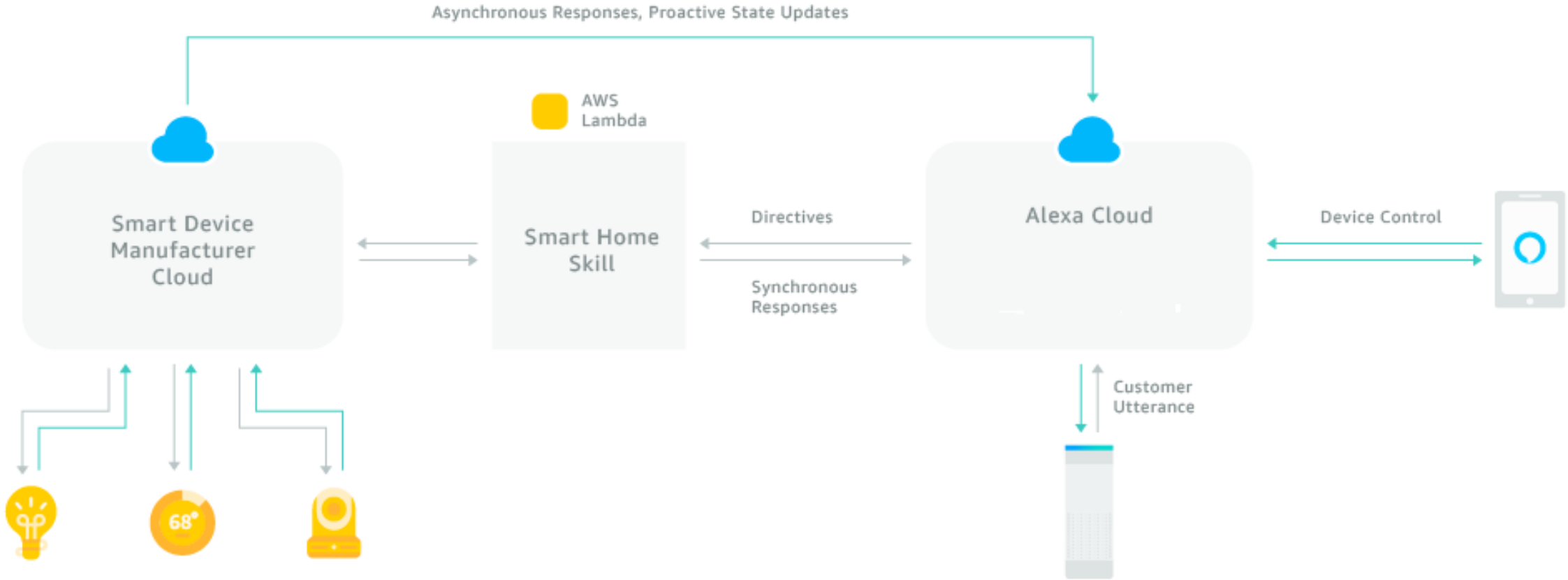
Alexa Smart Home Skill API - Summary

- Assumes devices controlled by “device cloud”: a web service with a public URL.
- Supports set of standard, built-in “intents” with predefined semantics
- When understands one of these intents, creates a “directive” which is sent to an “adapter”, which is typically an AWS lambda function. Lambda is called for discovery first, then later with directives.
- Directive contains: customer authentication, device identifier, and an action-specific payload.
- Adapter should check the authentication (OAuth2.0), then send the payload to the specified device via the device cloud. The “device identifier” includes uuid and cookies provided during discovery.
- Respond with an event that indicates success or failure. Can be synchronous (from the lambda) or asynchronous (from the device cloud).
- Devices can also have shadowed status information and this can be proactively updated.

→ *Note that all interactions MUST complete within 8 seconds, and ideally 5 seconds.*

For details, see https://developer.amazon.com/docs/smarthome/understand-the-smart-home-skill-api.html

Alexa Smart Home Skill API - Summary



AVS Home Skill Semantics: Capabilities

Device functionality is modeled by specifying a set of standard capabilities.

