Beetle

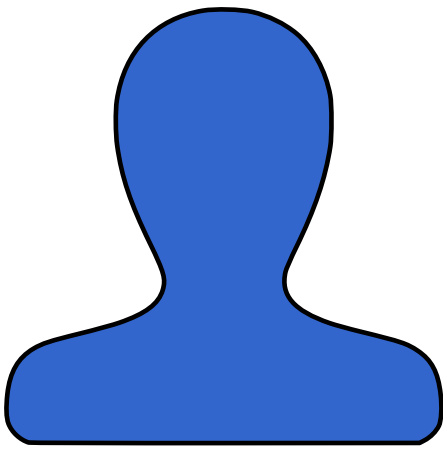
Sharing, flexibility and access control for Bluetooth Low Energy

Amit Levy James Hong Laurynas Riliskis
Philip Levis Keith Winstein

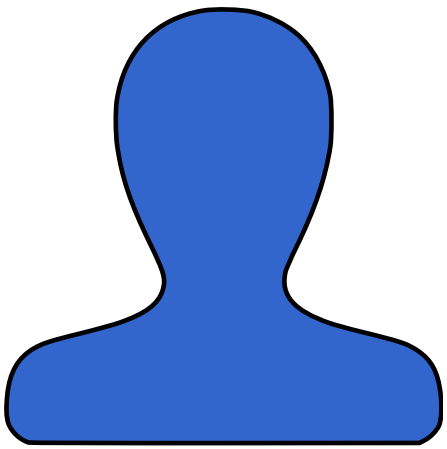
Stanford University

June 24, 2016

Meet Grace



Meet Grace



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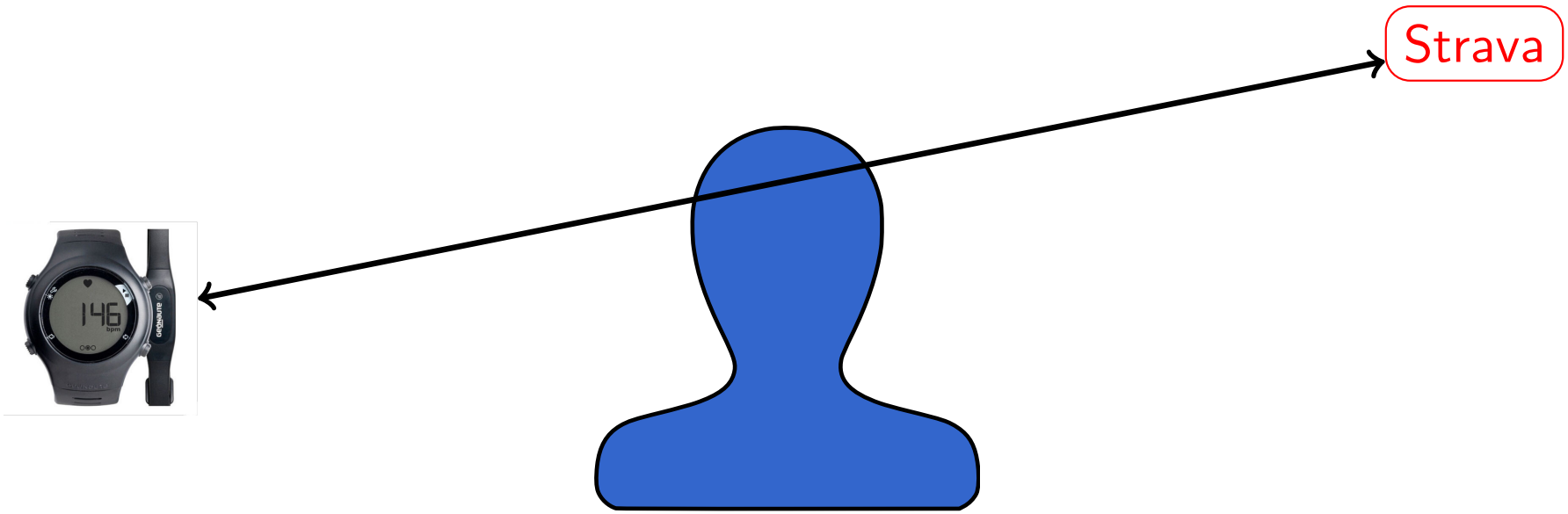

Meet Grace

Strava

HrView

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Meet Fabian

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BatteryMon

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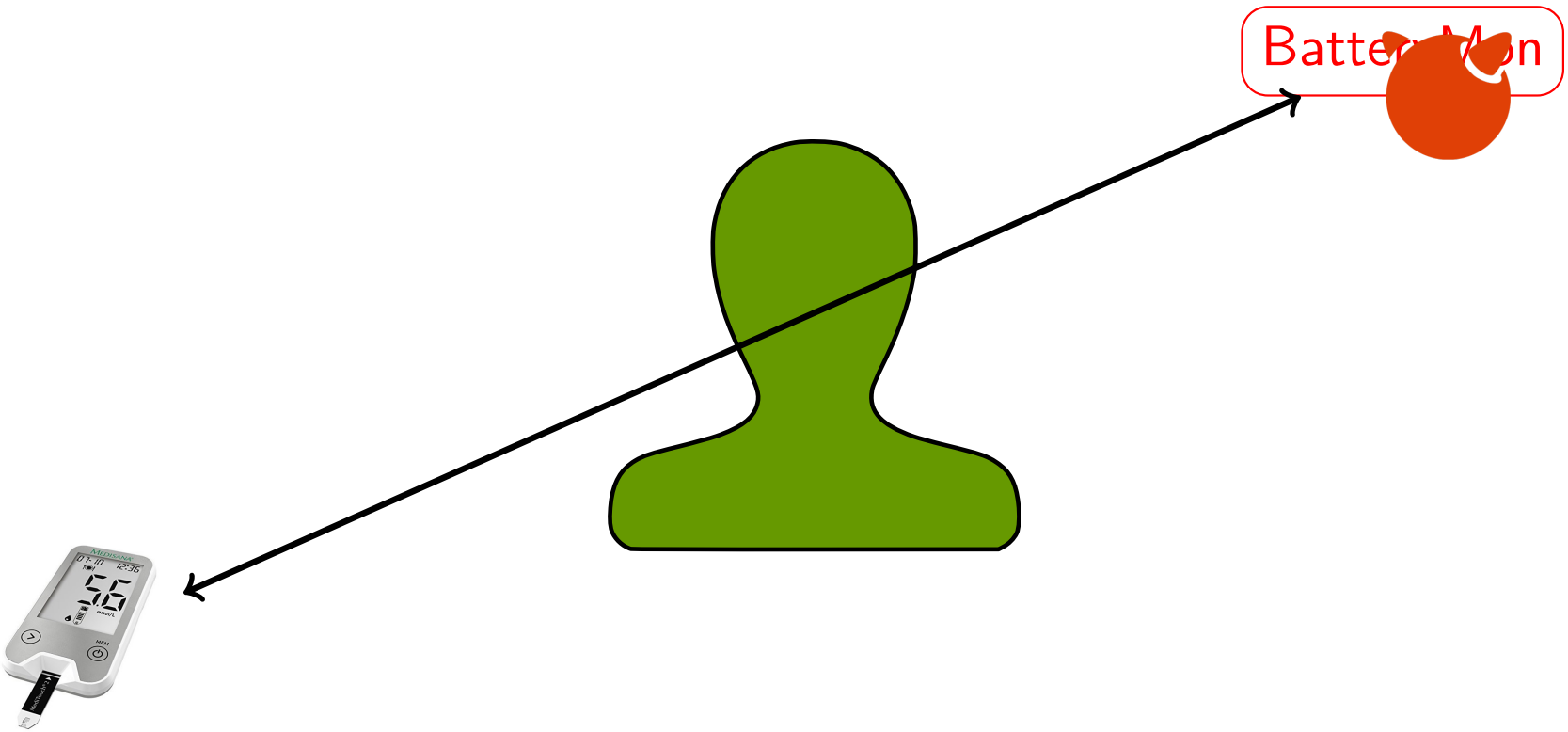

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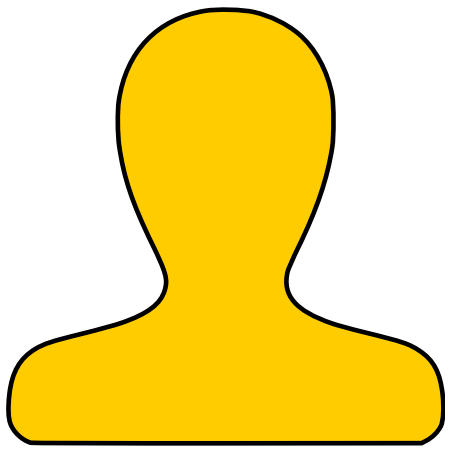

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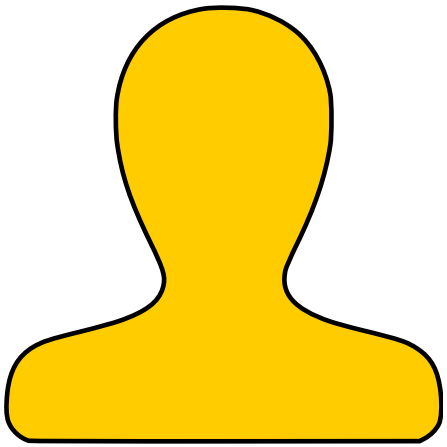

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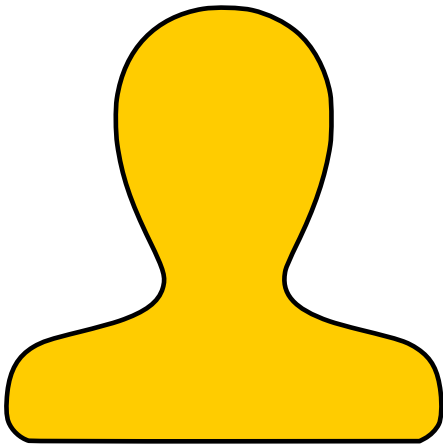

