Tutorial: **RFID as Ambient Data**

Jeffrey Dungen
reelyActive

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RFID as **Ambient Data**

There are **tens of billions of standard radio-identifiable things** shipping annually in the form of RAIN RFID (passive) tags and Bluetooth Low Energy (active) transceivers. **In any given physical space today**, it is not uncommon to discover such radio-identifiable things, often in the tens and even hundreds. The opportunistic discovery, identification, location and interpretation of sensor data from these RFID devices represents **ambient data**, which affords computers the ability to make sense of the physical spaces they occupy. In this tutorial we'll examine the collection and interpretation of ambient data from RFID, including the lookup of **digital twins** and the combination of data collected independently by **co-located systems**, leading to the concept of **collective hyperlocal context**.

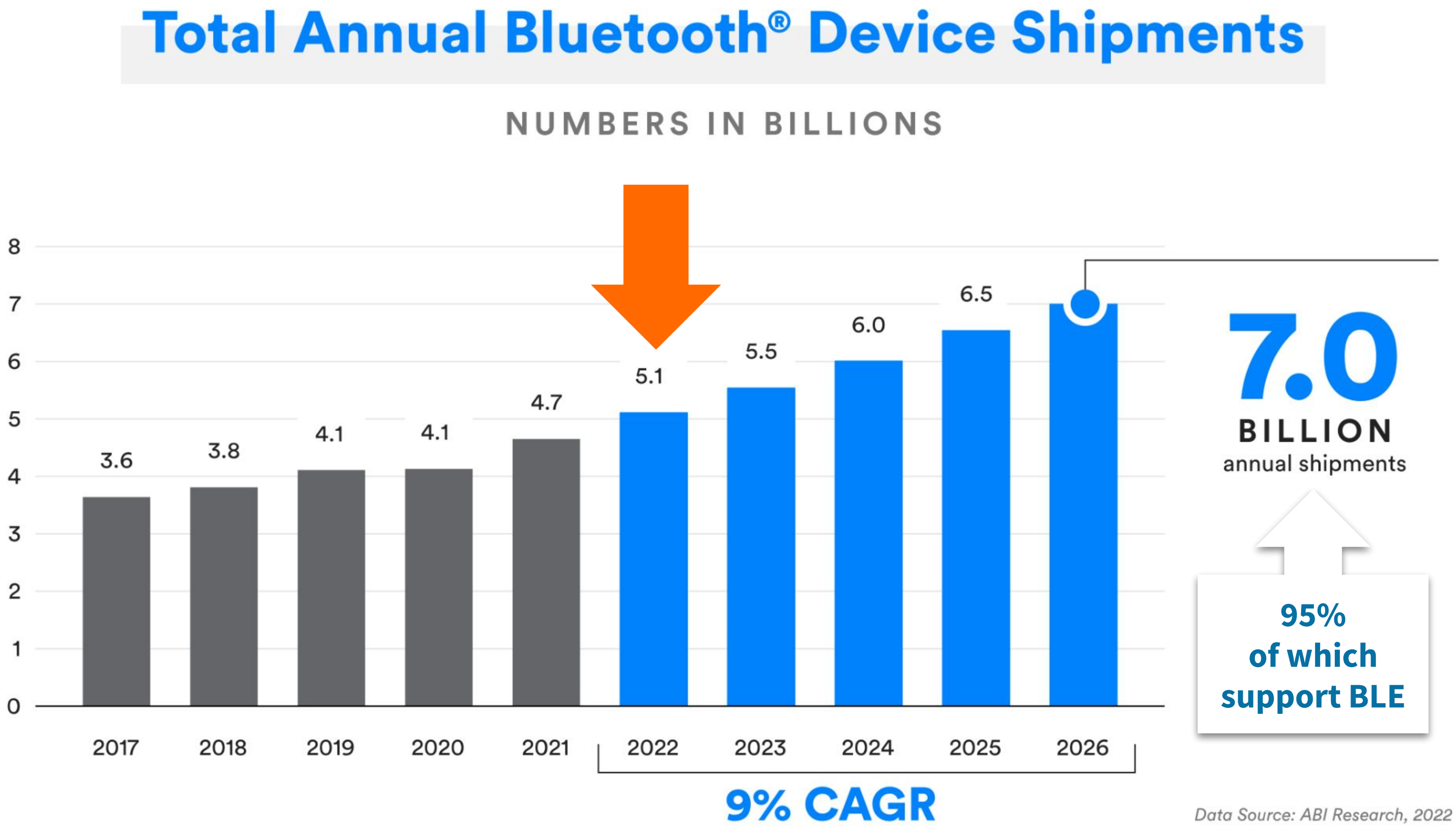
There are **tens of billions of standard radio-identifiable things** shipping annually in the form of RAIN RFID (passive) tags and Bluetooth Low Energy (active) transceivers.

By the end of 2021 there were over

112 Billion

RAIN RFID tags deployed.

— Steve Halliday, President of RAIN


Total Annual Bluetooth® Device Shipments
NUMBERS IN BILLIONS
8
7
6
5
4
3
2
1
0
3.6
3.8
4.1
4.1
4.7
5.1
5.5
6.0
6.5
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
9% CAGR
7.0
BILLION
annual shipments
95%
of which
support BLE
Data Source: ABI Research, 2022

is **RFID?**

Photo by charlesdeluvio on Unsplash

Indeed! I presented an entire tutorial on this

at IEEE RFID 2017

https://2017.ieee-rfid.org/files/2017/01/IEEE-RFID-2017-BLE-as-Active-RFID.pdf

Bluetooth®

(Specifically Bluetooth Low Energy)

RAIN® RFID

Active RFID

Spontaneously transmits,
via radio-frequencies,
its identifier,
using its own source of power.

UHF Passive RFID

Backscatters,
via radio-frequencies,
its identifier,
powered by an external signal.

Bluetooth®

(Specifically Bluetooth Low Energy)

RAIN® RFID

~10m+ range

~10m range

Human Scale

Identifiable within a physical space

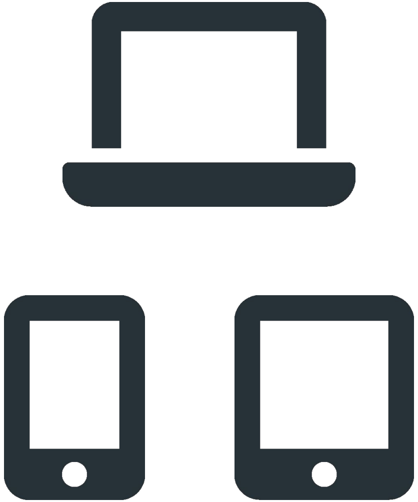
“Personal Area Network”

There are **tens of billions of standard radio-identifiable things** shipping annually in the form of RAIN RFID (passive) tags and Bluetooth Low Energy (active) transceivers.

⋮

In any given physical space today, it is not uncommon to discover such radio-identifiable things, often in the tens and even hundreds.

Bluetooth®



Nearly **100%** of key new platform devices support dual mode (Bluetooth® Classic + Bluetooth LE)

Data Source: ABI Research, 2022

The devices with which we interact are radio-identifiable.

Bluetooth®

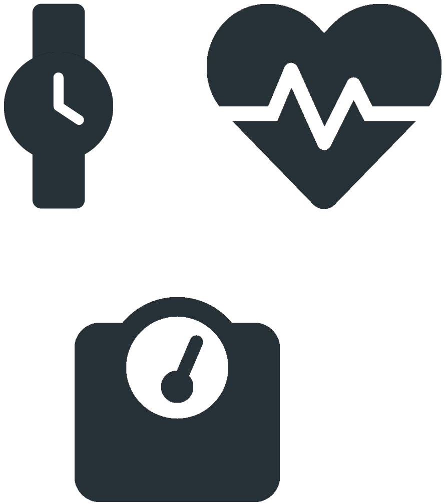
675
MILLION

Bluetooth® headphones will ship in 2022

Data Source: ABI Research, 2022

The devices we listen to are radio-identifiable.

Bluetooth®



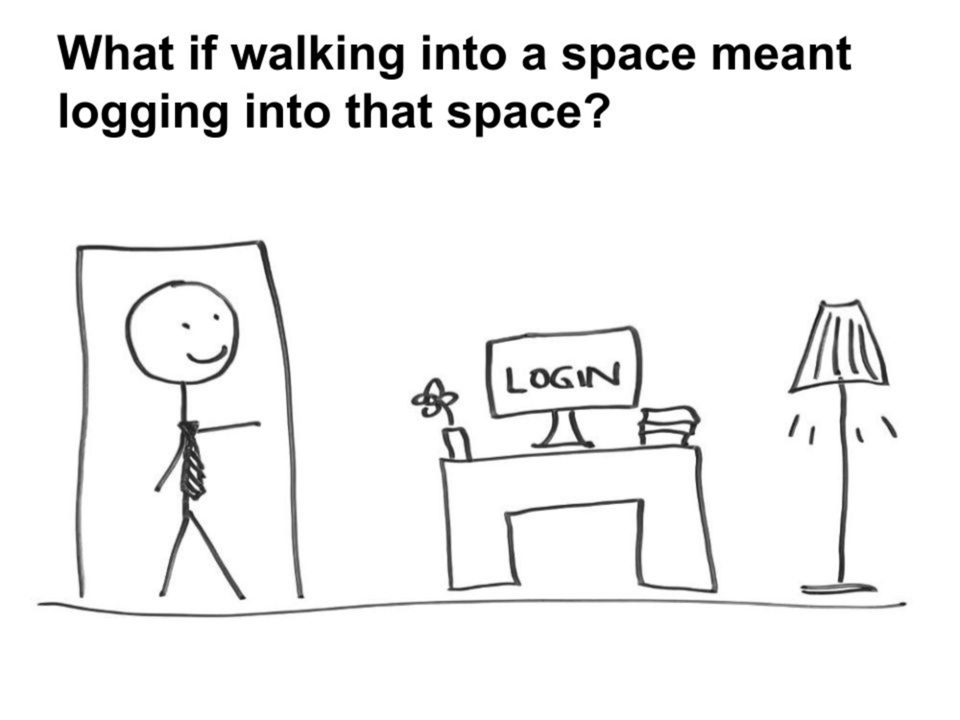
432
MILLION

personal Bluetooth® consumer electronics will ship in 2022

Data Source: ABI Research, 2022

The devices we wear and use are radio-identifiable.

In **2012**, we mused in our first ever pitch…

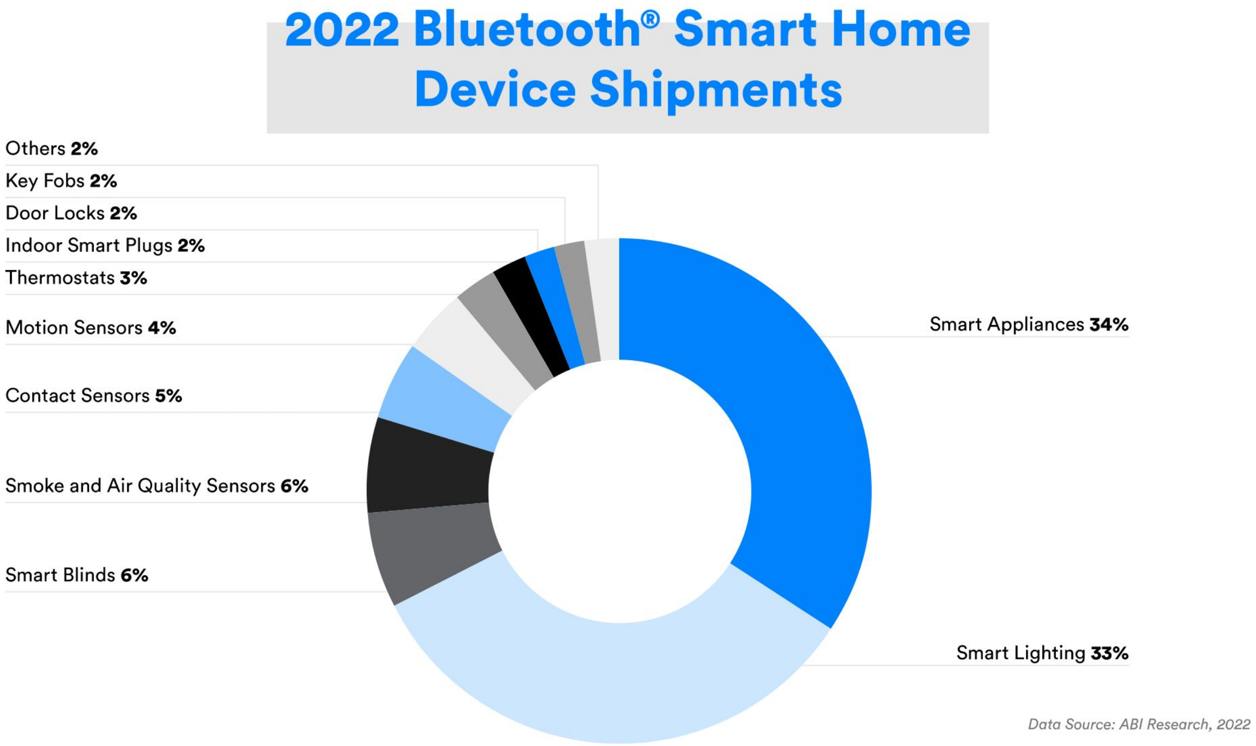


…now in **2022**, spaces are full of *personal* RFID!