- Each capability has a specific interaction model and payload
  …really more like an “interface” than just a semantic category
- Devices can support more than one capability
- “Device clouds” can have more than one device…

There are also a set of standard capabilities to get/set properties

Many capabilities support both absolute and relative mechanisms to adjust properties

Many “actions” also report the current state

AVS Home Skill Capabilities: Targets

Capability	Description
PowerController	TurnOn or TurnOff a device (has associated powerState)
PowerLevelController	SetPowerLevel (absolute) or AdjustPowerLevel (relative) on a device. Has an associated powerLevel property that can be set to a valuel between 0 and 100
PercentageController	Generic interface similar to PowerLevelController or BrightnessLevelController, but used when “power” or “brightness” is not a valid description of the controlled property. Assumes a value between 0 and 100 in an “percentage” property. Can also be used to read sensors.
TemperatureSensor	No controls, just use ReportState/StateReport to query “temperature” property.
BrightnessController	SetBrightness (absolute) or AdjustBrightness (relative) on a light. Has an associated brightness property that can be set to a value between 0 and 100
ColorTemperatureController	SetColorTemperature (absolute) or DecreaseColorTemperature, IncreaseColorTemperature (relative, no value) on a device. Has an associated colorTemperature property that can be set to a temperature in Kelvin (voice interface understands color names, “warm”, “daylight”, etc).
ColorController	SetColor of a light using “color” whose type is a hue, saturation, brightness (HSB) triple. Note that mapping from this to RGB involves a matrix transform and a nonlinearity. Voice interface uses color names.

AVS Home Skill Capability: Additional Examples

Capability	Description
LockController	Lock or Unlock a lock device
ThermostatController	Supports thermostats with one, two, or three setpoints. Can also be queried to find the current temperature using a property and ReportState/StateReport. There is also a “mode” property: ECO, AUTO, COOL, HEAT, etc.
InputController	Select AV input to a TV using set of standard names (HDMI, etc)
ChannelController	Select Channel on a TV (both absolute and relative)
PlaybackController	Start and stop audio source
SceneController	Select a scene by name. Some limits on discovery based on device type.
Speaker	SetVolume, AdjustVolume, SetMute
StepSpeaker	AdjustVolume, SetMute (a subset of “Speaker” with no absolute volume, for when range of volume is not known).
CameraStreamController	Start and stop streaming video

AVS Home Skill Semantics: System Messages

Directives can also get or create messages with various types corresponding to “system capabilities”.

Capability	Description
Discovery	Every device: reports initial identification and capabilities
Authorization	AcceptGrant, provides bearer token, currently only OAuth2.0 supported
Response	Respond to directive - success
ErrorResponse	Respond to directive – error/failure, gives type of error, message for logging. Errors can include system issues (eg connectivity) but also payload issues (value out of range).
ReportState	Request state report
StateReport	Reply to state report
DeferredResponse	Used to indicate that will respond asynchronously to request (typ. >8s needed)
EndPointHealth	Check if physical endpoint can be reached from cloud shadow. Has associated Boolean property, “connectivity”

AVS Issues and Notes

- "Device Cloud" (IoT service endpoint) *must* support HTTPS and be visible to AWS cloud
- OAuth2.0 authentication *must* be supported.
- Responses *cannot* take longer than 8s.
  - Live querying of the device status, if it takes longer than that, needs to use a shadow. The shadow state then needs to be proactively or asynchronously updated.
  - Actions that take longer than 8s to complete should use an asynchronous response to indicate completion.
- Property status reporting
  - Not just the value, but also the timestamp, time uncertainty, and units
- Optional features:
  - Status query, proactive status updates, scenes and scene discovery, streaming video and audio

3. Fog Integration

Goal: Make services discoverable and locally available using WoT combined with fog capabilities.