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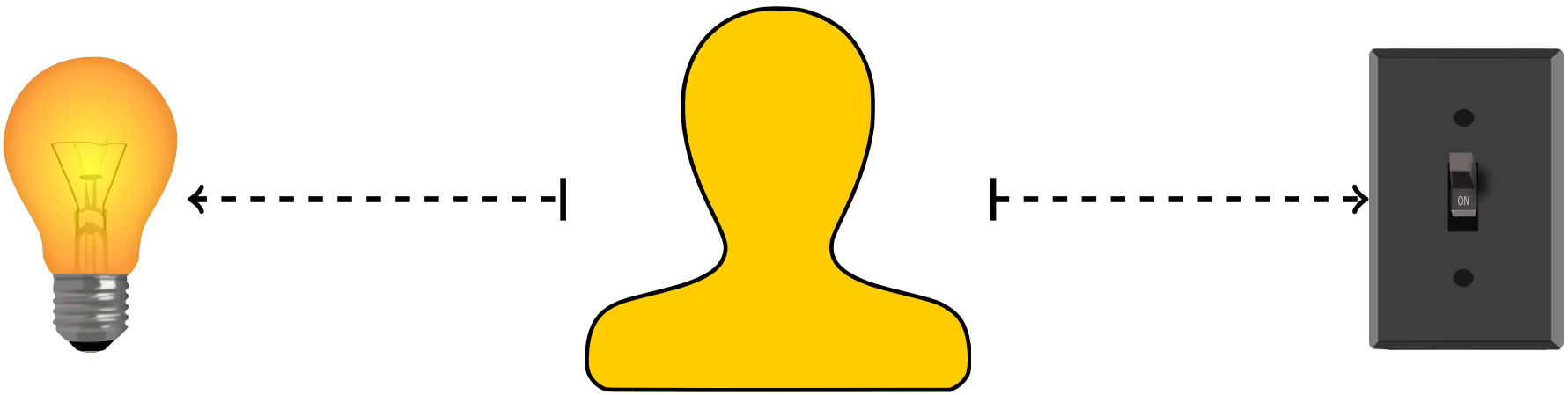

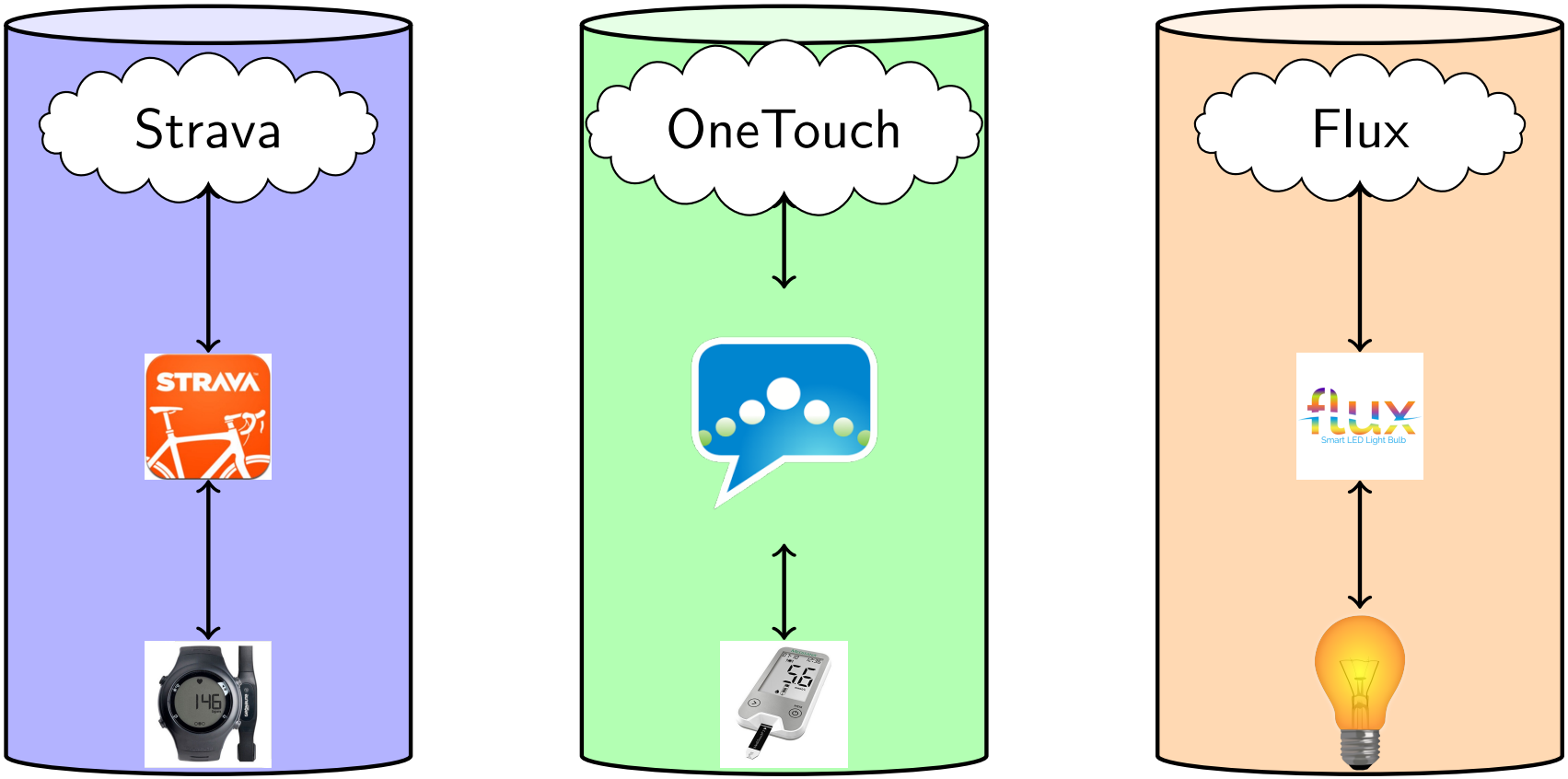

No extensibility, no access control, limited communication

Limitations of Bluetooth Low Energy (BLE)

1. Applications must run on the gateway
2. One application at a time
3. All-or-nothing access

Peripherals need to be simple

- Low cost
- Low power
- Hard to update

Gateway oblivious to peripheral functionality

- How to virtualize generally?
- Who can access what?

The gateway should enable flexible and safe sharing

Beetle

Sharing

Applications can safely share access to peripherals without explicit coordination.

Access Control

Users can specify fine-graned access policies on peripherals and applications.

Communication flexiblity

Many-to-many communication between peripherals, gateway applications and cloud applications.

Backwards compatible

Doesn't require changes to existing peripherals or applications.

Current Gateways: Explicit support

Dedicated drivers understand a class of peripherals:

- Printers
- Keyboards
- Disks

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Dedicated drivers understand a class of peripherals:

- Printers
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- Disks

Pros

- Safe virtualization
- Access control

Cons

- Need a trusted module for each device class
- Has worked OK for desktops, but does is scale?

Current Gateways: Exclusive access from one application

For special case peripherals, gateway provides an exclusive, raw channel:

- Oscilloscope, hardware debugger
- USB breathalyzer, USB blood pressure monitor
- Most IoT peripherals (door locks, lights, fitness bands)

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Pros

- Don't need explicit support for each new device class

Cons

- Can't allow multiple apps to use peripheral
- App gets complete control over peripheral

Current Gateway Systems

OS	Explicit Driver	Exclusive Access
HomeOS	✓	
Linux	✓	✓(BLE sockets)
Android	✓(Google Health)	✓
iOS	✓(Health/HomeKit)	✓

Explicit support

Impractical for operating systems to anticipate new device functionality

vs.

Exclusive access

No sharing, no access control, inflexible communication

Bluetooth Low Energy application protocol

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Attribute Protocol (ATT):

- Key-type-value store
- Transactional flow-control
- `READ`, `WRITE`, `NOTIFY`, `FIND-BY-TYPE`...

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- Characteristic: Groups attributes for a value
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Read handle 2

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Read handle 2

Char value at handle 4

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Read handle 2

Char value at handle 4

Read handle 4

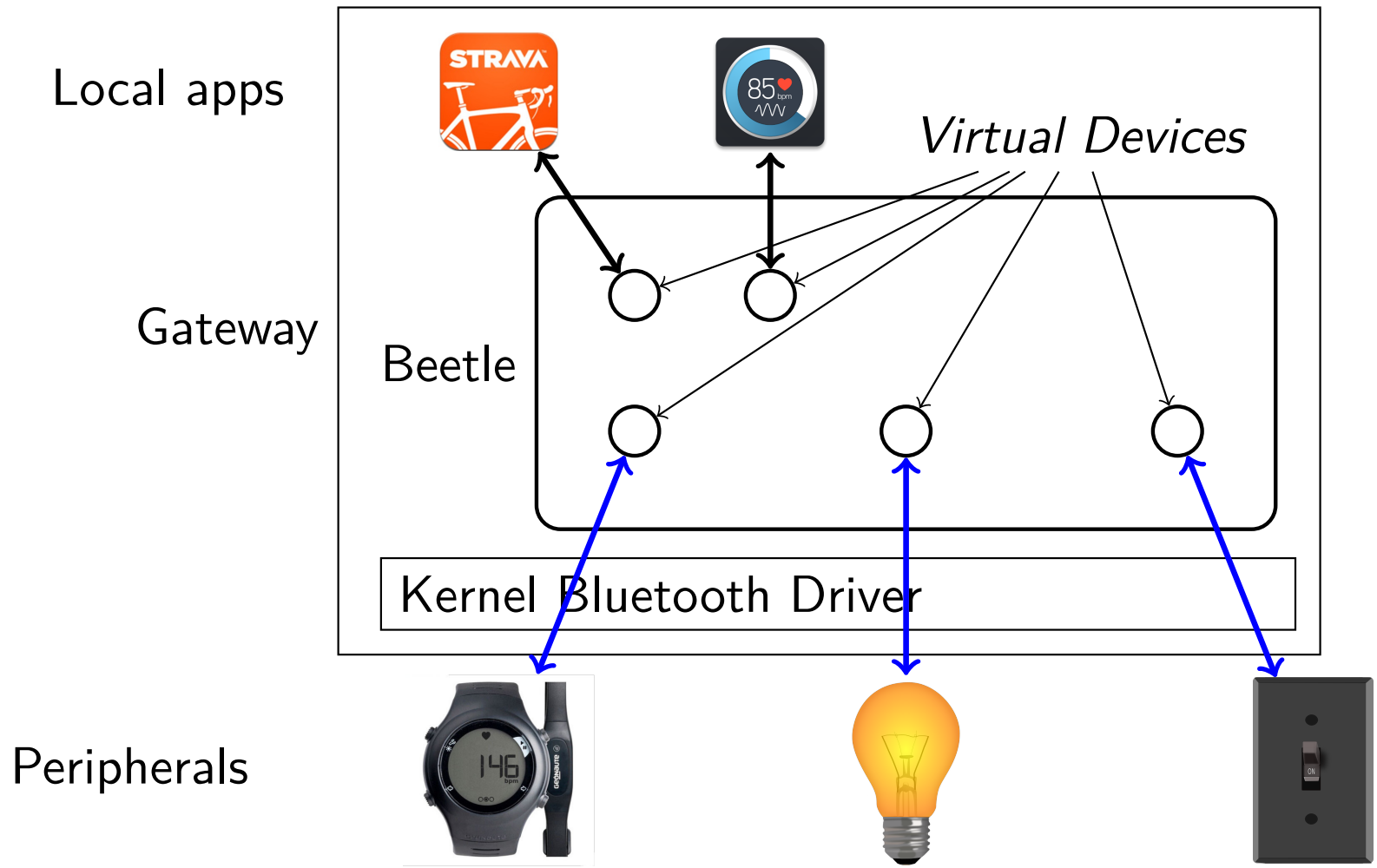
157BPM

Beetle: Key insight

BLE application protocol (GATT) is amenable to multiplexing:

- Unified data model
- Standardized data types
- Transactions are meaningful to applications

Beetle Architecture



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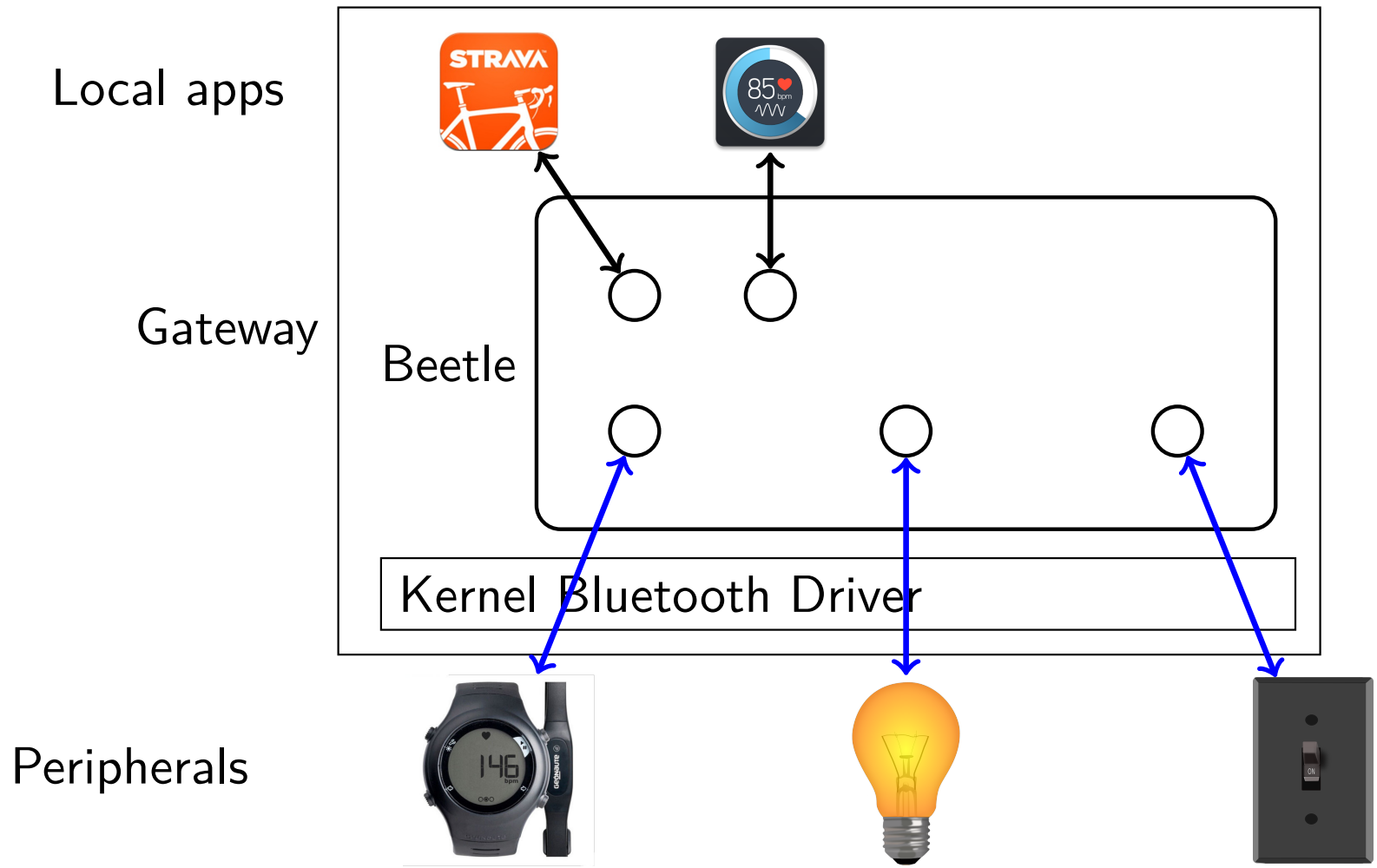

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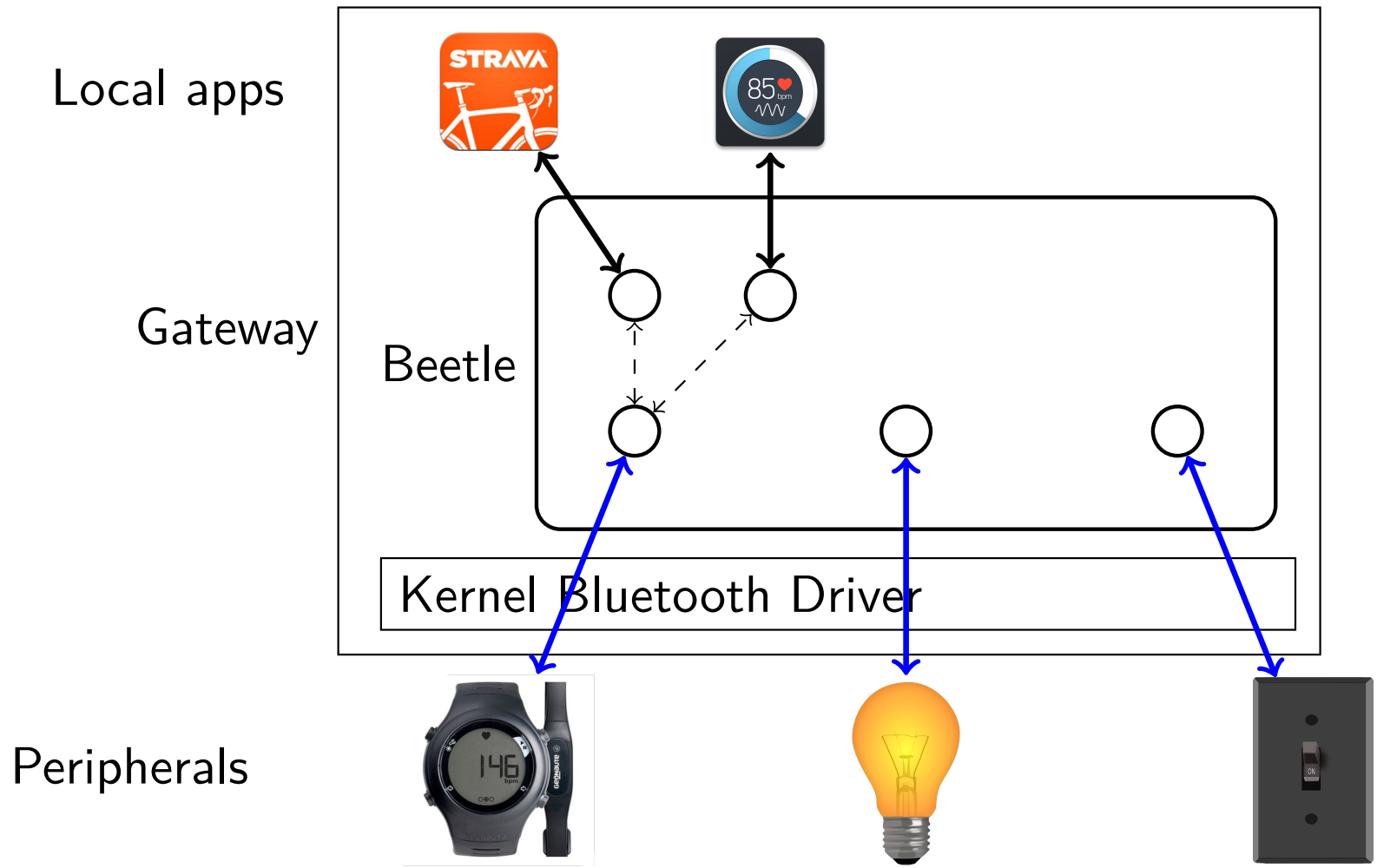