https://reelyactive.com/blog/archives/488

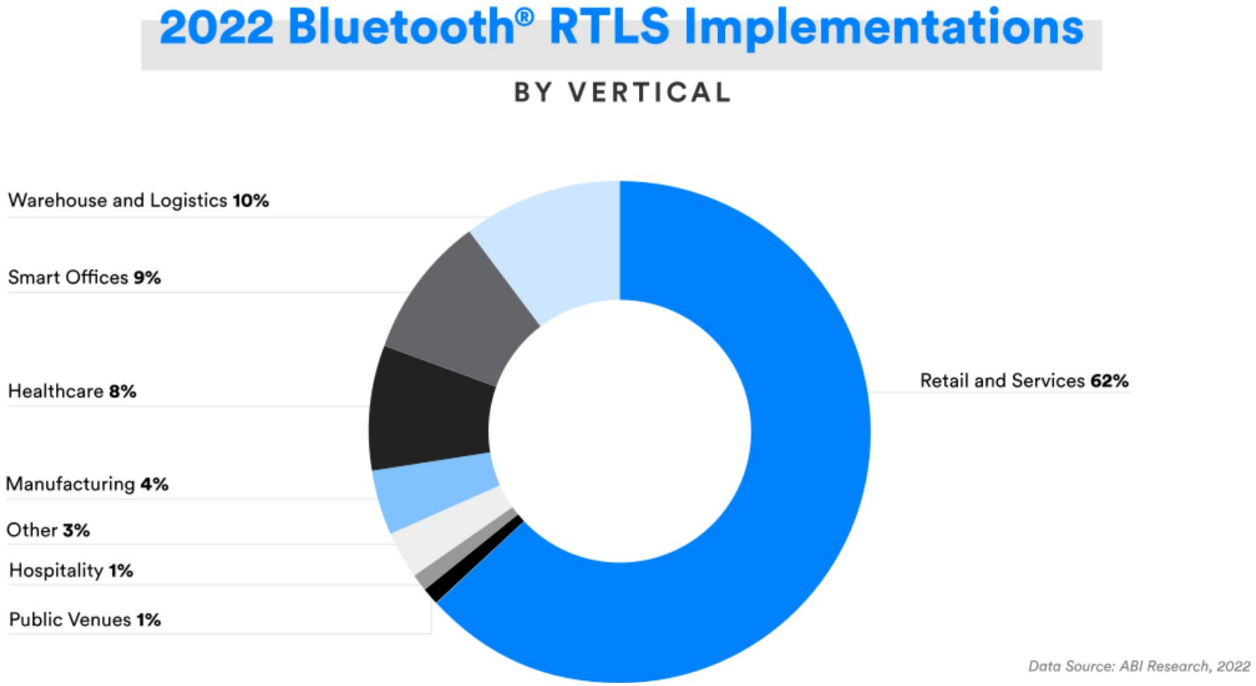
Bluetooth®

At home



Bluetooth®

Outside home



RAIN RFID

Item-level

	ANNUAL VOLUME & 2019 ATTACH RATES
FOOD ITEMS	• 2 Trillion • 0.03% Attach Rate
PARCELS	• 90 Billion • 0.02% Attach Rate
APPAREL & FOOTWEAR	• 80 Billion • 16% Attach Rate
COSMETICS	• 120 Billion • 0.01% Attach Rate
AIRLINE BAGGAGE	• 4 Billion • 7% Attach Rate
AUTOMOTIVE	• 603 Billion • 0.02% Attach Rate
LOGISTICS	• 10 Billion • 15% Attach Rate

Source: VDC Research (2020)

Bluetooth®

(Specifically Bluetooth Low Energy)

RAIN® RFID

People & Assets

Dollars-per-device…

—but—

Most spaces already include potential readers!* ✓

* any Bluetooth Low Energy device with a network connection and continuous power supply can be a reader

Item-level

Pennies-per-tag! ✓

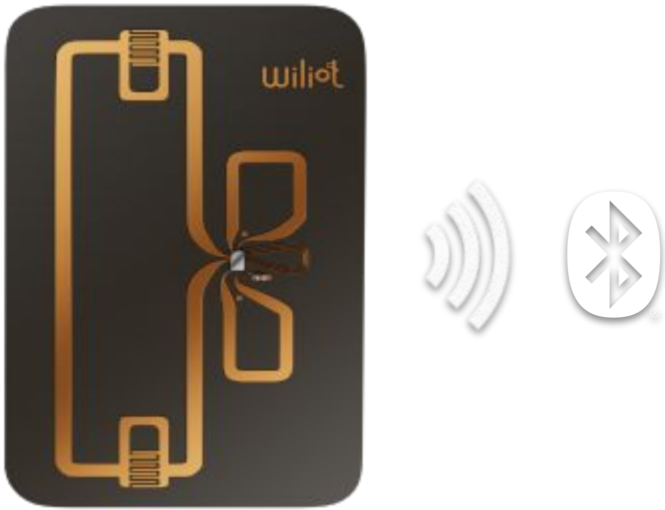
—but—

Few spaces equipped with readers*…

* readers are typically limited to dedicated deployments due to cost and complexity

UT WAIT...

What if it were possible to create Bluetooth tags inexpensive enough to be used for **item-level traceability** which leverage the near-ubiquity of Bluetooth readers throughout the spaces in which we live, work and play?!? 🤔



Wiliot's IoT Pixels combine the cost-effectiveness of passive inlay manufacturing with Bluetooth Low Energy advertising to realise the prospect of item-level traceability throughout *any* space. 😎

In any given physical space today, it is not uncommon to discover such radio-identifiable things, often in the tens and even hundreds.

⋮

The opportunistic discovery, identification, location and interpretation of sensor data from these RFID devices represents **ambient data**, which affords computers the ability to make sense of the physical spaces they occupy.

Ambient: existing in the surrounding area

Source: Cambridge Dictionary

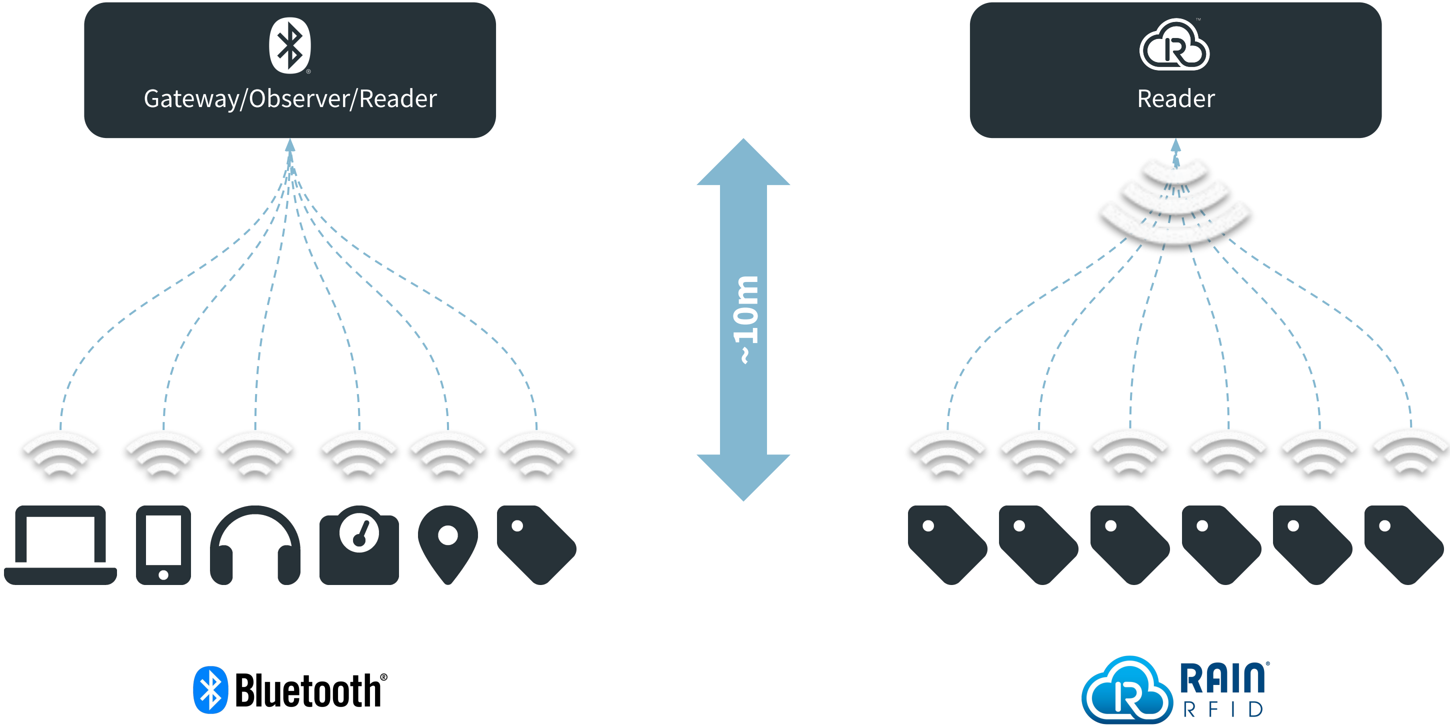
Ambient data:

data existing in the surrounding area

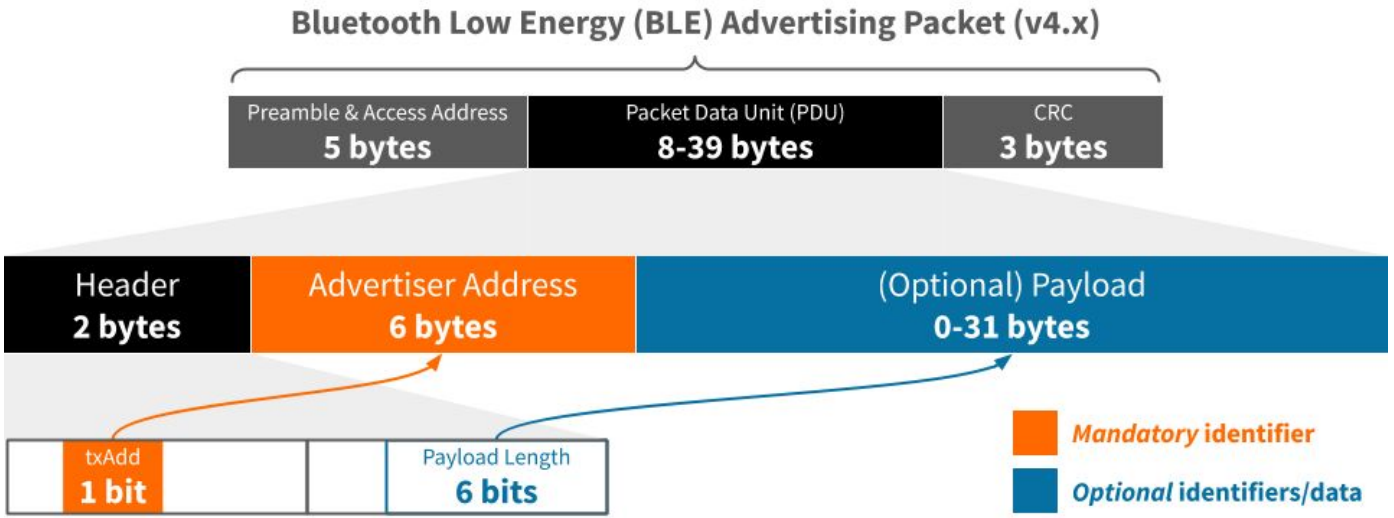
Let's get to **ambient data** in four ***opportunistic*** steps:

1. Discovery
2. Identification
3. Location
4. Interpretation of sensor data

1. Opportunistic **discovery**



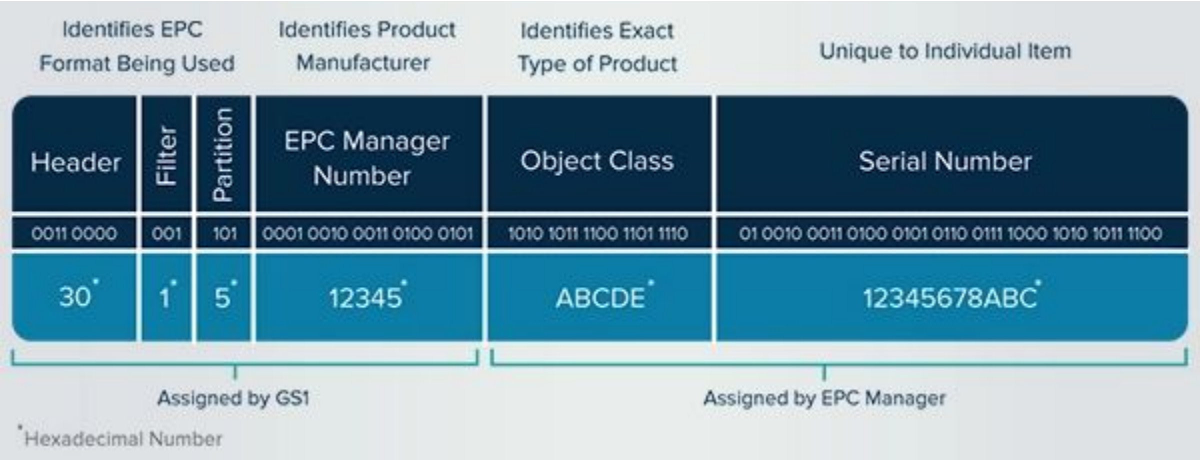
2a. Opportunistic **identification**



Every Bluetooth Low Energy advertising packet includes a **48-bit advertiser address** as an identifier, and *may* contain **additional identifiers** in the *optional* payload.

https://reelyactive.github.io/diy/best-practices-ble-identifiers/

2b. Opportunistic **identification**



Every RAIN RFID tag includes a unique **160-bit tag identifier (TID)** and *may* include an **electronic product code (EPC)** in its memory banks.

Image source: https://www.impinj.com/products/technology/how-do-rain-rfid-systems-work

What sense can computers make of the **ambient data** from opportunistic **discovery** and **identification**?

- **How many?**
- *What?**
- *Who?**

* could this be looked up against the EPC or other optional identifiers?

Electronic Product Code (EPC) = **What** is this item?

EPCglobal® is a GS1 initiative to innovate and develop industry-driven standards for the Electronic Product Code™ (EPC) to support the use of Radio Frequency Identification (RFID) and allow global visibility of items (EPCIS) in today's fast-moving, information rich, trading networks.

Source: https://www.gs1.org/epcglobal

Solve this challenge: https://www.herox.com/digitaltwins

IEEE CRFID and RAIN Alliance

6,949 Share Follow (58)

Resolving the Internet of *Every* Thing

Design a web resolver that connects physical things to their digital twins in the cloud, enabling people to securely access their twins.