- Run WoT services on fog (OpenFog) software stack
  - Thing directory (WoT discovery)
  - Metadata bridges (eg to OCF)
  - Voice skill services (eg AVS)
  - Application servients (IoT services)
- Connect to computational services
  - Recognition service (eg Movidius NCS)

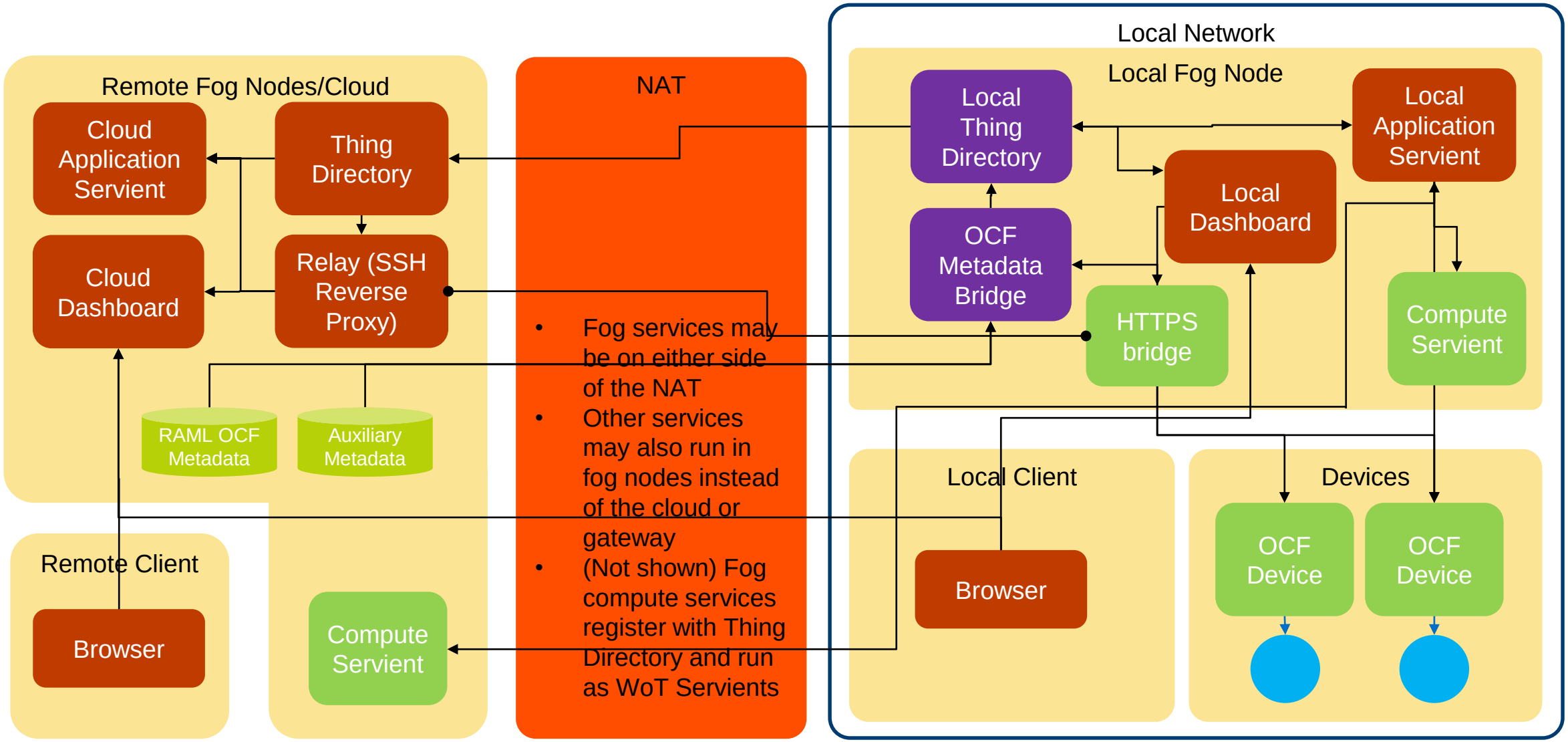
3.5 Fog Integration

Goal: Provide accelerated compute services in the fog.