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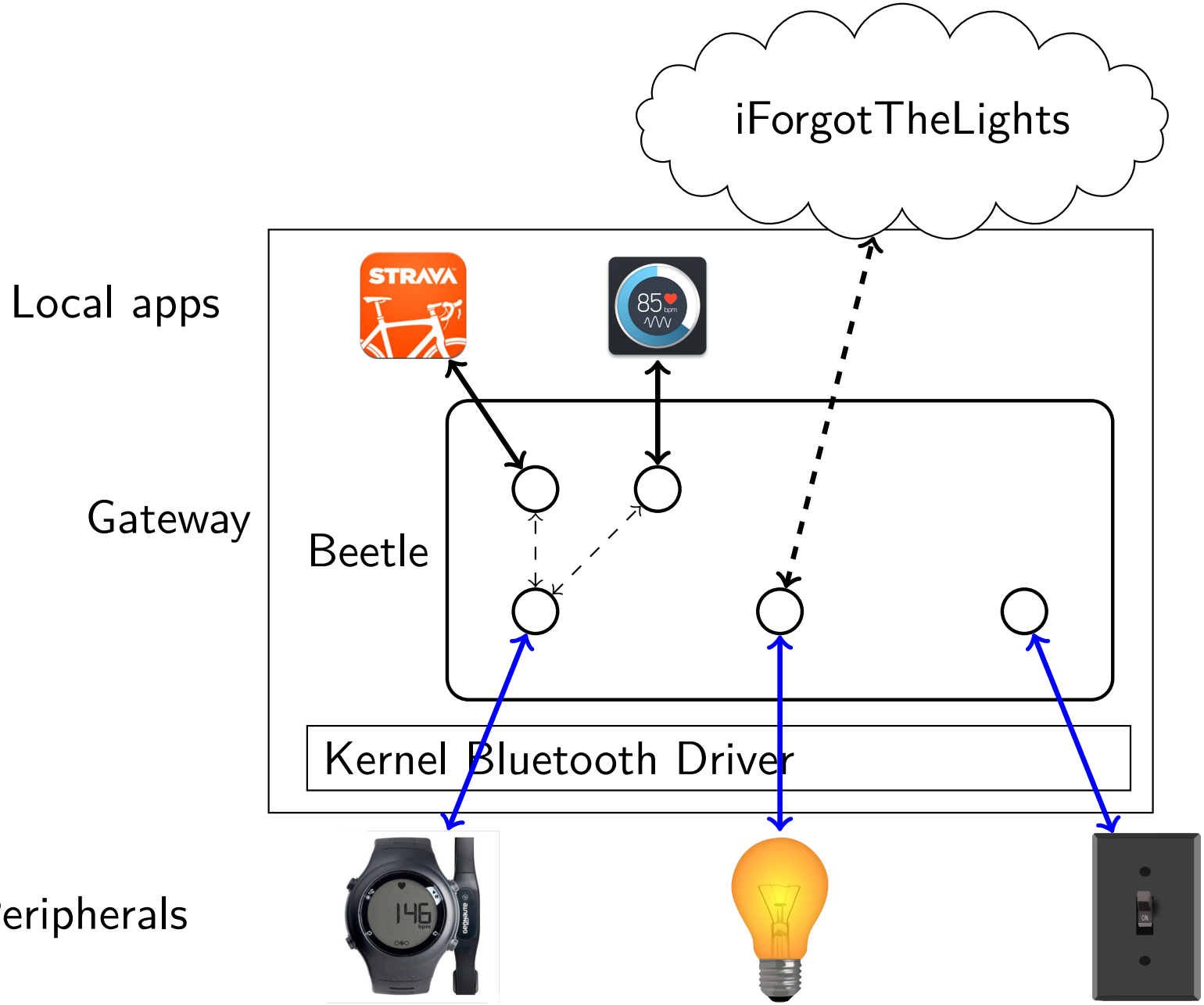

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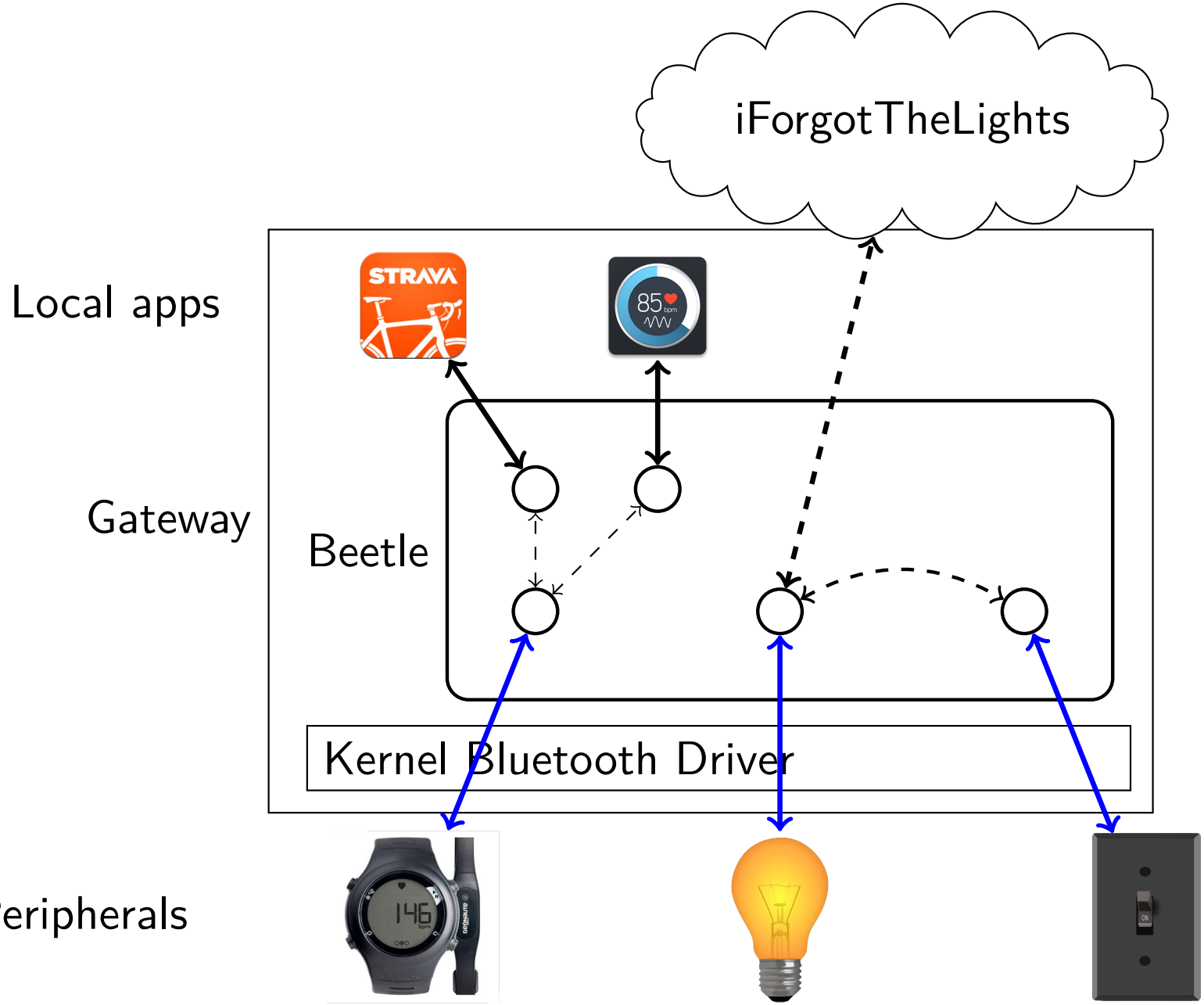

Virtual Devices: Just speak GATT

Look like a peripheral to applications.

Look like a gateway to peripherals.

Provide:

- Sharing by multiplexing transactions from different clients
- Access control by mapping handle space
- Flexible communication by allowing transactions over any link