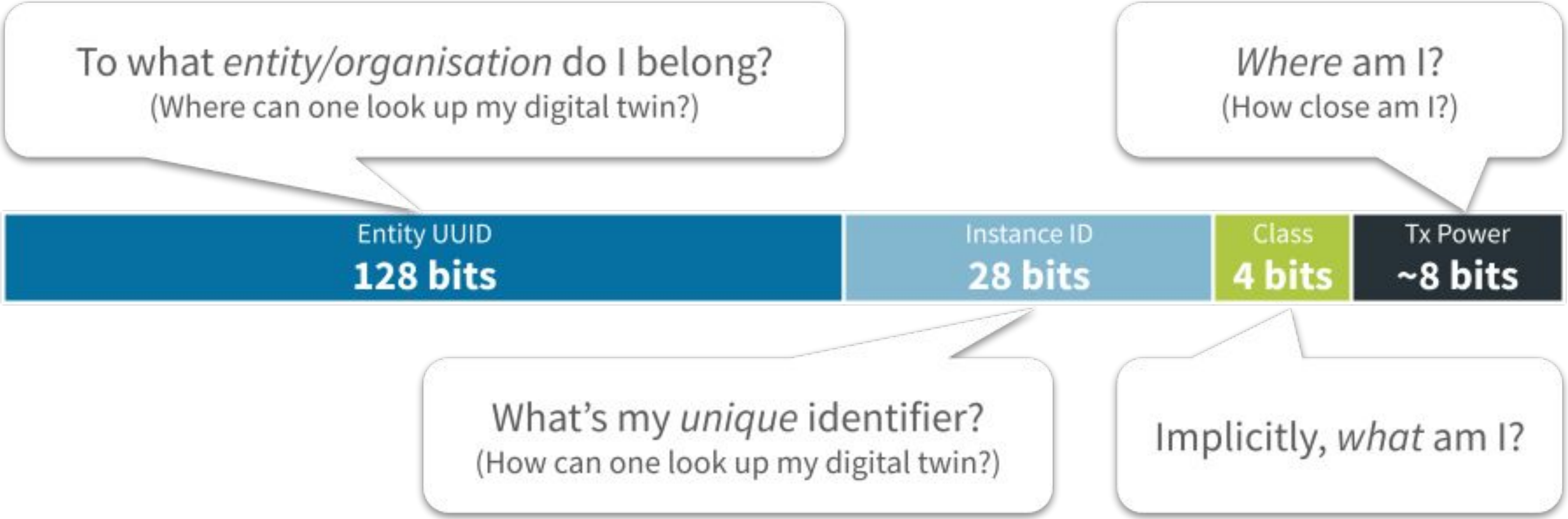
Engineering | Infrastructure | Technology | Powered By HeroX

Stage:
Live Q&A

Prize:
$10,000

SOLVE THIS CHALLENGE

We propose: the **InteroperaBLE Identifier**



Compatible with: Apple **iBeacon** Google **Eddystone**

Learn more: https://reelyactive.github.io/interoperable-identifier/

Universally Unique ID (UUID) = **What** is this product/service?

Some UUIDs can be associated with a specific product or a class of products. **Sniffypedia.org** facilitates the lookup of UUIDs and other identifiers against standard machine-readable data in the form of Schema.org & JSON-LD.

Lookup: https://sniffypedia.org/

Company Code = **What** is the company behind this device?

The Bluetooth SIG maintains a list of assigned numbers including company identifiers. Each 16-bit code is assigned to a specific organisation which may use it to transmit custom payloads (which may in turn contain additional identifiers).

Lookup: https://www.bluetooth.com/specifications/assigned-numbers/company-identifiers/

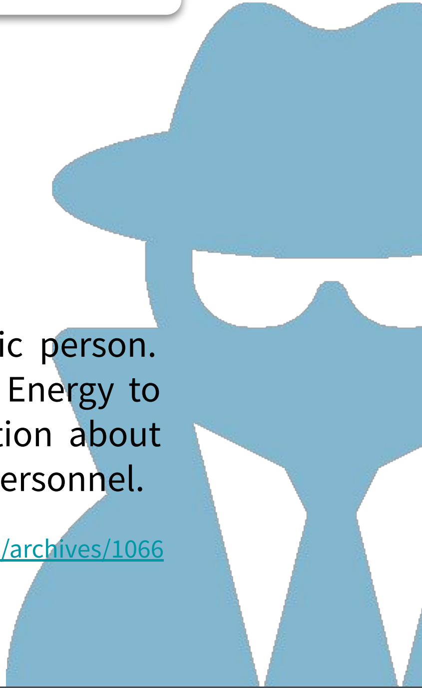
Complete Local Name: Harald’s iPhone

URI: https://jeffyactive.github.io

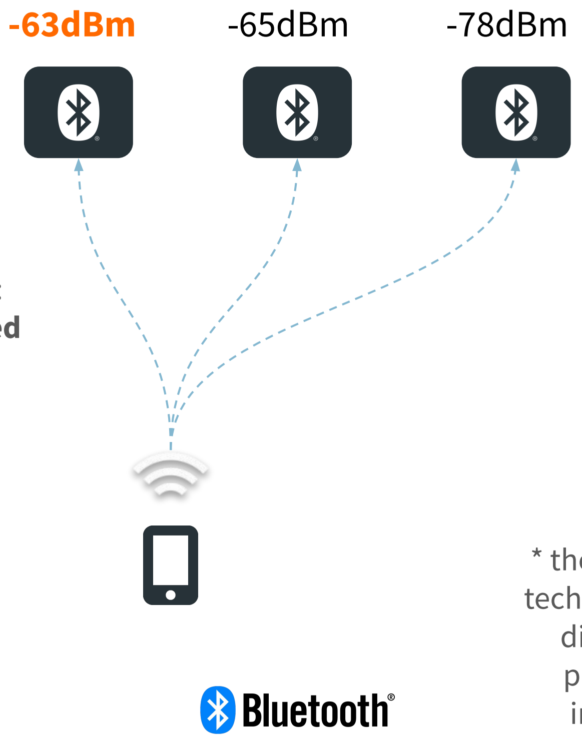
Who is this?

There is—*for obvious reasons*—no explicit public means to look up a specific person. Nonetheless, should one choose to do so, it is possible with Bluetooth Low Energy to transmit a short name or a URI which points to machine-readable information about oneself. An organisation may also maintain an internal lookup of identifiers to personnel.

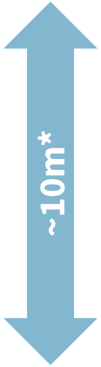
“Advertise yourself” with the Physical Web and beyond: https://reelyactive.com/blog/archives/1066



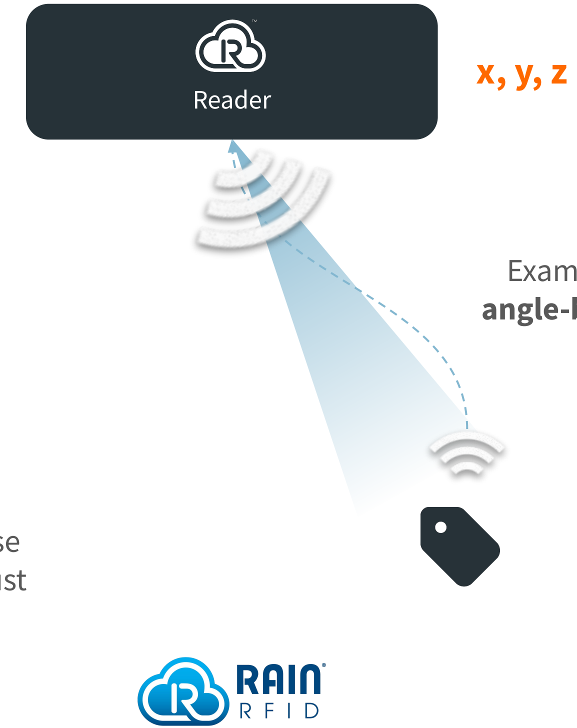
3. Opportunistic **location**



Example:
RSSI-based



* the human-scale-range of these technologies means that even just discovery/identification may provide meaningful location information in and of itself!



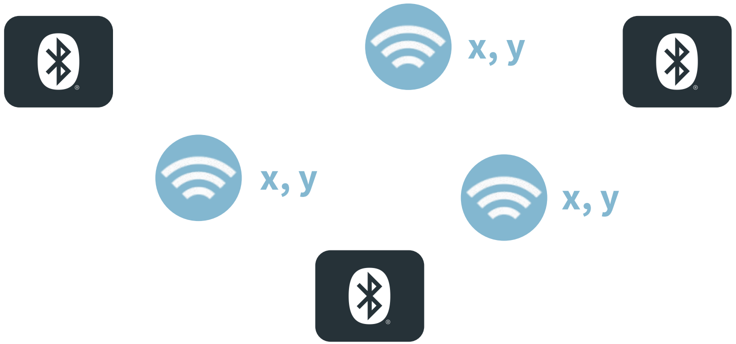
Example:
angle-based

What sense can computers make of the **ambient data** from opportunistic **location**?

- **Where?**
- Displacements
- *Occupancy**

* assuming “occupants” can be identified distinctly from other devices

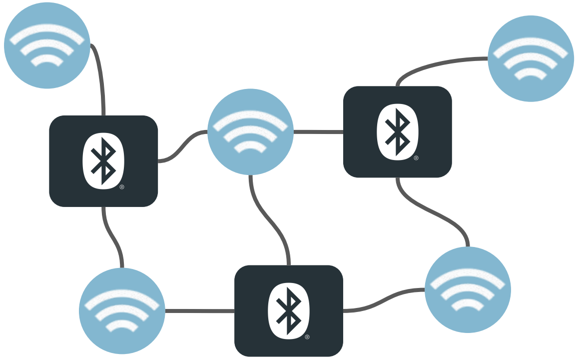
Location as *geocoordinates*



Where exactly is each device?

Precision has generally been the metric for real-time location systems (RTLS) and for some applications, precise location using geocoordinates is essential.

Location as *a graph*



What is each device nearest to?

A graph representation lends itself better to **opportunistic location** given that proximity (either binary or RSSI-based) is all that can be reasonably expected across systems.

4. Opportunistic **interpretation of sensor data**

(Optional) **Payload**

Temperature
Battery Level
Humidity
Illuminance
Heart Rate

Motion Detected
Acceleration
Uptime
Contact Detected
Magnetic Field

Bluetooth®

Process
Decode
Interpret

Memory Banks

Temperature
Pressure
Moisture
Touch
…

RAIN RFID

What sense can computers make of the **ambient data** from opportunistic **interpretation of sensor data**?

- **How?**
- Physical environment
- *Interaction dynamics**

* occupants can be detected by sensors, not only via their own devices

EnOcean EMSIB

Motion Detected
via accelerometer

- Chair occupied
- Desk occupied
- Vehicle in motion
- Machine in operation
- …

Minew B10

Button Pressed
via mechanical pushbutton

- Assistance requested
- Manual check-in
- Action requested
- Acknowledgment
- …

EnOcean EMDCB

Motion Detected
via passive infrared (PIR)

- Room occupied
- Desk occupied
- Passage detected
- Intrusion detected
- …

Minew S4

Contact Detected
via magnetic proximity sensor

- Door closed
- Window closed
- Cabinet closed
- Lid closed
- …

advlib is an open source library which decodes sensor data (**How?**) and identifiers (**What?**) from raw payloads.

advlib outputs a **standard set of properties** ensuring interoperability across vendors and technologies.

Repository: https://github.com/reelyactive/advlib

Property	Type	Notes
acceleration	Array of Number	[x, y, z] In g
angleOfRotation	Number	In degrees
appearance	String	From Bluetooth
batteryPercentage	Number	0 to 100 (%)
batteryVoltage	Number	In volts
deviceIds	Array of String	
elevation	Number	In m
heading	Number	In degrees
heartRate	Number	In beats per minute
illuminance	Number	In lx
interactionDigest	Array of Object	
isButtonPressed	Array of Boolean	
isContactDetected	Array of Boolean	
isMotionDetected	Array of Boolean	
magneticField	Array of Number	[x, y, z] In G
name	String	
nearest	Array of Object	
position	Array of Number	[lon, lat, ele]
pressure	Number	In Pa
relativeHumidity	Number	0 to 100 (%)
relay	Object	See note below
speed	Number	In m/s
temperature	Number	In Celcius
txCount	Number	
txPower	Number	In dBm
uptime	Number	In milliseconds
uri	String	
uuids	Array of String	
version	String	Format pending

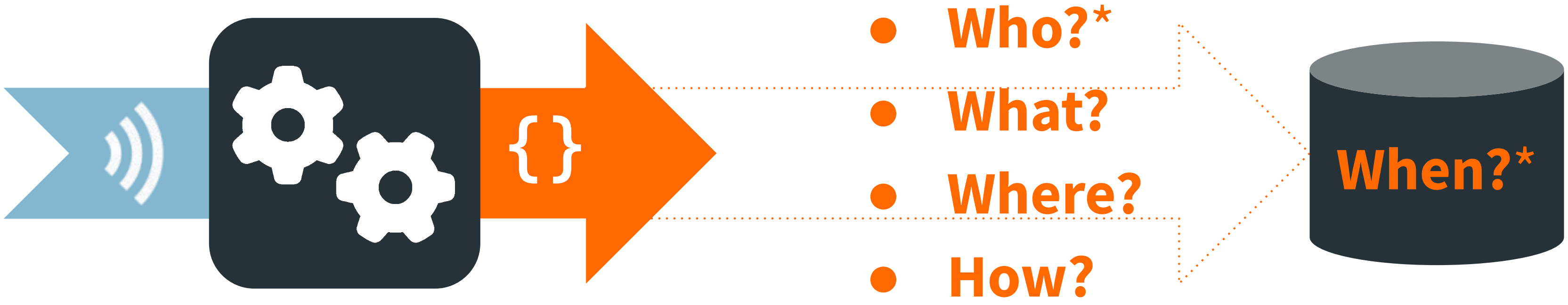
The **InteroperaBLE Identifier** applies to sensor data too!

UUID	Instance ID	Interpretation
496f4944-434f-4445-b73e-427574746f6e	n/a	**isButtonPressed**: true
496f4944-434f-4445-b73e-5554462d3332	ex: 001f989	**Unicode Code Point**: 🦉
496f4944-434f-4445-b73e-2e2f2e6d7033	ex: 0000001	**Sound file**: 0000001.mp3

👍

Learn more: https://reelyactive.github.io/interoperable-identifier/

What sense can computers make of the **ambient data** from opportunistic **discovery**, **identification**, **location** *and* **interpretation of sensor data** of *all* the RFID devices present?



* with informed consent

* with a database

We need to **empower computers** with their own means of gathering information, so they can see, hear and smell the world for themselves, in all its random glory. **RFID** and sensor technology enable computers to observe, identify and understand the world—***without the limitations of human-entered data.***

— Kevin Ashton

That 'Internet of Things' Thing
RFID Journal, 2009

1999

Kevin Ashton coins the term

Internet of Things

at a time when RFID technology is largely confined to laboratories.

Computers can make sense of the physical world around them only in **controlled demos**.