- Hardware and software stack
  - Fog Reference Design (FRD)
  - Kaby Lake CPU and Arria 10 FPGA
  - DLIA and OpenCL software libraries
- Host accelerated compute service
  - WoT Servient (virtual Thing)
  - Discovery via Thing Directory
  - *Other management services needed*

3.x Fog Integration

Add: Compute services running on local and remote fog nodes



To Do: Industrial POCs

- Voice control is primarily a *home* use case
- What do we want for industrial use cases?
- What is different about industrial requirements?
  - Set of standards and their requirements are different
  - Real-time, pub-sub architectures, TSN, functional safety, central management, asset management, complex access controls, energy management…
  - Less emphasis on privacy, more on safety
- Are municipal and building use cases more like home or industrial use cases?
- What about automotive? Transportation? Retail? Medical?
  - They all have their own ecosystems…

Scenarios

Need to work through some specific scenarios…

- Voice Control for Consumer End Users
- Service Composition for System Integrators
- Compute Services (eg person recognition) for other Service Providers

Include not only home, but also industrial and municipal

- Long tail – translation to older protocols
- Adapt to different requirements, eg real time and functional safety

→ Need to talk to industrial users about requirements

Smart Security Scenario: Person Detection

This specific scenario can be demonstrated using OCF Smart Home capabilities, combined with one or more IP cameras. This application is of use in multiple verticals (home (eg security system), industrial (eg functional safety), municipal (eg subway track ingress).

Problem: Simple proximity detection systems, such as motion sensors, can be triggered by events other than human presence, leading to false alarms. However, constantly running AI-based human recognition is expensive.

Solution: Combine simple distributed motion sensors with AI-based person recognition. When a motion sensor is triggered, an image is captured in that location and sent to a person recognition service. Only if a person is detected is an alarm triggered. In addition, the AI service can be centralized so that only one recognition service is needed even if there are multiple cameras and motion sensors. As an extension, cameras could be mounted on mobile platforms (aka robots…).

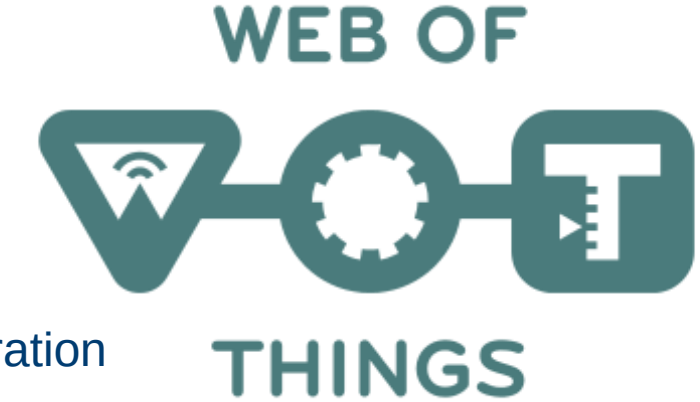
Summary

- Interoperability has significant business value in IoT
- The Web of Things approach supports interoperability
  - By describing system interfaces (as opposed to prescribing them)
  - Main deliverable: a universal metadata format (“Thing Description”) for IoT services (“Things”)
- *We need to work though some concrete scenarios (POCs)*
- Ideally, include fog computing in system architecture

WoT: Related W3C Standards

- RDF: Resource Description Framework
  - General mechanisms for defining data semantics and vocabularies
  - Useful for working with metadata
- SSNO: Semantic Sensor Network Ontology
  - Vocabularies (ontologies) and semantics for sensor data
- JSON-LD: JSON (JavaScript Object Notation) Linked Data
  - Mechanism for encoding RDF in JSON, used for Thing Description serialization
- See also:
  - iot.schema.org: Vocabularies and semantics for IoT, defined using RDF

Web of Things: Resources and Links



W3C: World Wide Web Consortium: https://www.w3.org

Web of Things Interest Group: https://www.w3.org/WoT/IG/

- Charter: Leverage web standards and technology to enable IoT interoperation
- Web architecture: https://www.w3.org/standards/webarch/

Web of Things Working Group in the W3C to develop standard recommendations:

- https://www.w3.org/2016/09/wot-wg-charter.html
- Co-chairs: Matthias Kovatsch (Siemens), Kazuo Kajimoto (Panasonic), Michael McCool (Intel)
- White paper on WoT architecture: http://w3c.github.io/wot/charters/wot-white-paper-2016.html

WoT current practices: http://w3c.github.io/wot/current-practices/wot-practices.html