Virtual Devices: Sharing

Strava

HrView

Virtual Devices: Sharing

Strava

READ REQ: 1

READ REQ: 2

HrView

Virtual Devices: Sharing

READ REQ: 1

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READ RESP: 1

Strava

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Strava

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READ RESP: 2

Strava

HrView

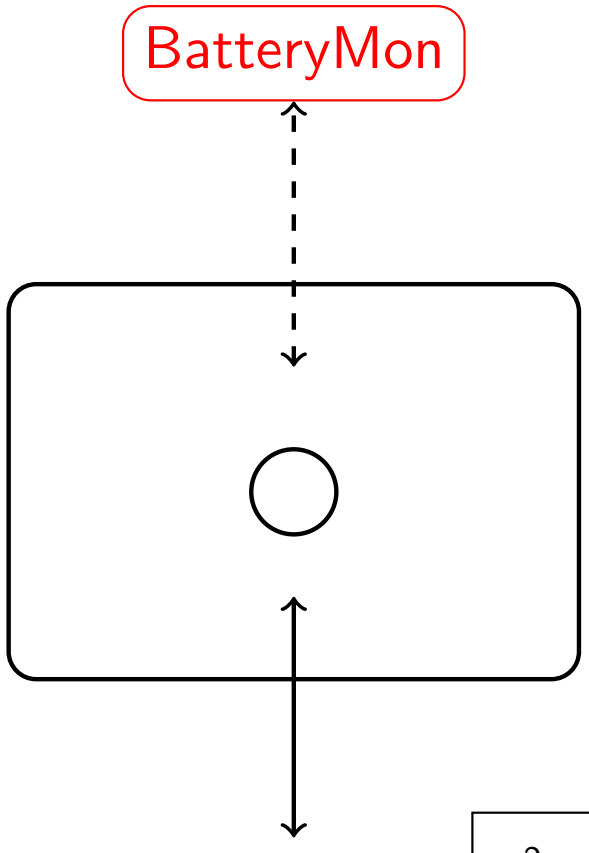
Virtual Devices: Sharing

Strava

READ RESP: 2

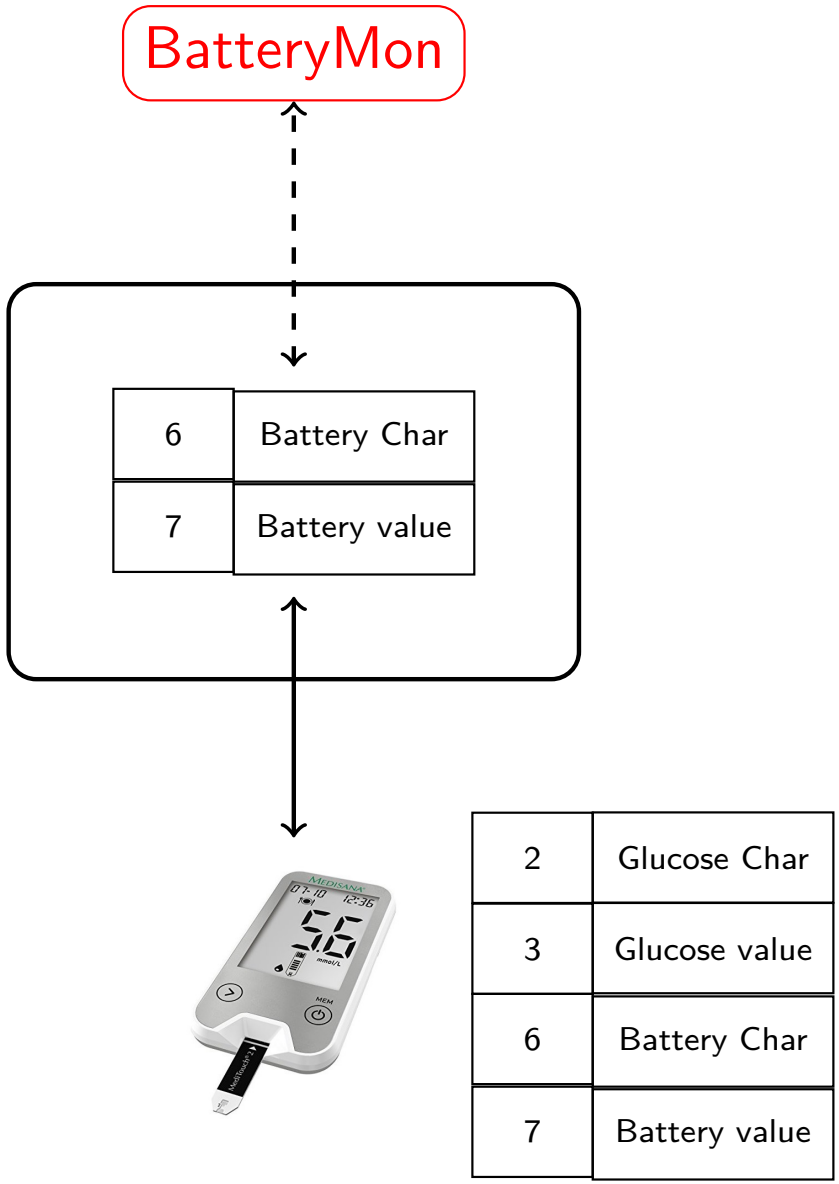
HrView

Virtual Devices: Access Control



2	Glucose Char
3	Glucose value
6	Battery Char
7	Battery value

Virtual Devices: Access Control



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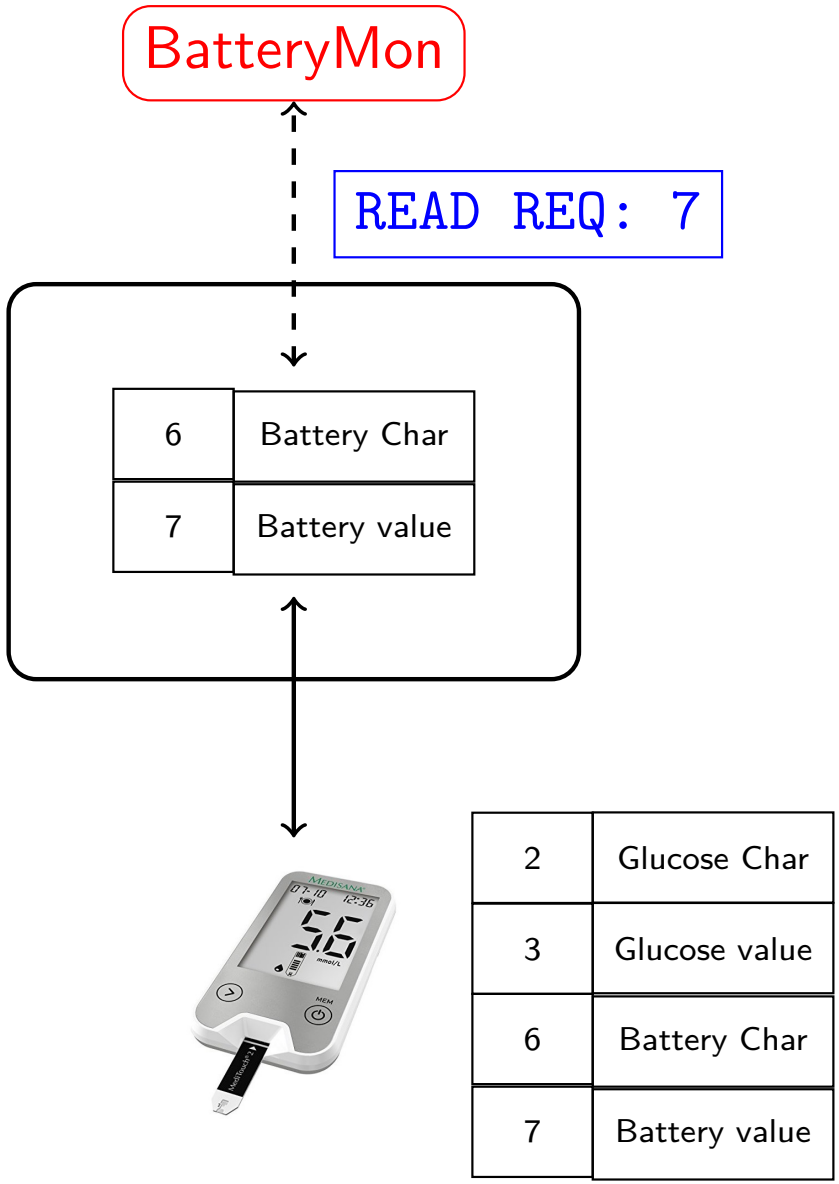

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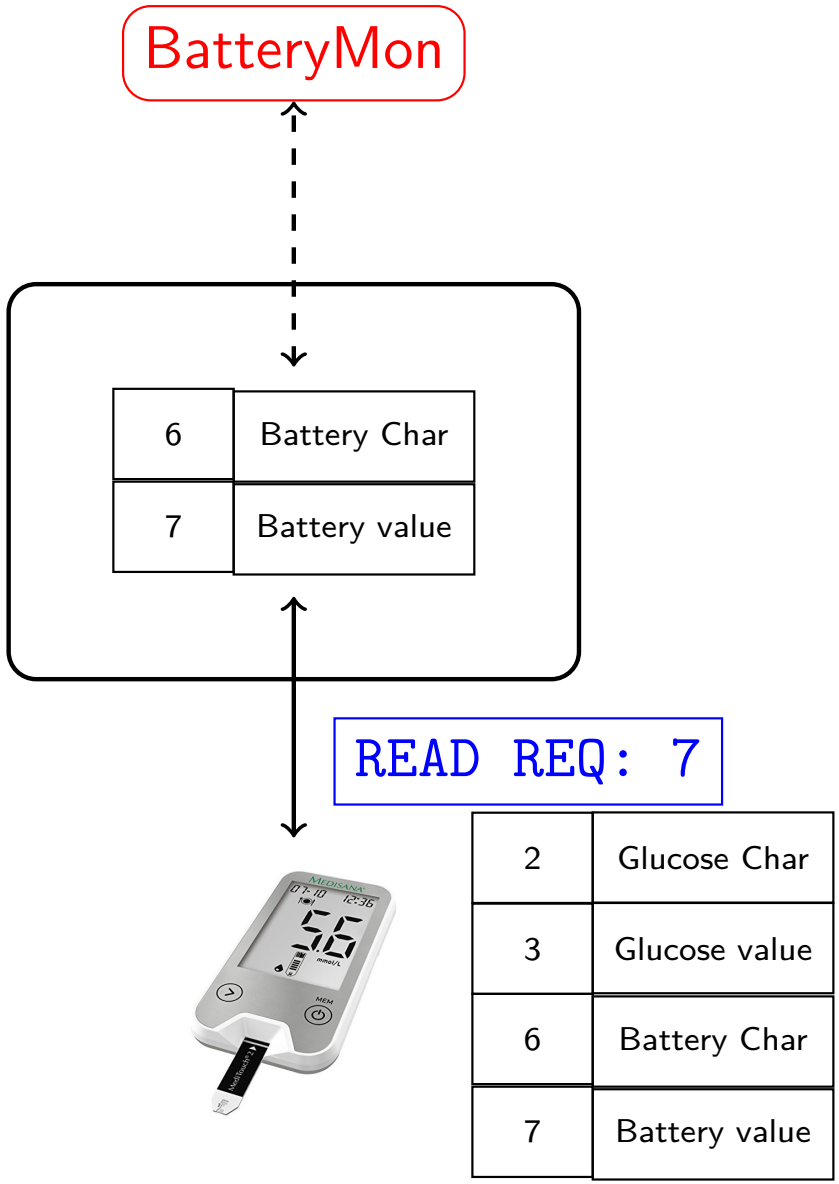

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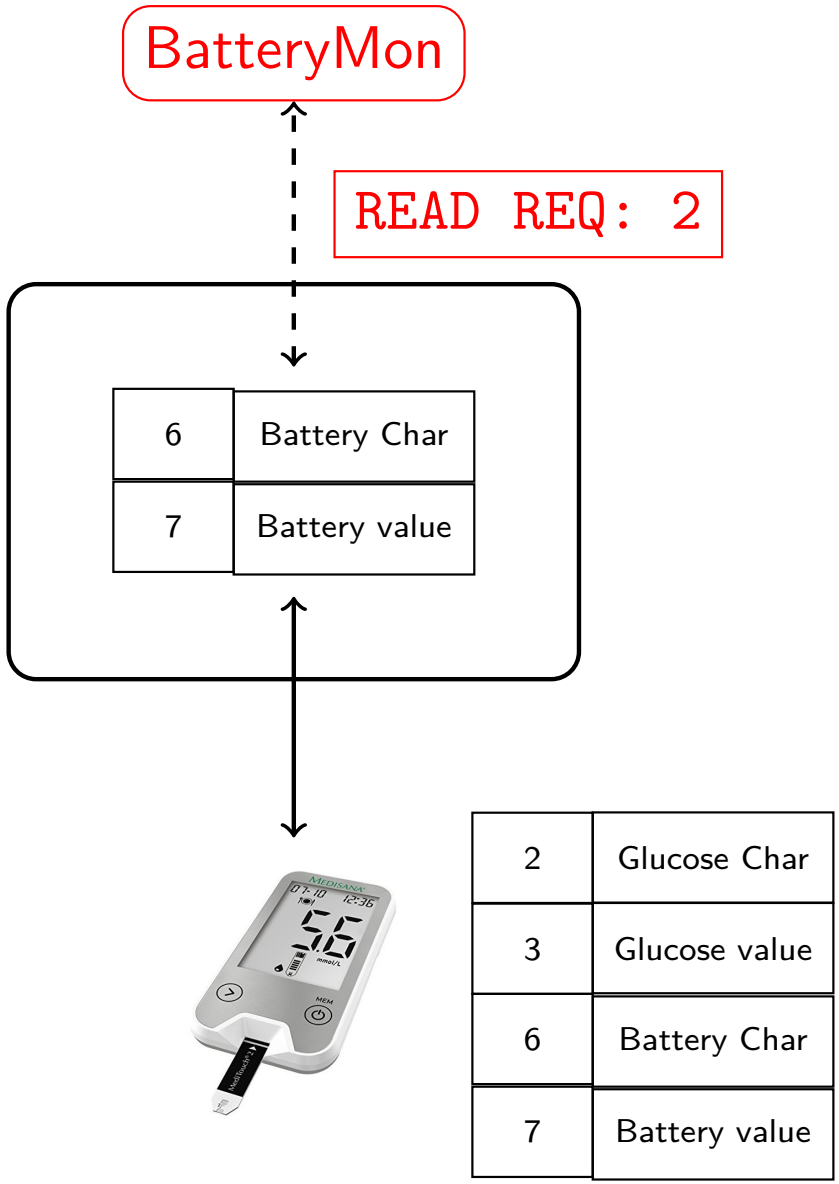