2022

Human-scale RFID has become so prevalent in our daily lives that it can be considered

ambient data.

Computers can **opportunistically** make sense of the physical world around them.

The opportunistic discovery, identification, location and interpretation of sensor data from these RFID devices represents **ambient data**, which affords computers the ability to make sense of the physical spaces they occupy.

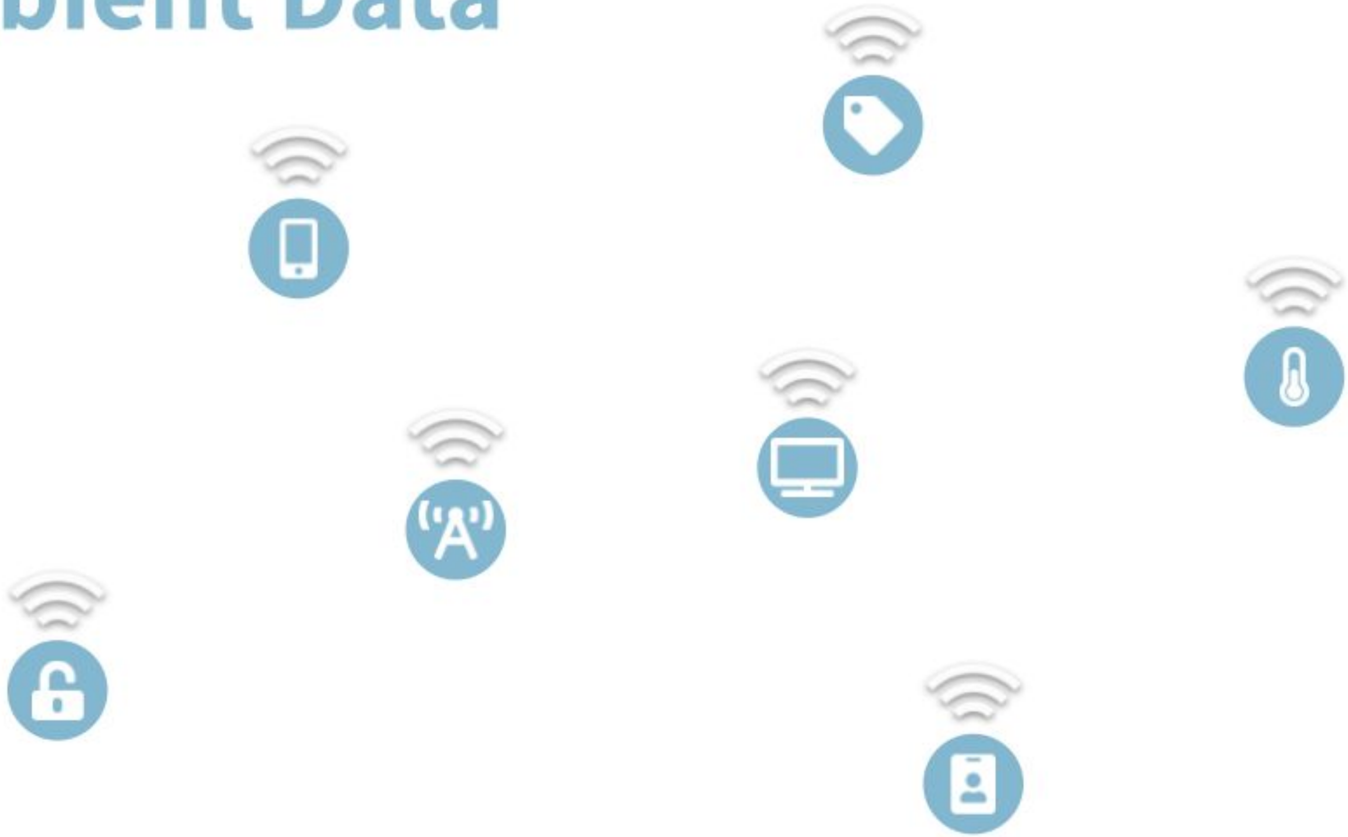
⋮

In this tutorial we'll examine the collection and interpretation of ambient data from RFID, including the lookup of **digital twins** and the combination of data collected independently by **co-located systems**, leading to the concept of **collective hyperlocal context**.

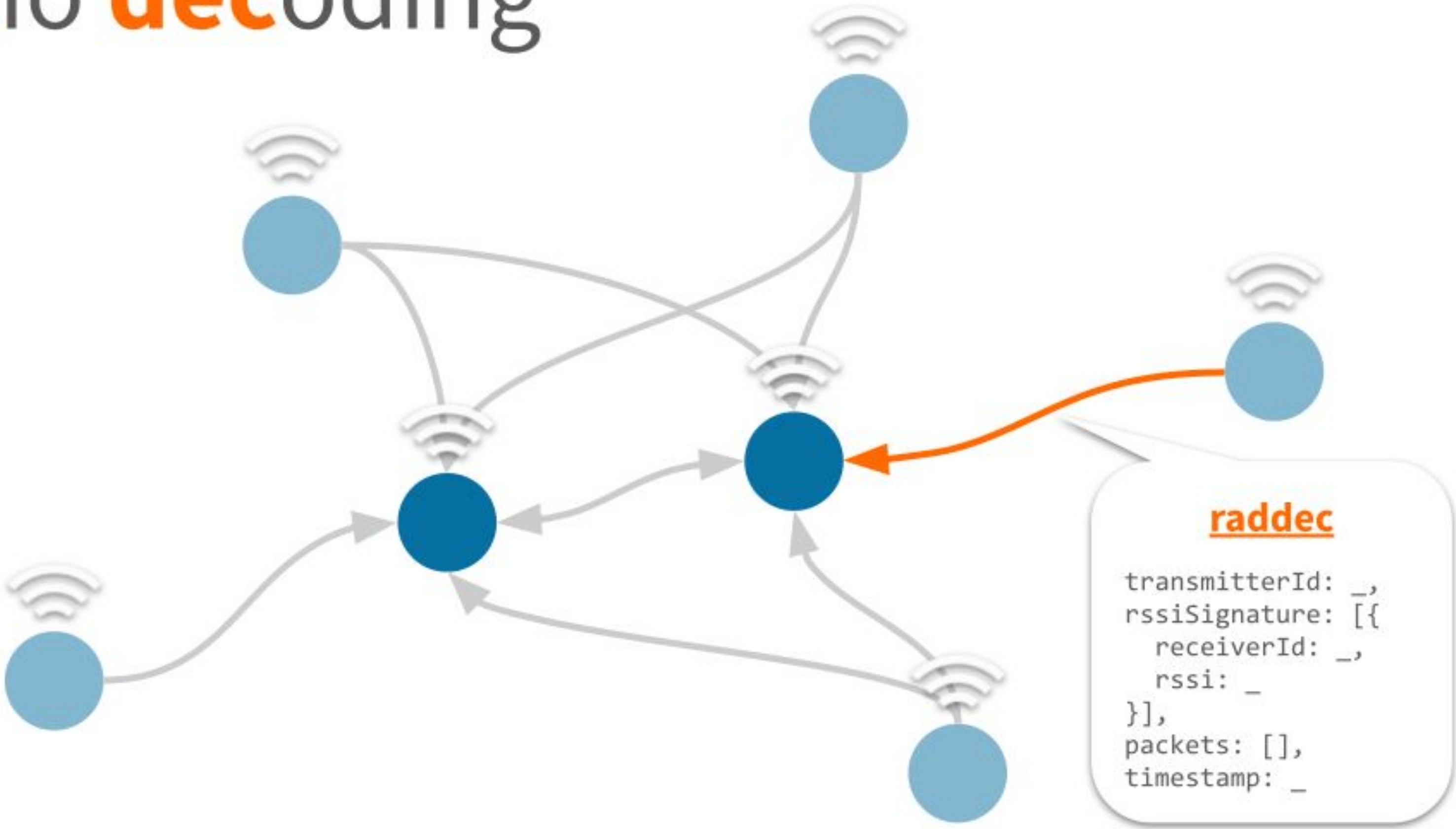
First, let's get from **ambient data** to **hyperlocal context** in nine steps.

As presented at: https://www.reelyactive.com/context/

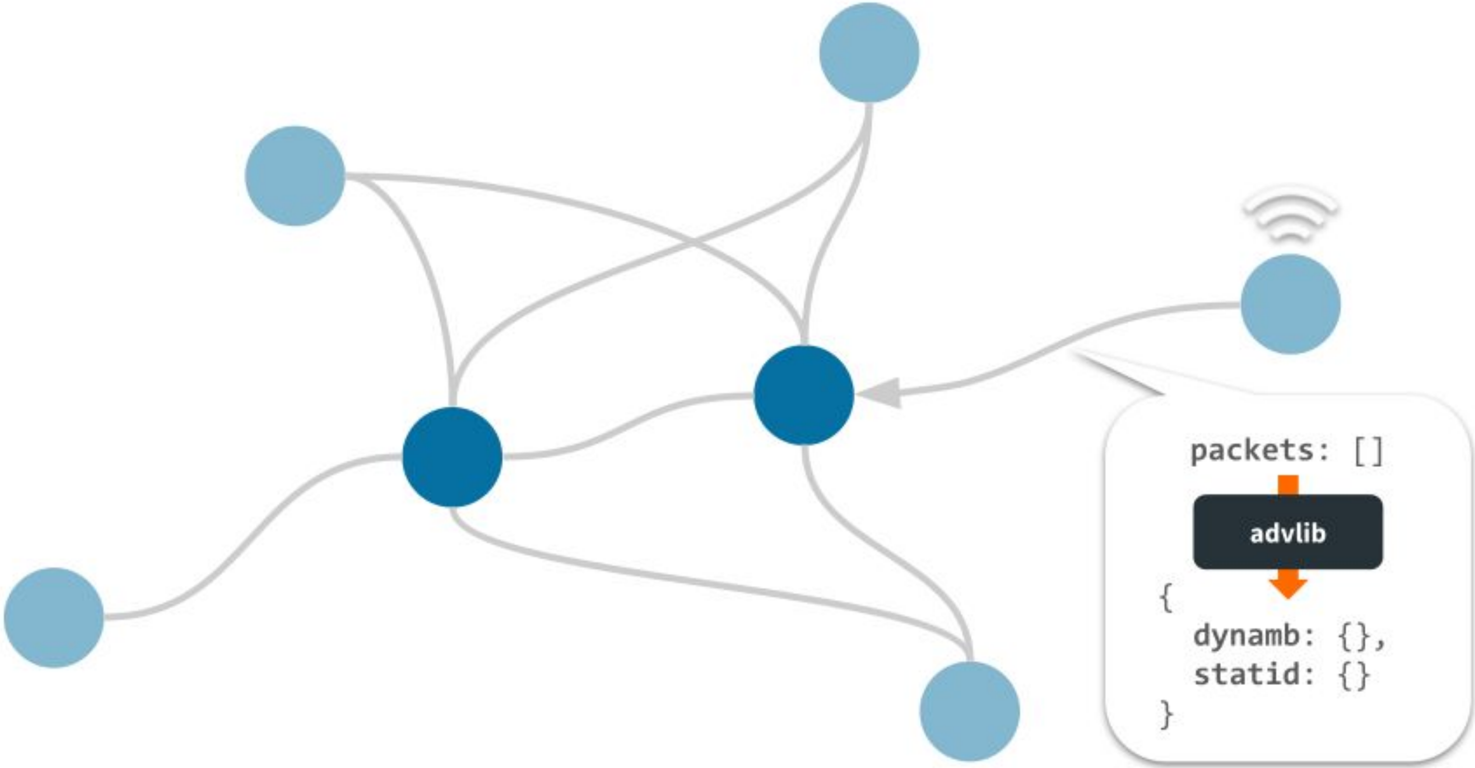
1 Ambient Data



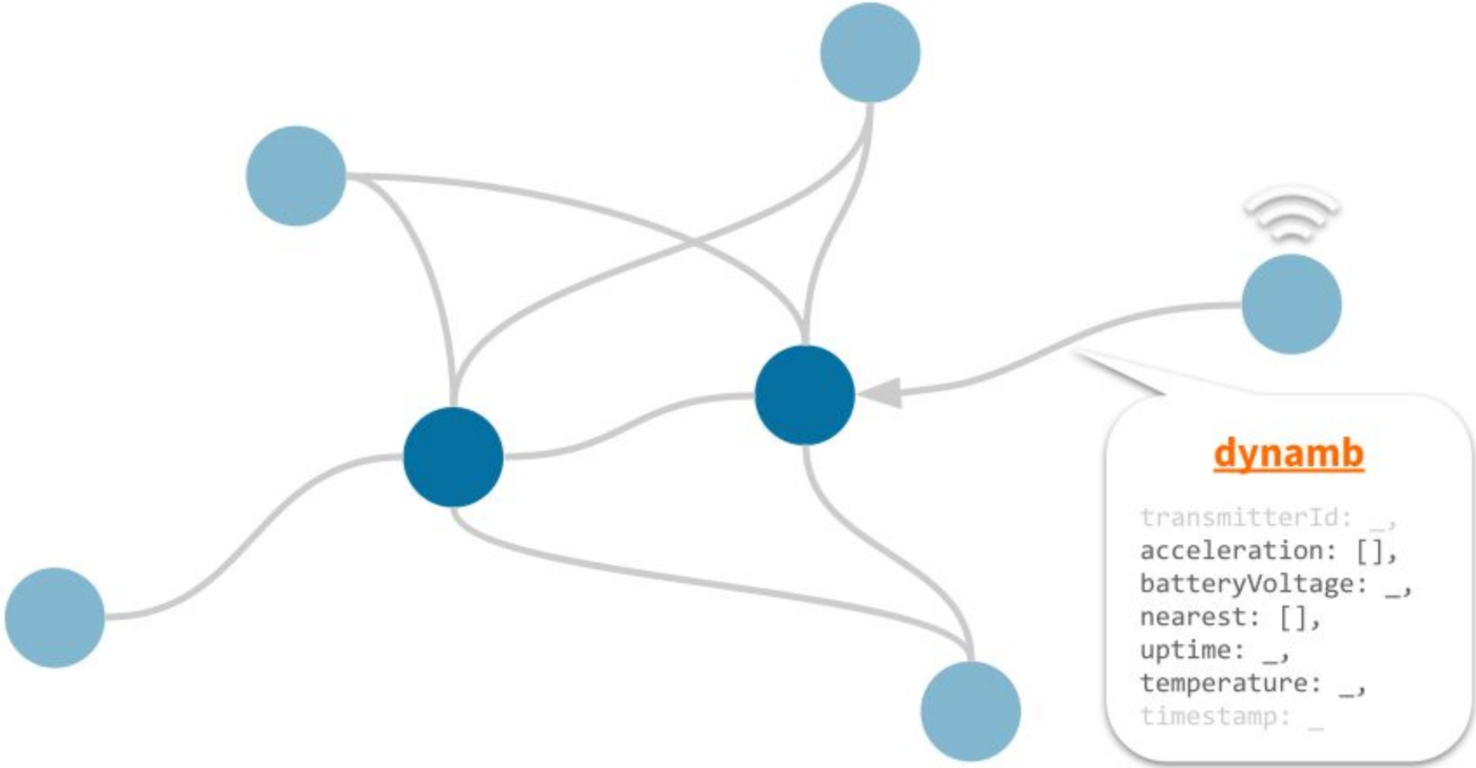
2 radio decoding



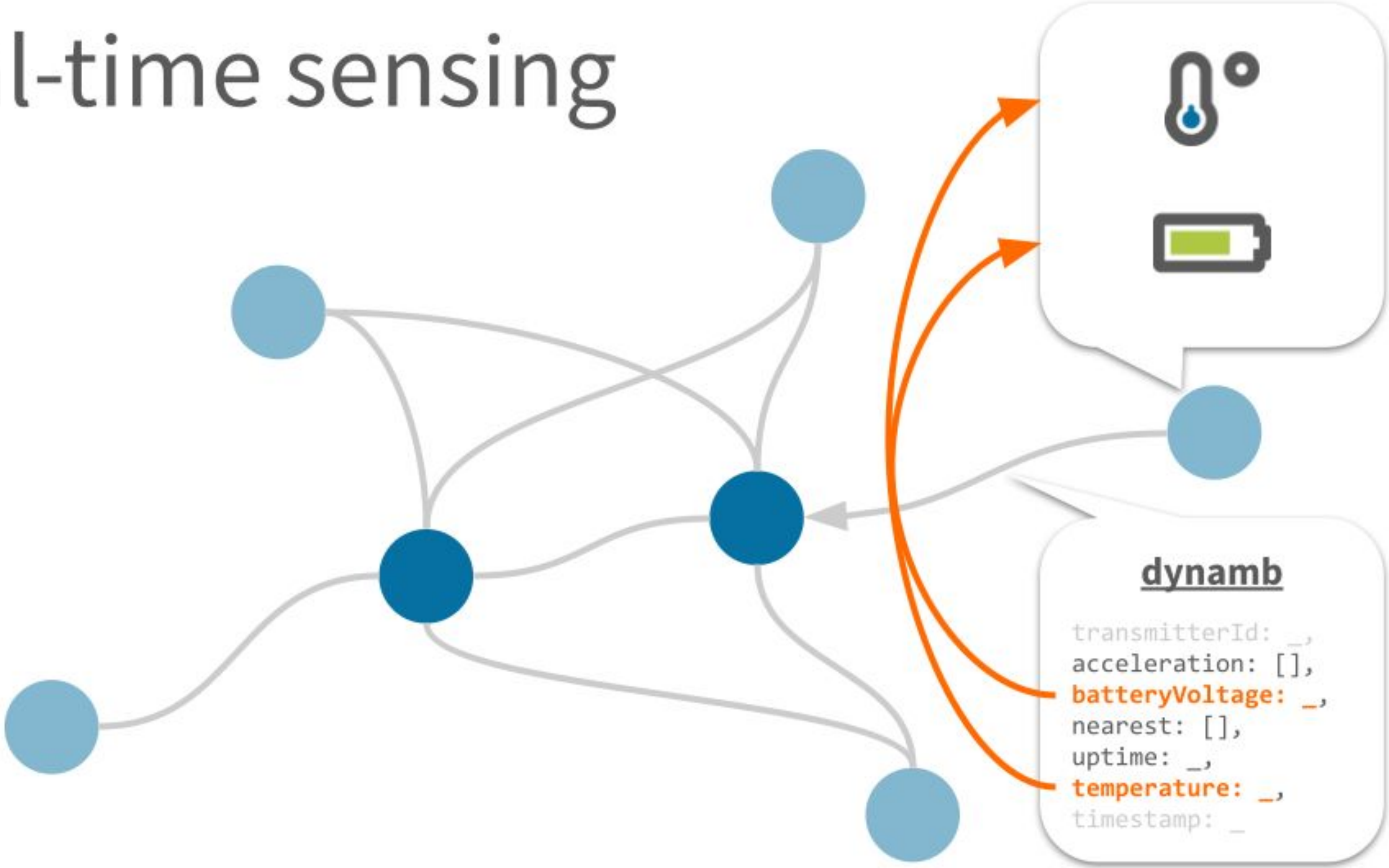
3 Packet processing



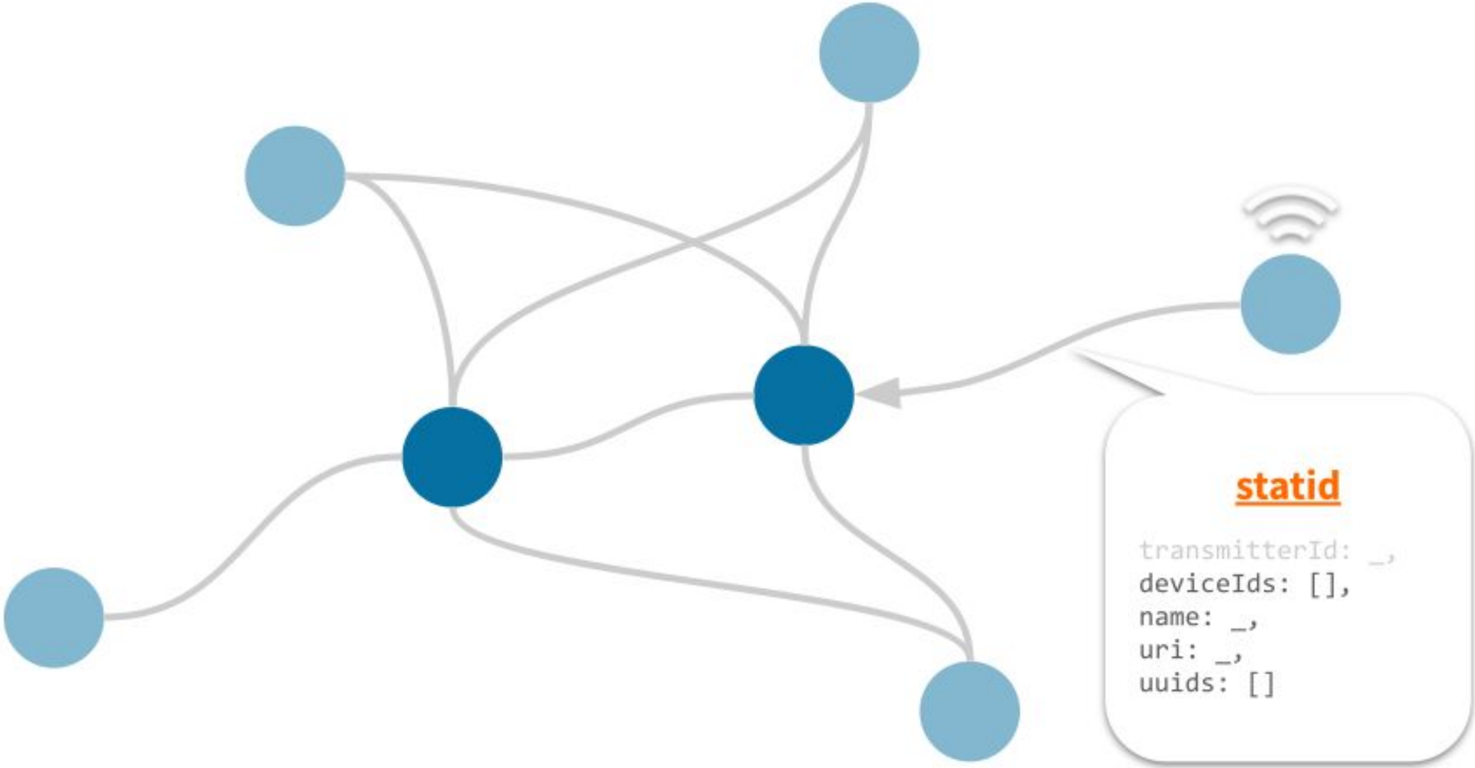
4 dynamic ambient data



5 Real-time sensing

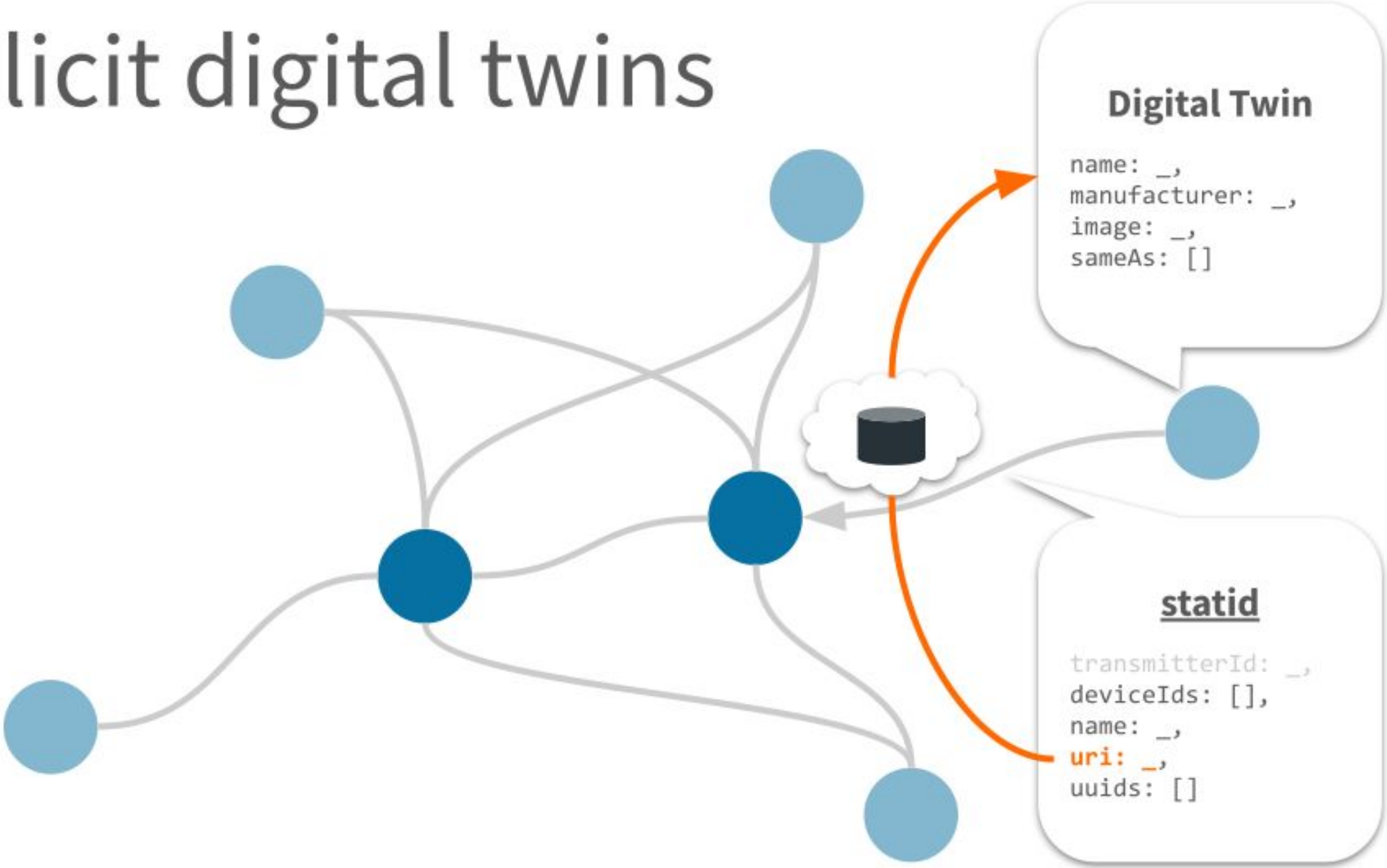


6 static identifier data

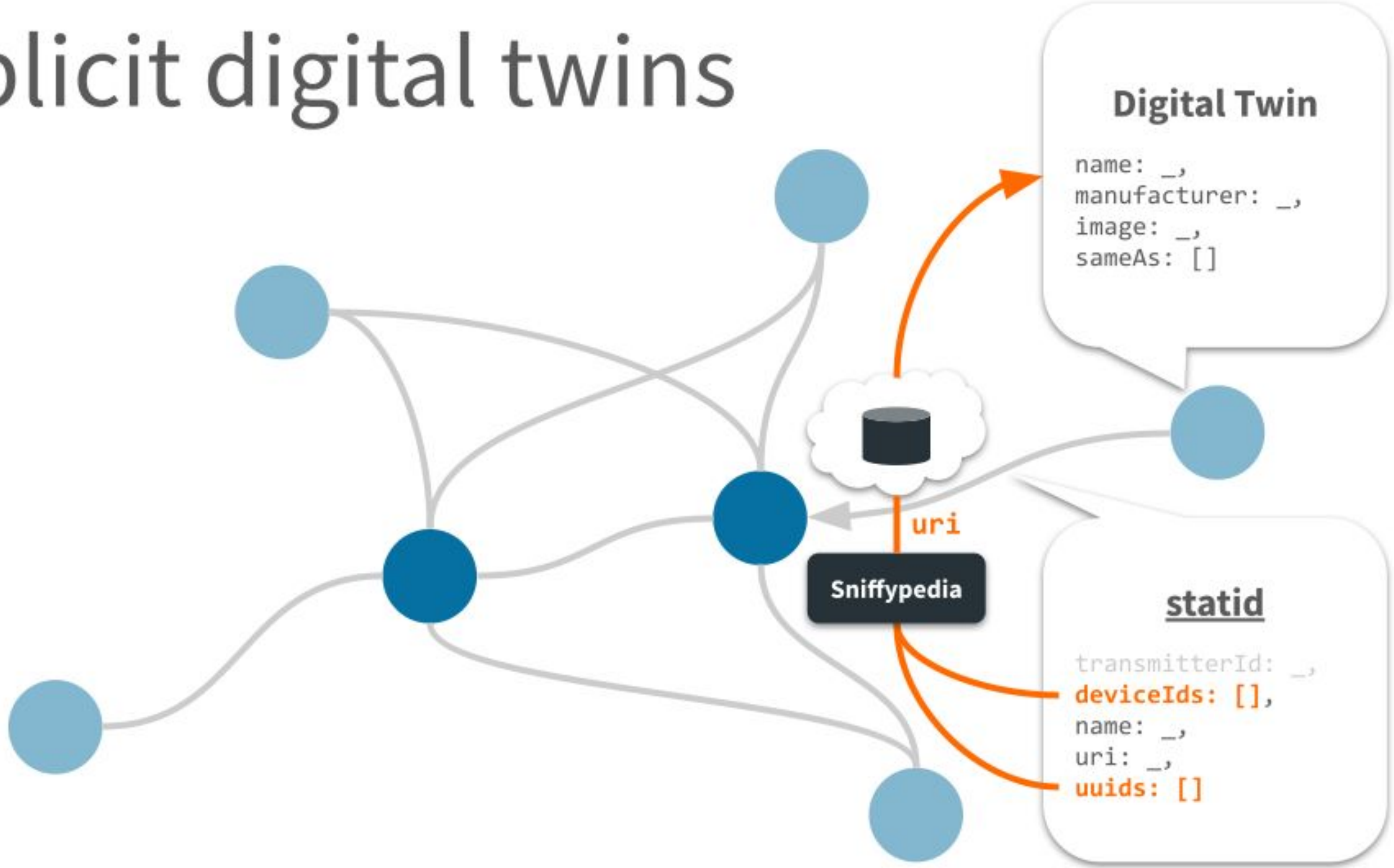


7

Explicit digital twins



8 Implicit digital twins



9

Hyperlocal Context

Hyperlocal context lends itself well to machine-readable (JSON) representation.