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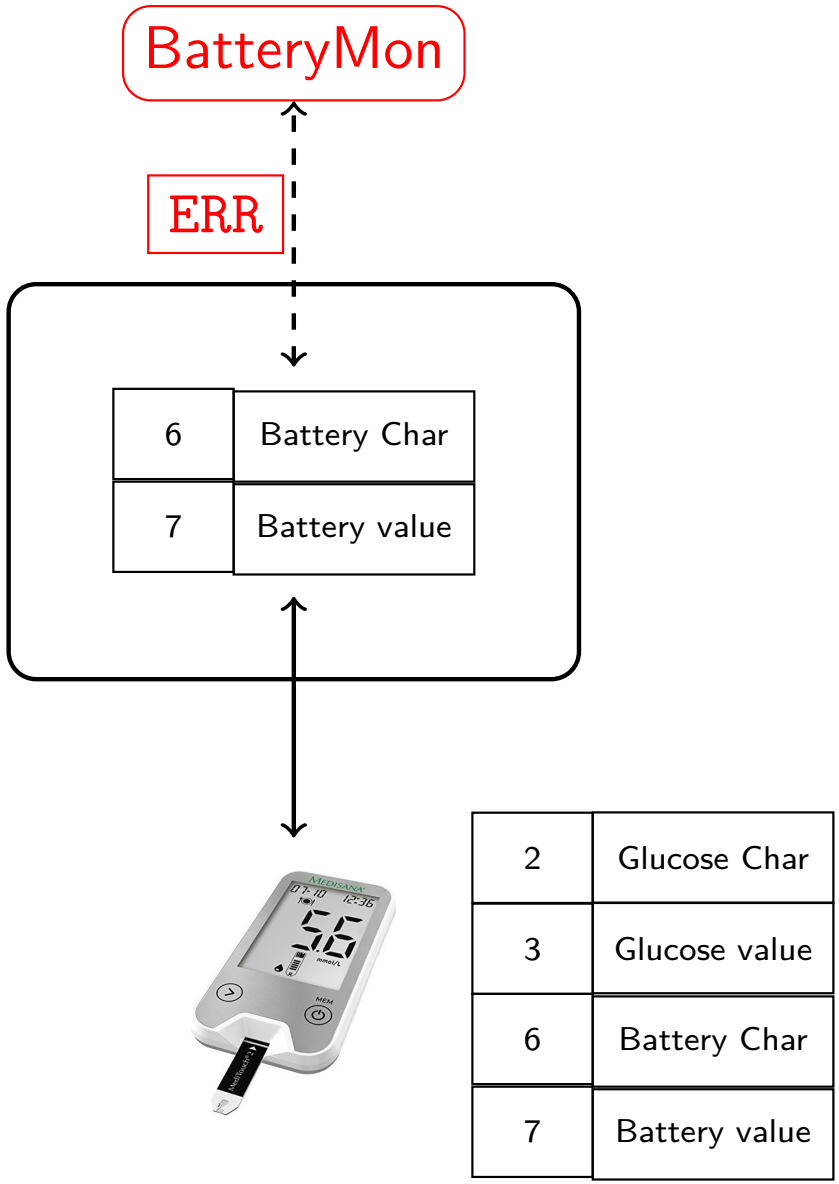


Implementation

Linux

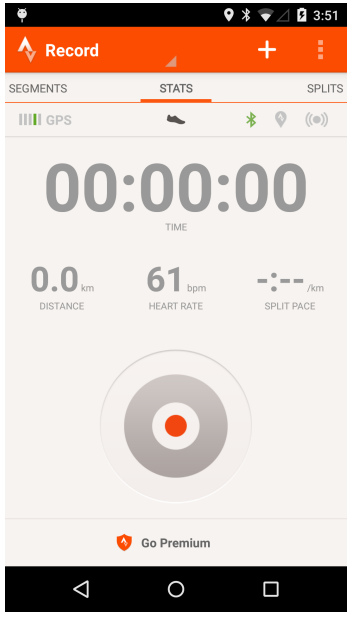
- User-space daemon (C++)
- Applications connect via UNIX domain or TCP sockets
- Access control via database + browser interface

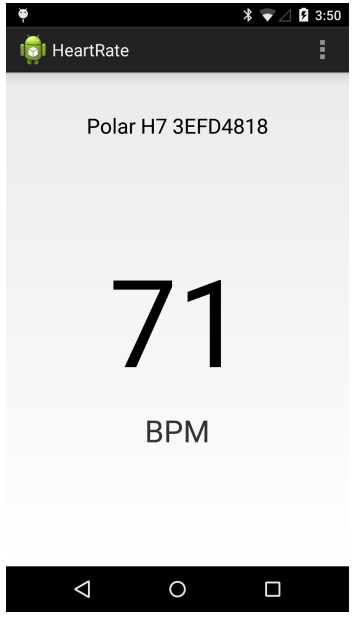
Android

- Modified Android's Bluetooth Service app
- Applications connect over Intents (IPC)
- Access control via normal user control flow

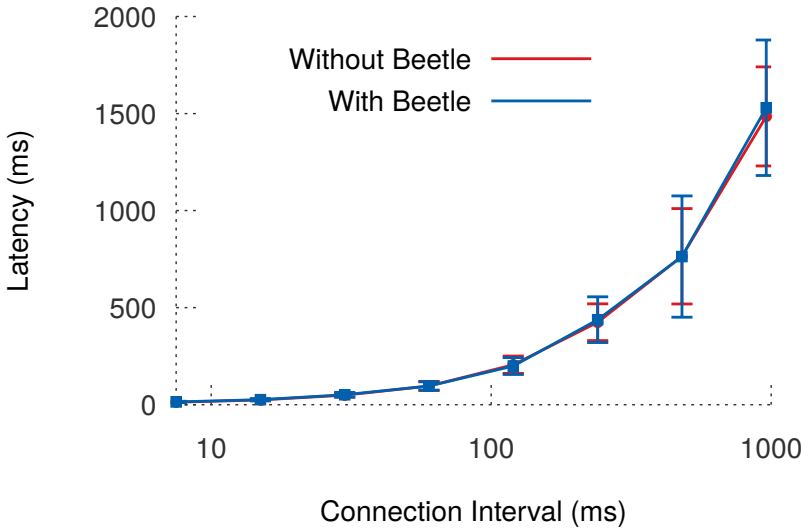
Applications

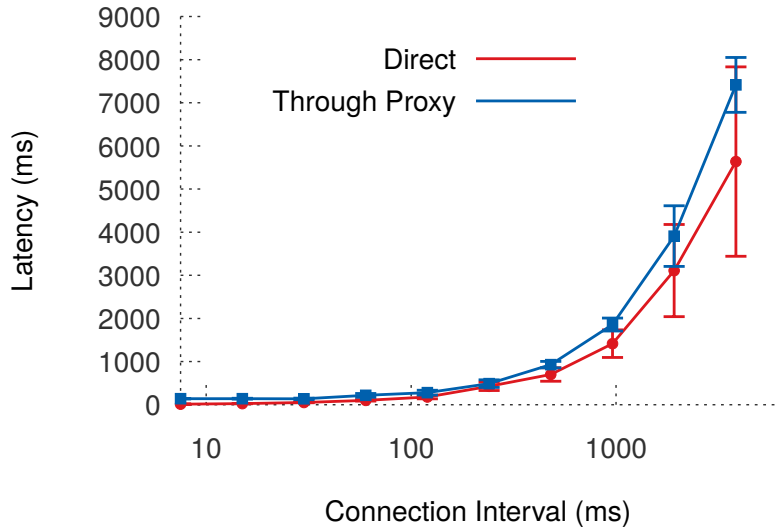
- Multi-app Heart Rate Monitor
- Battery Monitor
- Generic Home Gateway





Performance





- One app to one peripheral – no significant overhead
  - 1.7x connection interval with/without Beetle
- Multi-client throughput depends on workload
  - Reads are linearly scalable via caching
- Peripheral-to-peripheral ~2-3x due to extra hop
  - Could be improved with better coordination by gateway

Limitations

- Bluetooth Low Energy specific
  - Relies on properties of the application layer protocol
- Peripherals must conform to GATT transactional semantics
  - But peripheral-specific virtual devices could mask violations
- Access control does not solve secure naming
- Does not offer a management solution
  - Complimentary to systems, like HomeOS

Discussion

Safe and flexible peripheral sharing

Can and should be provided first-class by the gateway

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Lessons for protocol design

- Data model at the right abstraction level
- Standardized data types
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Lessons for BLE peripheral builders

- Don't rely on exclusive access for semantics
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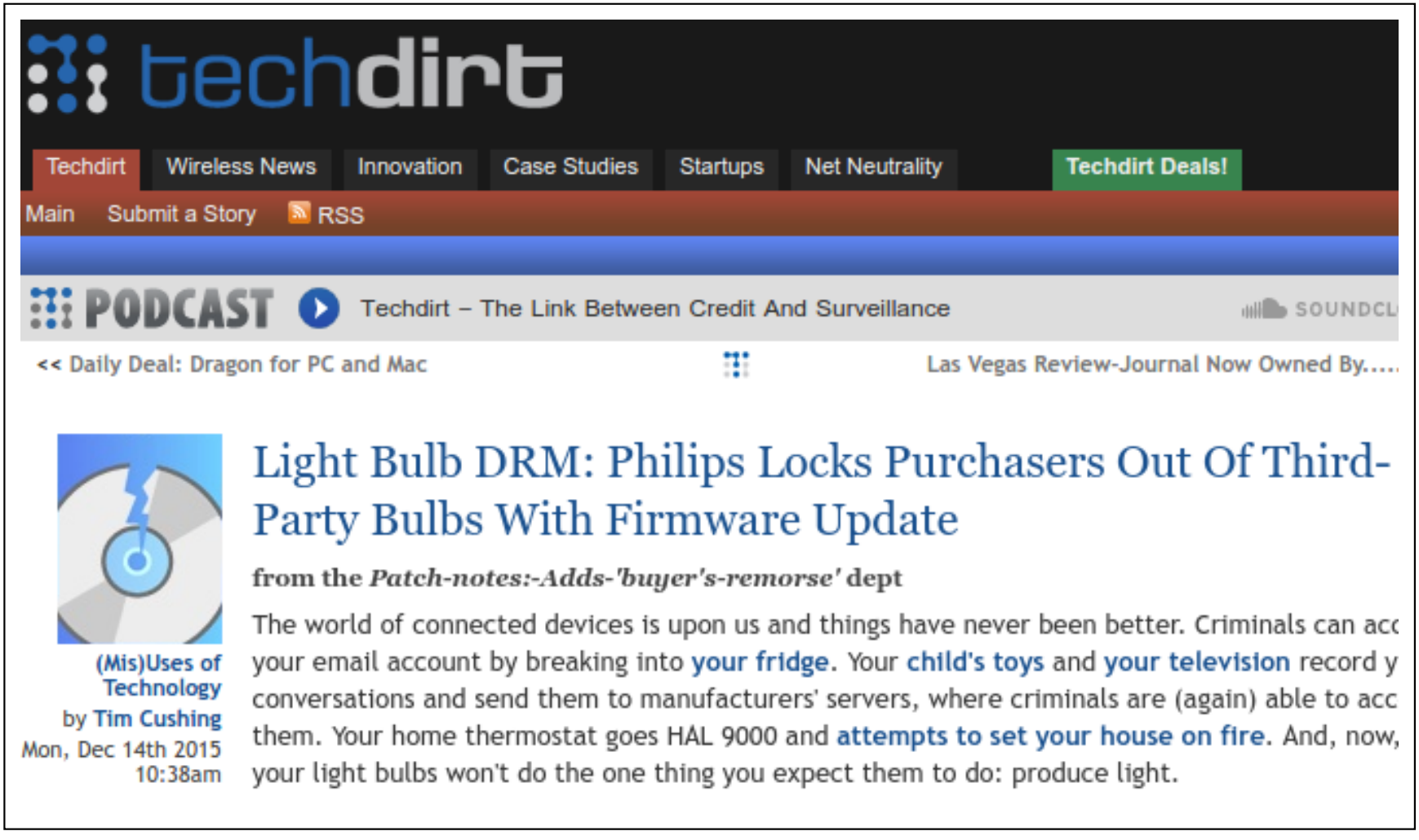
`https://github.com/helena-project/beetle`

Are corporations just evil?



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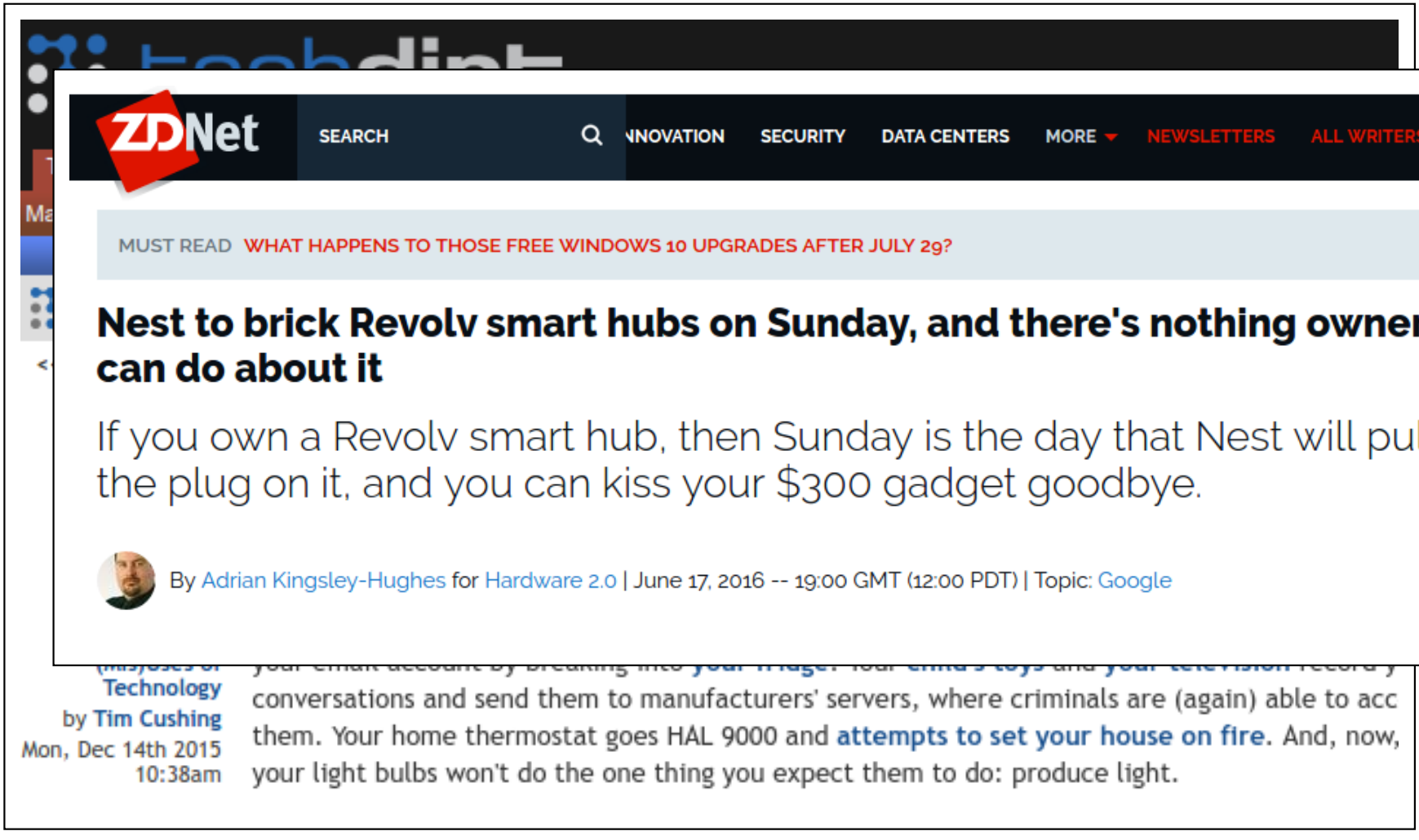

ZDNet SEARCH INNOVATION SECURITY DATA CENTERS MORE NEWSLETTERS ALL WRITERS

MUST READ WHAT HAPPENS TO THOSE FREE WINDOWS 10 UPGRADES AFTER JULY 29?

Nest to brick Revolv smart hubs on Sunday, and there's nothing owners can do about it

If you own a Revolv smart hub, then Sunday is the day that Nest will pull the plug on it, and you can kiss your $300 gadget goodbye.

By Adrian Kingsley-Hughes for Hardware 2.0 | June 17, 2016 -- 19:00 GMT (12:00 PDT) | Topic: Google

Technology
by Tim Cushing
Mon, Dec 14th 2015
10:38am

conversations and send them to manufacturers' servers, where criminals are (again) able to acc
them. Your home thermostat goes HAL 9000 and **attempts to set your house on fire.** And, now,
your light bulbs won't do the one thing you expect them to do: produce light.