The graph is represented as a **list of devices**, each of which represents a **node**.

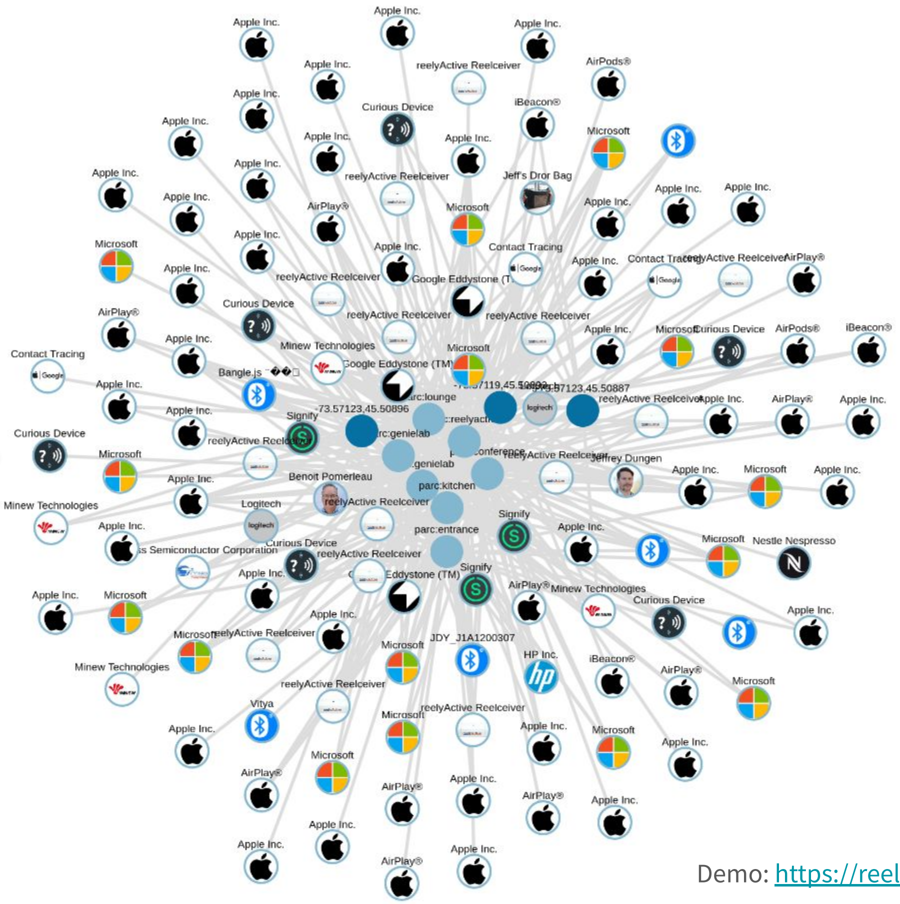
Each device has a **nearest** property which is a set of devices that decoded its transmission(s), ordered by proximity (RSSI), each of which represents an **edge**.

```
"devices": {
    "{id}/{type}": { ... },

    "{id}/{type}": {
        "nearest": [ ... ],
        "dynamb": { ... },
        "statid": { ... },
        "url": "https://...",
        "tags": [ ... ],
        "directory": "a:b:c",
        "position": [ x, y, z ]
    }

    "{id}/{type}": { ... }
}
```

Learn more: https://www.reelyactive.com/context/

/context

11:39:13



hlc-explorer
web app in
Pareto Anywhere

Captured at
reelyActive Parc

Demo: https://reelyactive.github.io/pareto-anywhere-apps/

And **digital twins** are machine-readable (JSON) too thanks to web standards!

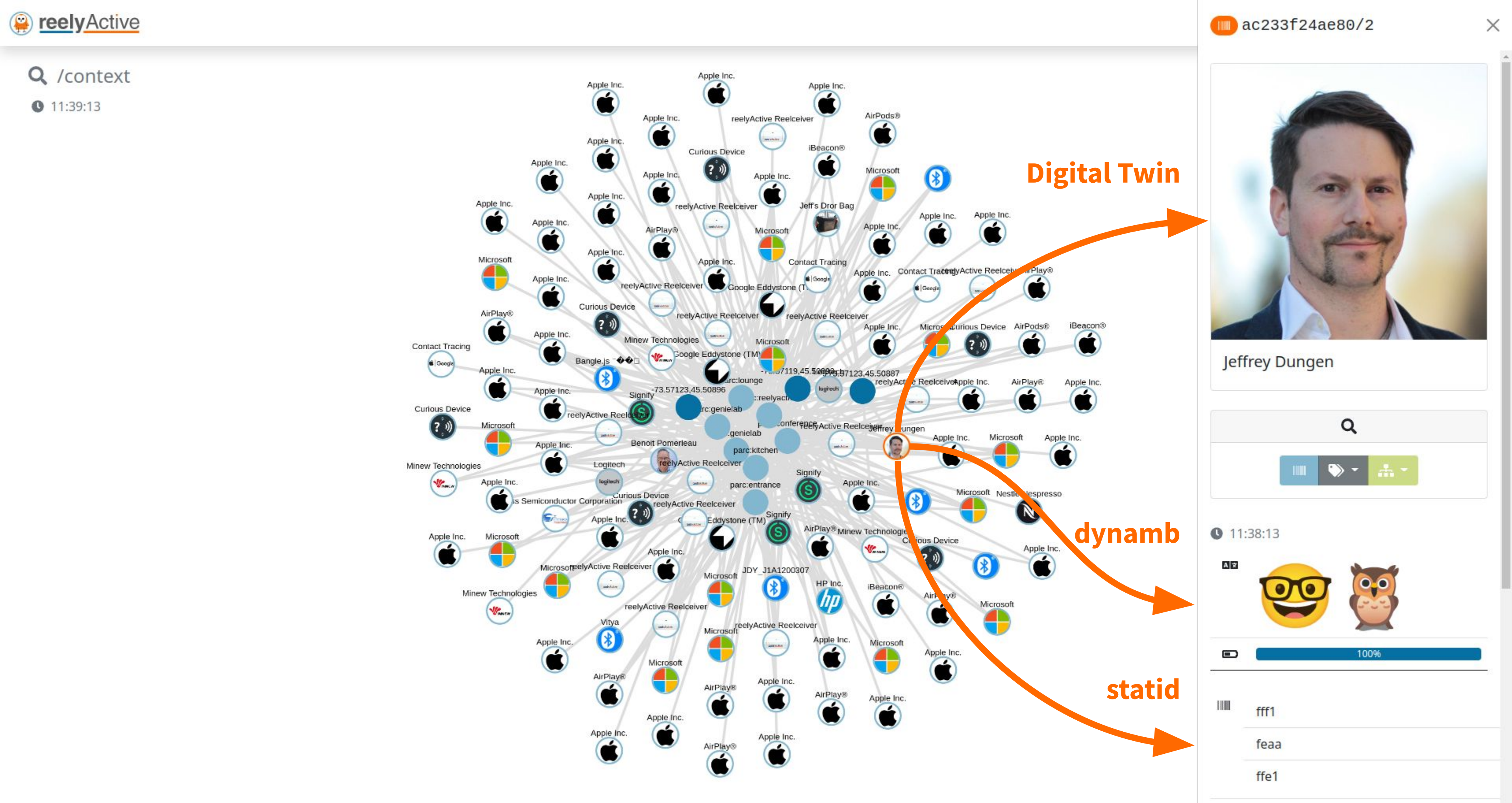
JSON-LD **links data** in a web-standard way so that the date can be organised and connected across web sites.

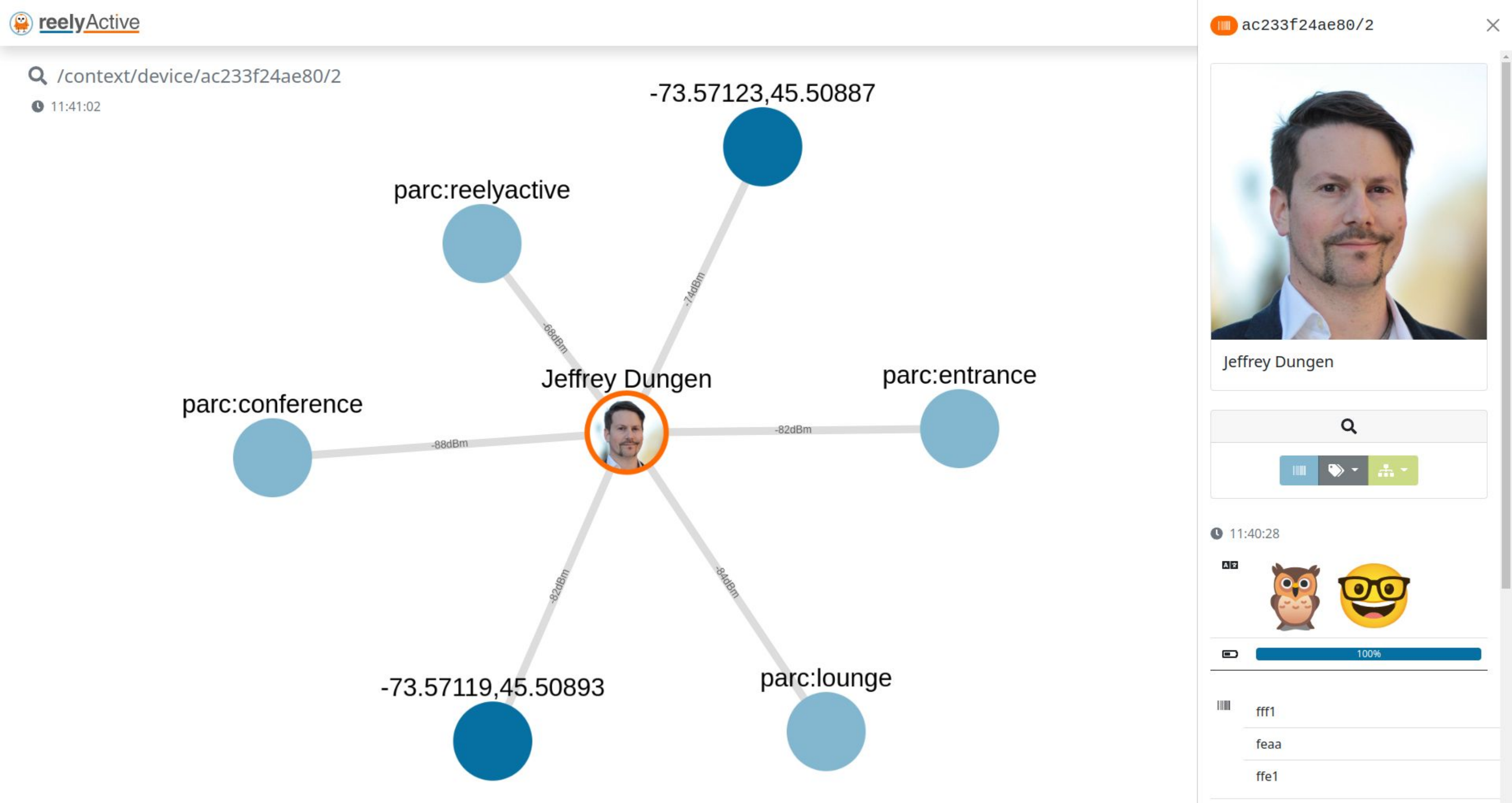
See: https://json-ld.org

Schema.org provides a web-standard **vocabulary** for structured data.

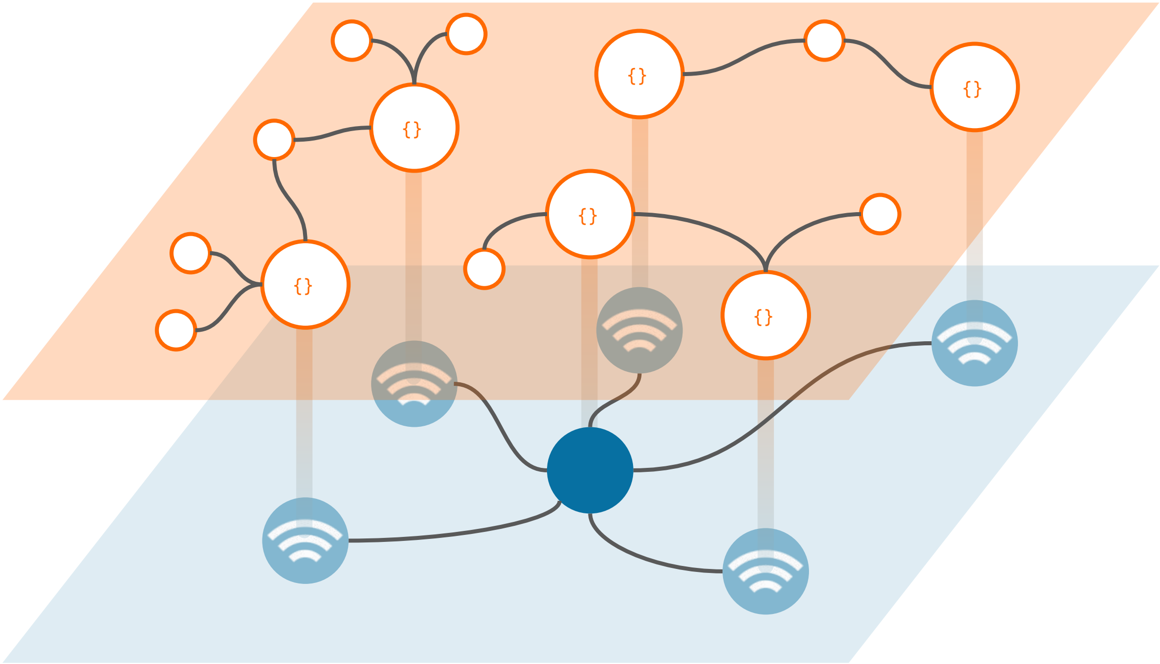
See: https://schema.org


```
{
  "@context":
    { "schema": "https://schema.org/" },
  "@graph": [
    {
      "@id": "JD",
      "@type": "schema:Person",
      "schema:givenName": "Jeffrey",
      "schema:familyName": "Dungen",
      "schema:gender": "Male",
      "schema:nationality": "CA",
      "schema:worksFor": {
        "@type": "schema:Organization",
        "schema:name": "reelyActive",
        "schema:url": "https://reelyactive.com"
      },
      "schema:jobTitle": "Co-founder and CEO",
      "schema:image": "https://...",
      "schema:sameAs": [
        "https://www.linkedin.com/in/dungen/",
        "https://github.com/jeffyactive"
      ]
    }
  ]
}
```


reelyActive
/context
11:39:13
Digital Twin
dynamb
statid
ac233f24ae80/2
Jeffrey Dungen
11:38:13
100%
fff1
feaa
ffe1


reelyActive
/context/device/ac233f24ae80/2
11:41:02
-73.57123,45.50887
parc:reelyactive
-74dBm
-68dBm
Jeffrey Dungen
parc:entrance
parc:conference
-88dBm
-82dBm
-82dBm
-84dBm
-73.57119,45.50893
parc:lounge
ac233f24ae80/2
Jeffrey Dungen
11:40:28
100%
fff1
feaa
ffe1

Technology that makes sense—*literally!*

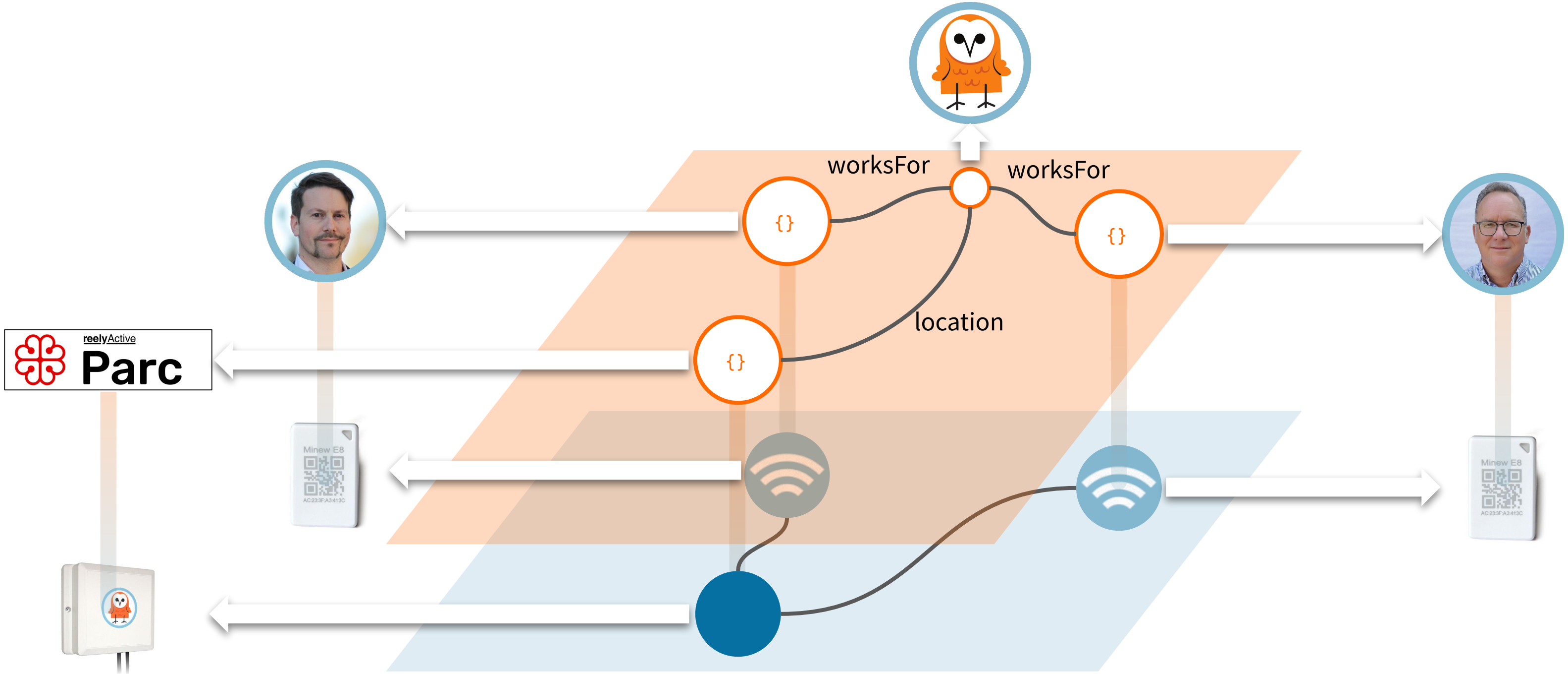


Digital
The Web
from structured, Linked Data
* Edges are ***logical relationships*** *

Physical
Hyperlocal Context
from Ambient Data
* Edges are ***physical proximity*** *

It's a dynamic, searchable graph. 🤓

Jeffrey and Benoît—*who work for reelyActive,* are at reelyActive Parc—*the reelyActive office.*

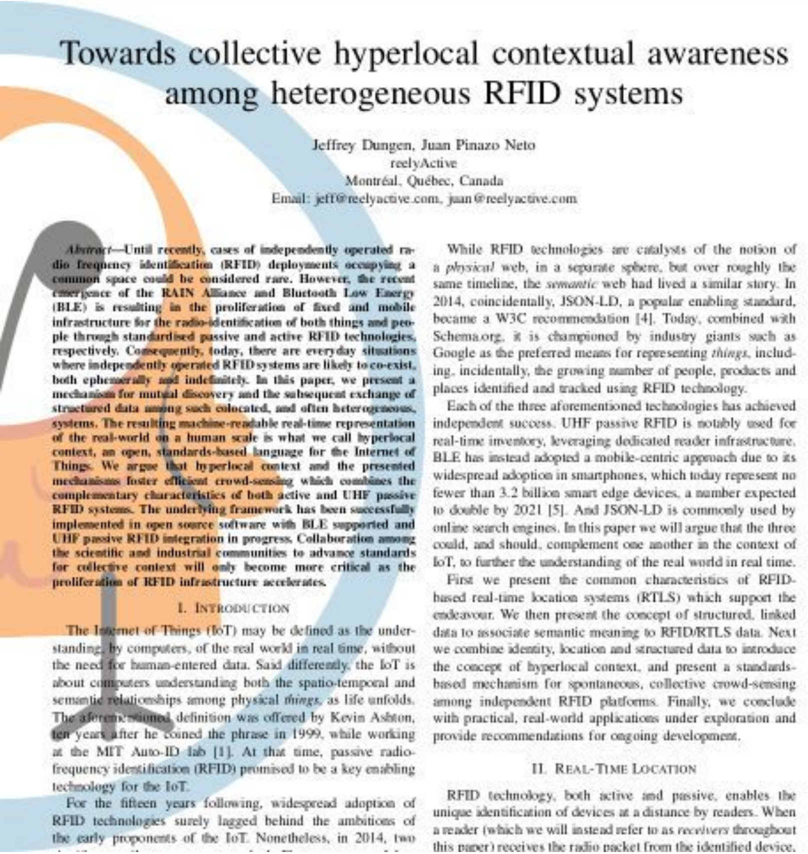


But how do we get **hyperlocal context** to extend *across* readers/gateways and physical spaces so that it is meaningfully searchable at broader scale? 🤔

I presented an entire tutorial on this too

at IEEE RFID 2019

https://2019.ieee-rfid.org/co-located-rfid-systems-unite/



Towards collective hyperlocal contextual awareness among heterogeneous RFID systems

Jeffrey Dungen, Juan Pinazo Neto
reelyActive
Montréal, Québec, Canada
Email: jeff@reelyactive.com, juan@reelyactive.com

Abstract—Until recently, cases of independently operated radio frequency identification (RFID) deployments occupying a common space could be considered rare. However, the recent emergence of the RAIN Alliance and Bluetooth Low Energy (BLE) is resulting in the proliferation of fixed and mobile infrastructure for the radio-identification of both things and people through standardised passive and active RFID technologies, respectively. Consequently, today, there are everyday situations where independently operated RFID systems are likely to co-exist, both ephemerally and indefinitely. In this paper, we present a mechanism for mutual discovery and the subsequent exchange of structured data among such colocated, and often heterogeneous, systems. The resulting machine-readable real-time representation of the real-world on a human scale is what we call hyperlocal context, an open, standards-based language for the Internet of Things. We argue that hyperlocal context and the presented mechanisms foster efficient crowd-sensing which combines the complementary characteristics of both active and UHF passive RFID systems. The underlying framework has been successfully implemented in open source software with BLE supported and UHF passive RFID integration in progress. Collaboration among the scientific and industrial communities to advance standards for collective context will only become more critical as the proliferation of RFID infrastructure accelerates.

I. Introduction

The Internet of Things (IoT) may be defined as the understanding, by computers, of the real world in real time, without the need for human-entered data. Said differently, the IoT is about computers understanding both the spatio-temporal and semantic relationships among physical *things*, as life unfolds. The aforementioned definition was offered by Kevin Ashton, ten years after he coined the phrase in 1999, while working at the MIT Auto-ID lab [1]. At that time, passive radio-frequency identification (RFID) promised to be a key enabling technology for the IoT.

For the fifteen years following, widespread adoption of RFID technologies surely lagged behind the ambitions of the early proponents of the IoT. Nonetheless, in 2014, two

While RFID technologies are catalysts of the notion of a *physical* web, in a separate sphere, but over roughly the same timeline, the *semantic* web had lived a similar story. In 2014, coincidentally, JSON-LD, a popular enabling standard, became a W3C recommendation [4]. Today, combined with Schema.org, it is championed by industry giants such as Google as the preferred means for representing *things*, including, incidentally, the growing number of people, products and places identified and tracked using RFID technology.

Each of the three aforementioned technologies has achieved independent success. UHF passive RFID is notably used for real-time inventory, leveraging dedicated reader infrastructure. BLE has instead adopted a mobile-centric approach due to its widespread adoption in smartphones, which today represent no fewer than 3.2 billion smart edge devices, a number expected to double by 2021 [5]. And JSON-LD is commonly used by online search engines. In this paper we will argue that the three could, and should, complement one another in the context of IoT, to further the understanding of the real world in real time.

First we present the common characteristics of RFID-based real-time location systems (RTLS) which support the endeavour. We then present the concept of structured, linked data to associate semantic meaning to RFID/RTLS data. Next we combine identity, location and structured data to introduce the concept of hyperlocal context, and present a standards-based mechanism for spontaneous, collective crowd-sensing among independent RFID platforms. Finally, we conclude with practical, real-world applications under exploration and provide recommendations for ongoing development.

II. Real-Time Location

RFID technology, both active and passive, enables the unique identification of devices at a distance by readers. When a reader (which we will instead refer to as *receivers* throughout this paper) receives the radio packet from the identified device.

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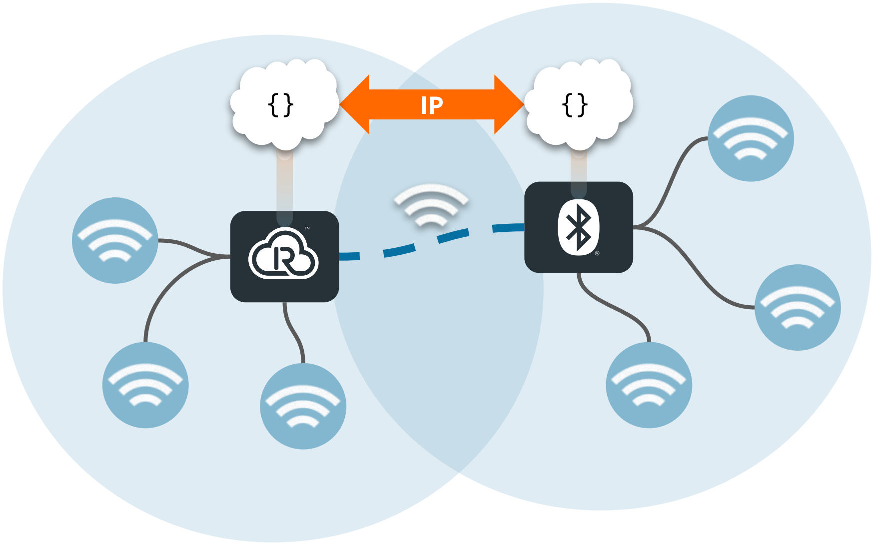
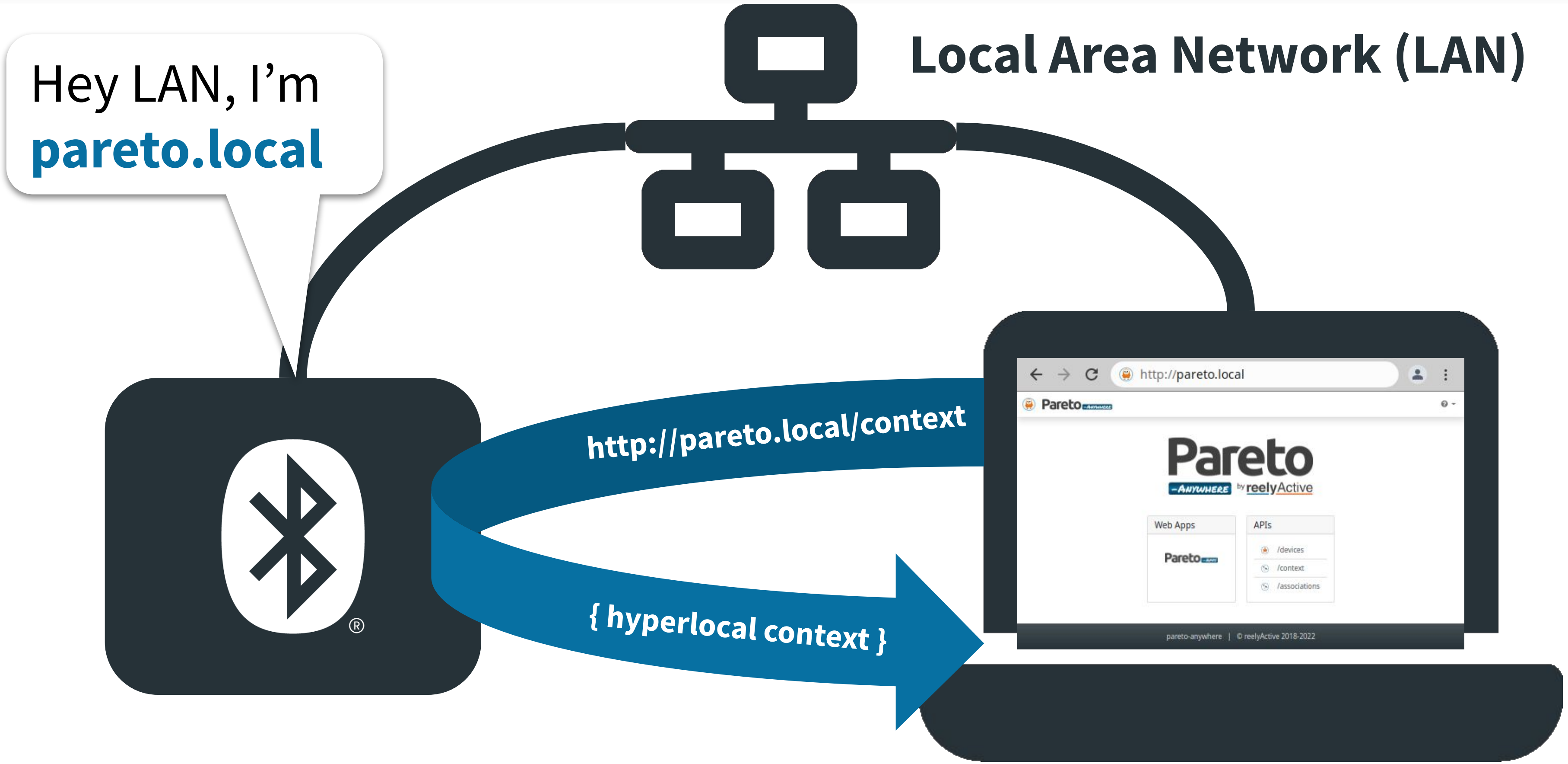
1. Co-located reader **discovery** via Bluetooth Low Energy.
2. Hyperlocal context **exchange** via IP.



Can we take it a step further *(closer?)* and put the **.local** in hyperlocal context? 🤔

Support **.local**!

Learn more: https://wikipedia.org/wiki/.local


Local Area Network (LAN)
Hey LAN, I'm
pareto.local
http://pareto.local/context
{ hyperlocal context }
http://pareto.local
Pareto
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Web Apps
Pareto
APIs
/devices
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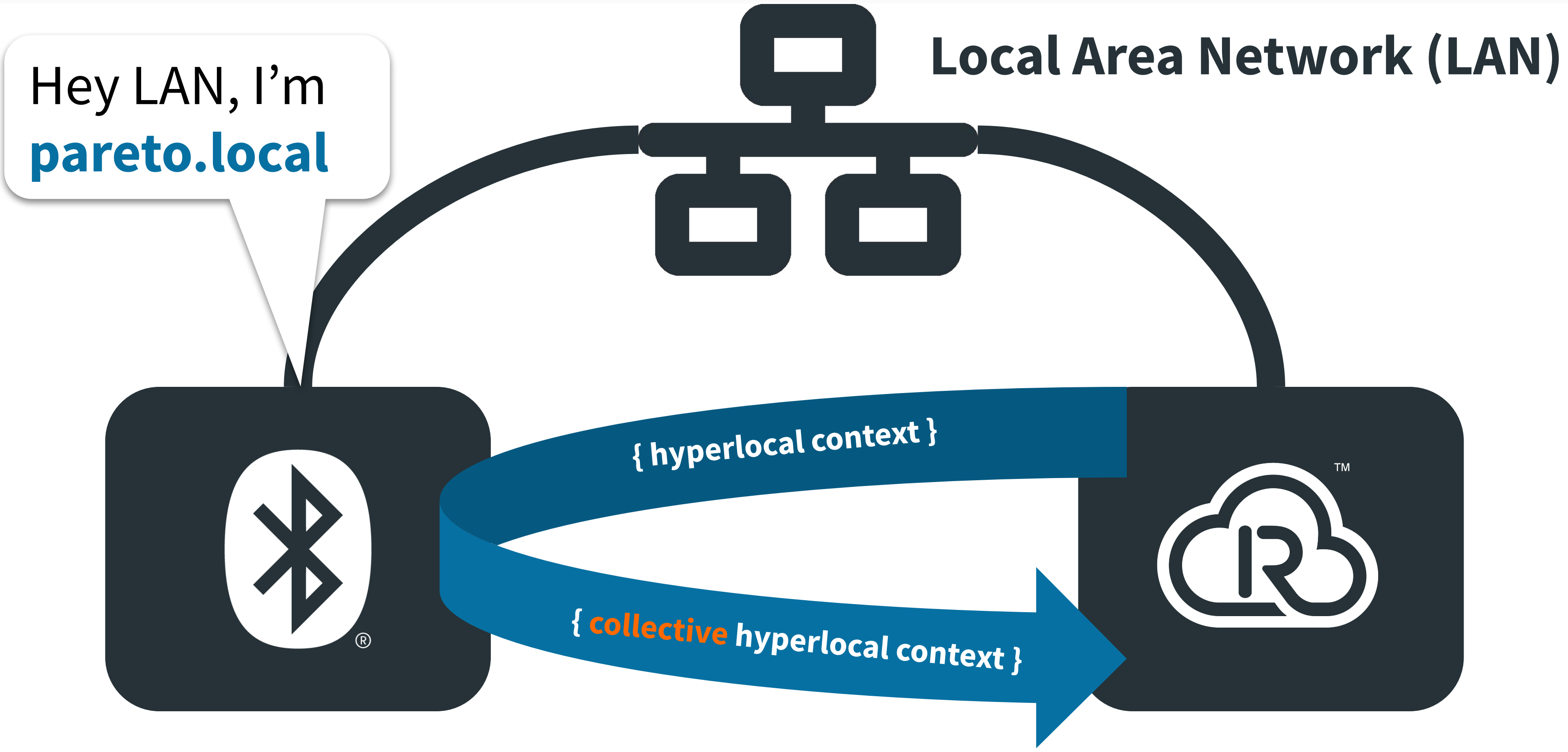

Hey LAN, I'm
pareto.local
Local Area Network (LAN)
{ hyperlocal context }
{ collective hyperlocal context }

Pareto?

Vilfredo Pareto is famously known for the 80-20 rule, where 80% of the outcomes are due to 20% of the causes, also called the Pareto principle.

At reelyActive, we named our software Pareto to reflect the fact that a *modest* amount of ambient data is often “good enough” to make a *lot* of sense.

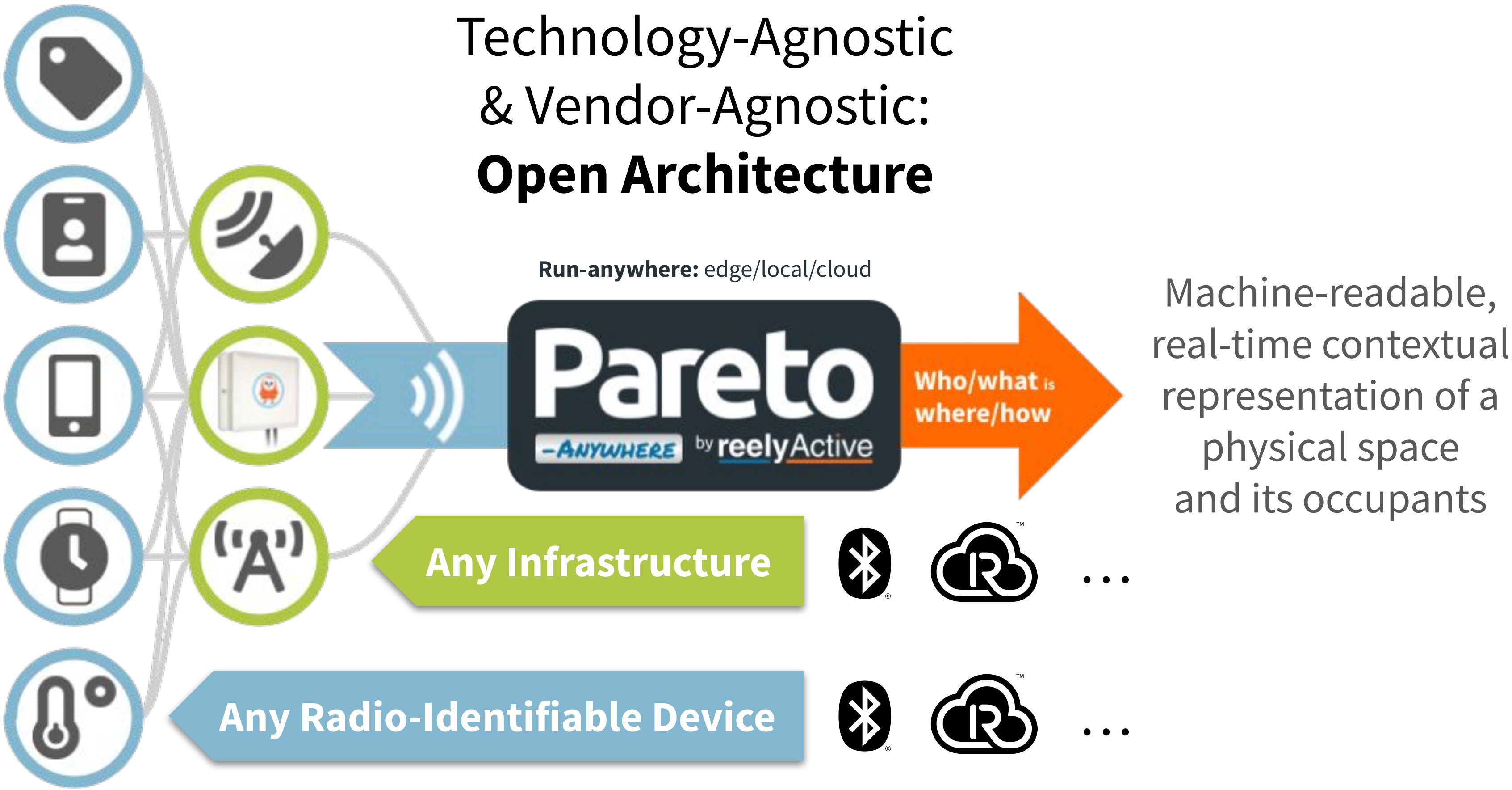
Pareto Anywhere is open source and run-anywhere, transforming ambient data into hyperlocal context.

www.reelyactive.com/pareto/anywhere/

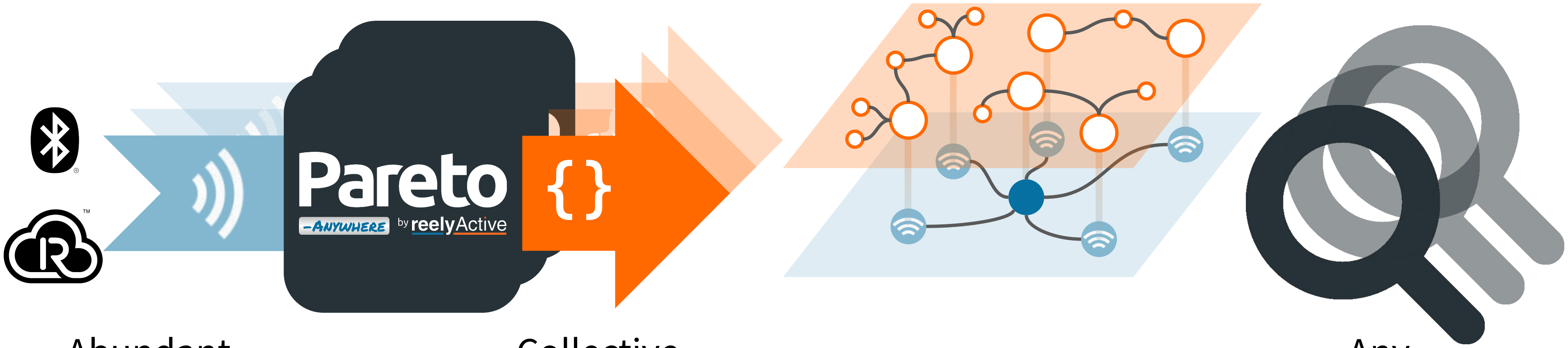
Create context-aware physical spaces with a Raspberry Pi

Our step-by-step guide to create #CAPSpaces with a 🍓 Pi using open source technologies.

Tutorial: https://reelyactive.github.io/diy/capspaces-pi/


Technology-Agnostic
& Vendor-Agnostic:
Open Architecture
Run-anywhere: edge/local/cloud
Pareto
–ANYWHERE
by reelyActive
Who/what is where/how
Machine-readable, real-time contextual representation of a physical space and its occupants
Any Infrastructure
…
Any Radio-Identifiable Device
…

Makes sense?



Abundant
Ambient Data

Collective
Hyperlocal Context

Any
Application

RFID as **Ambient Data**

Presented by Jeffrey Dungen

Co-founder & CEO of reelyActive

at IEEE RFID 2022 in Las Vegas

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