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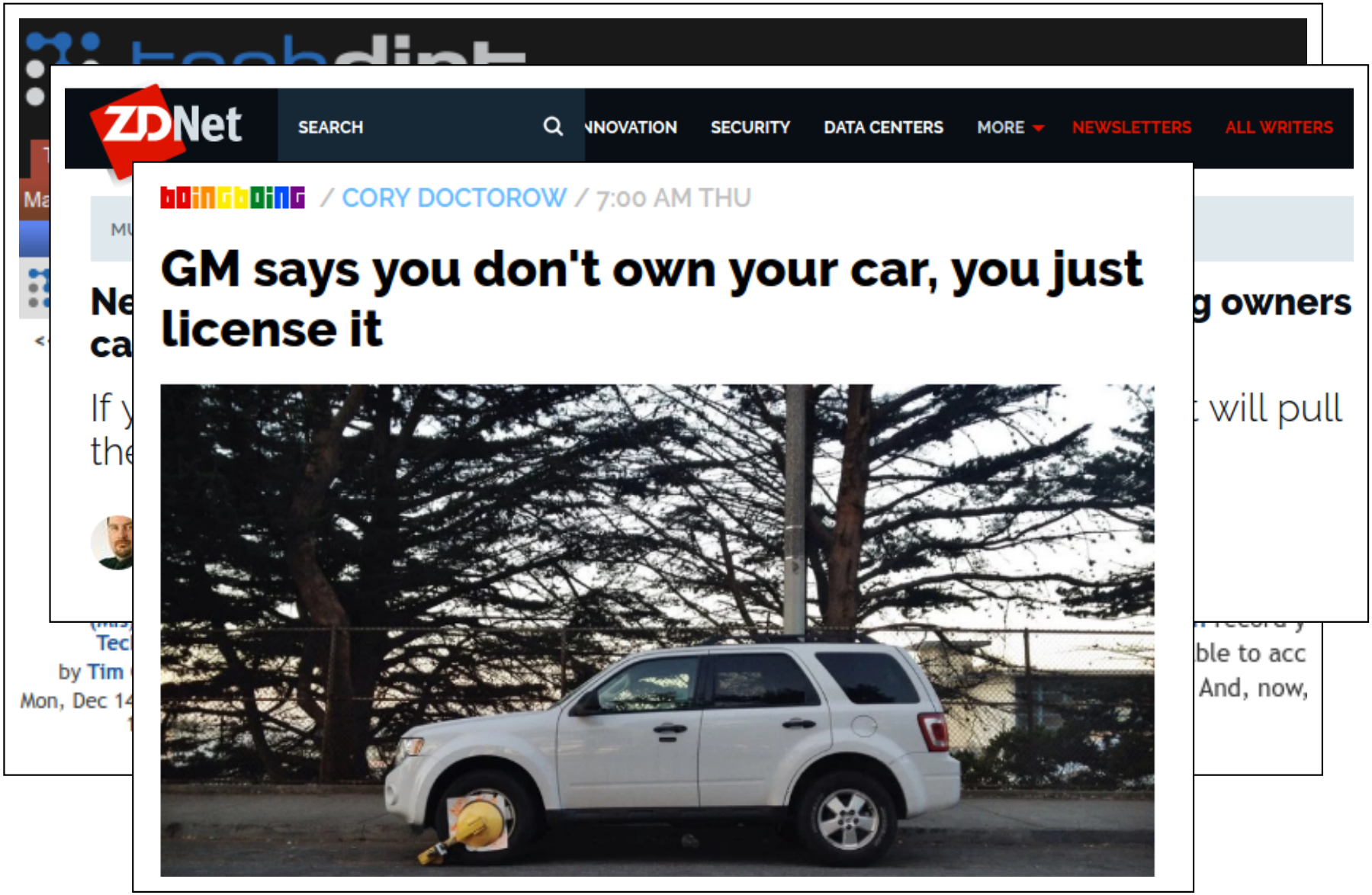
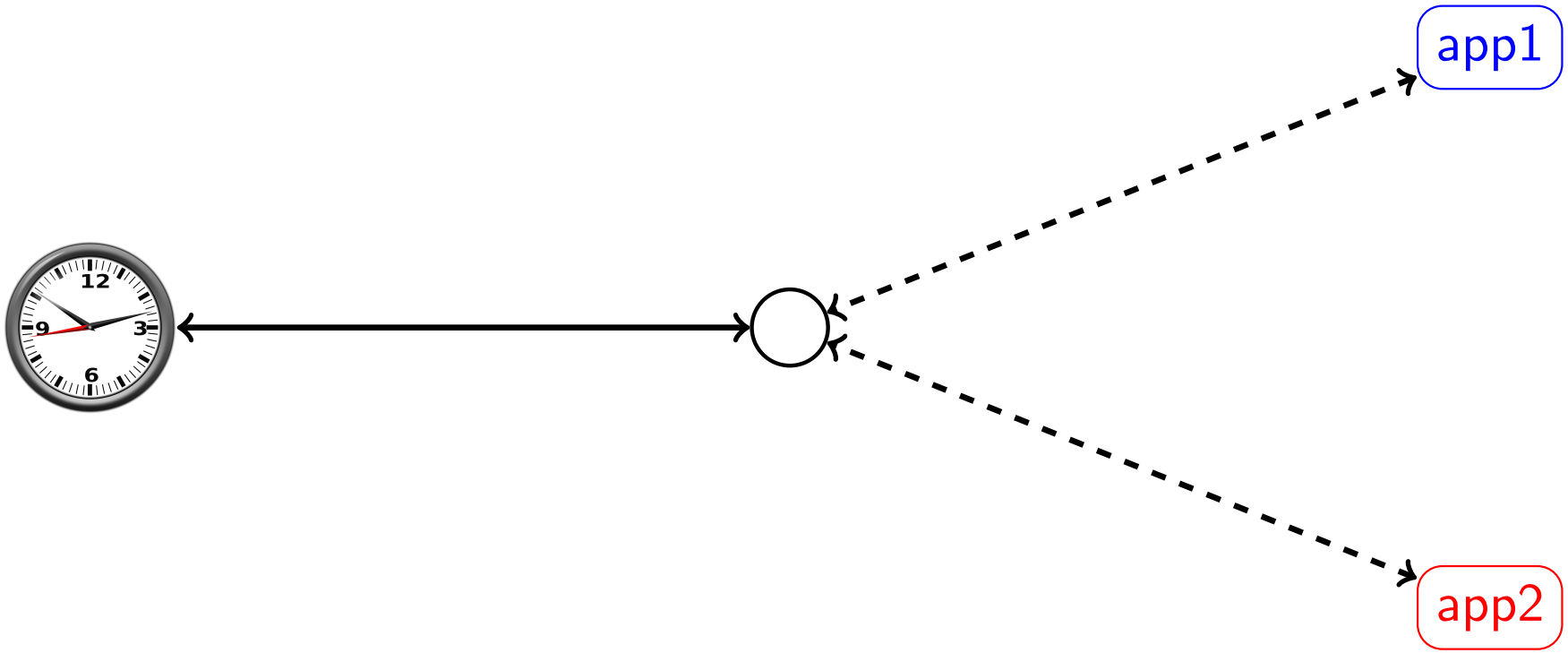


Attribute Caching



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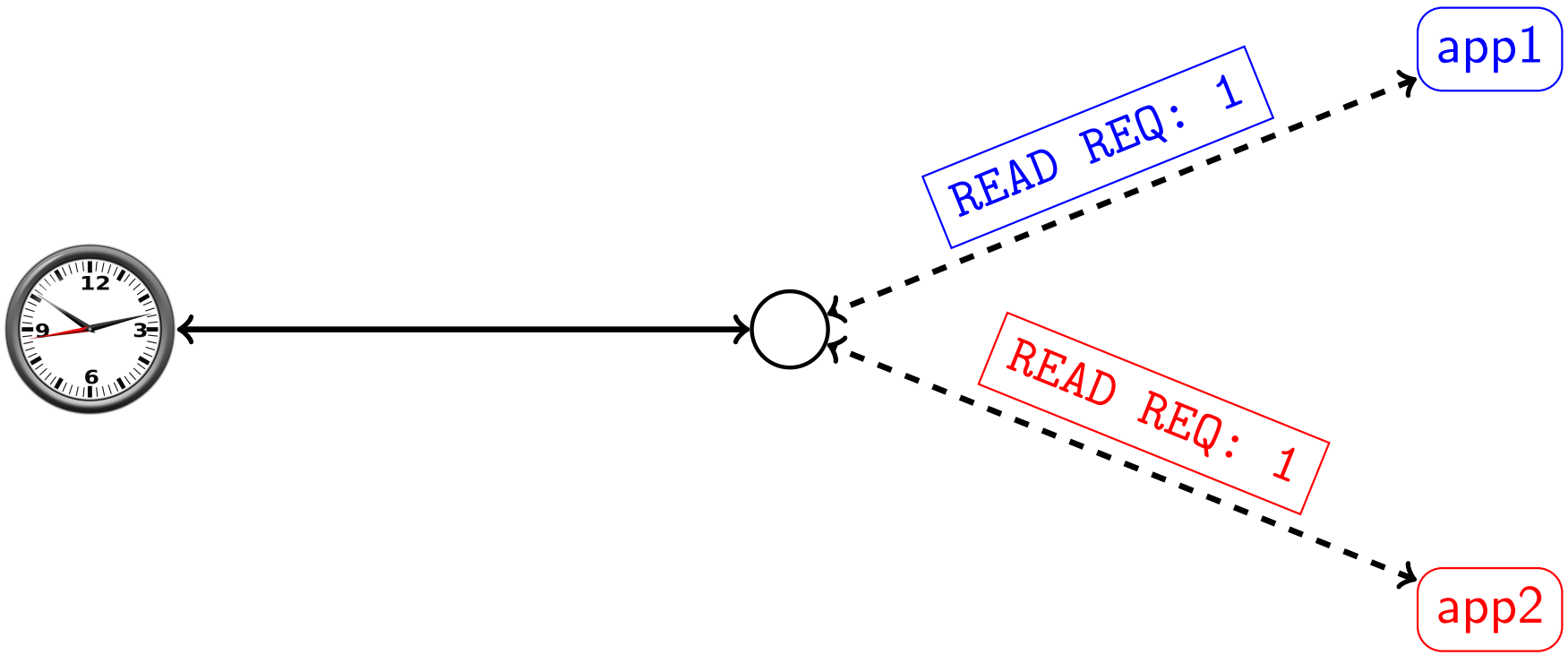

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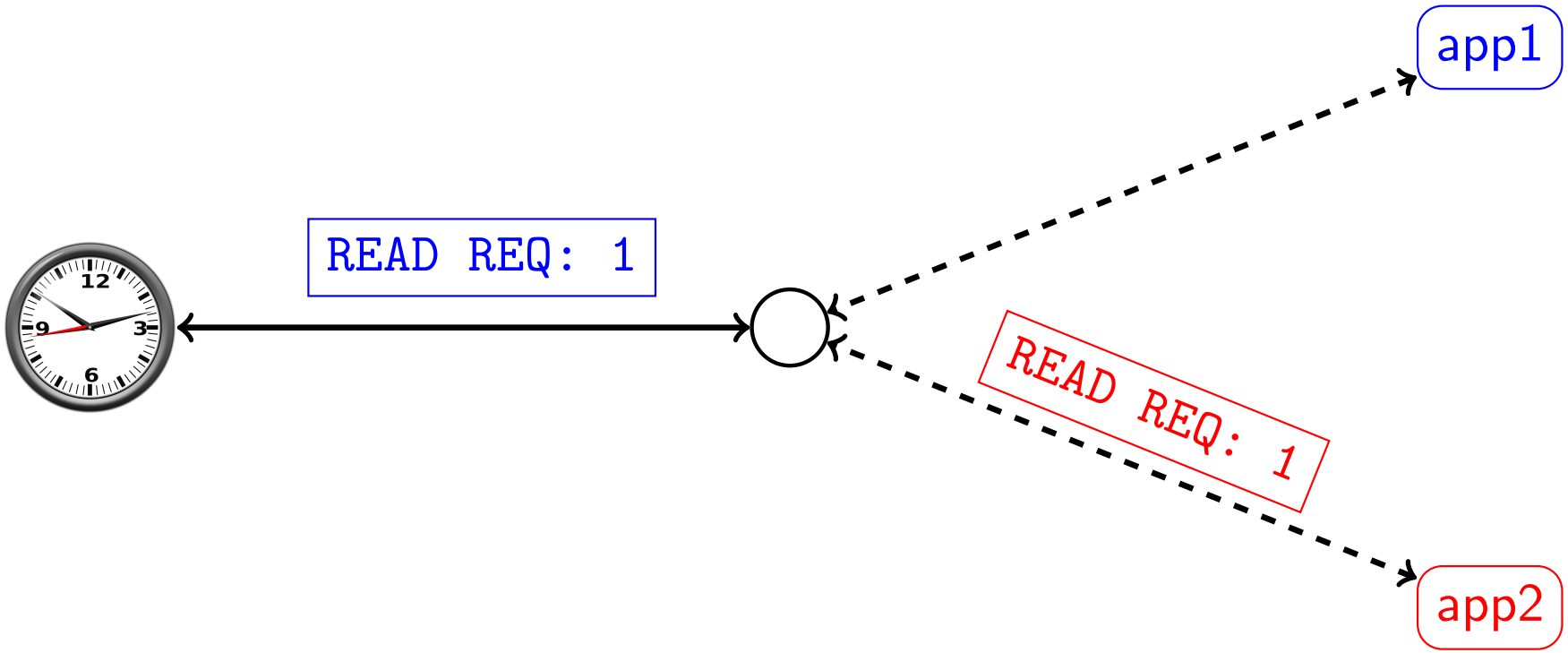

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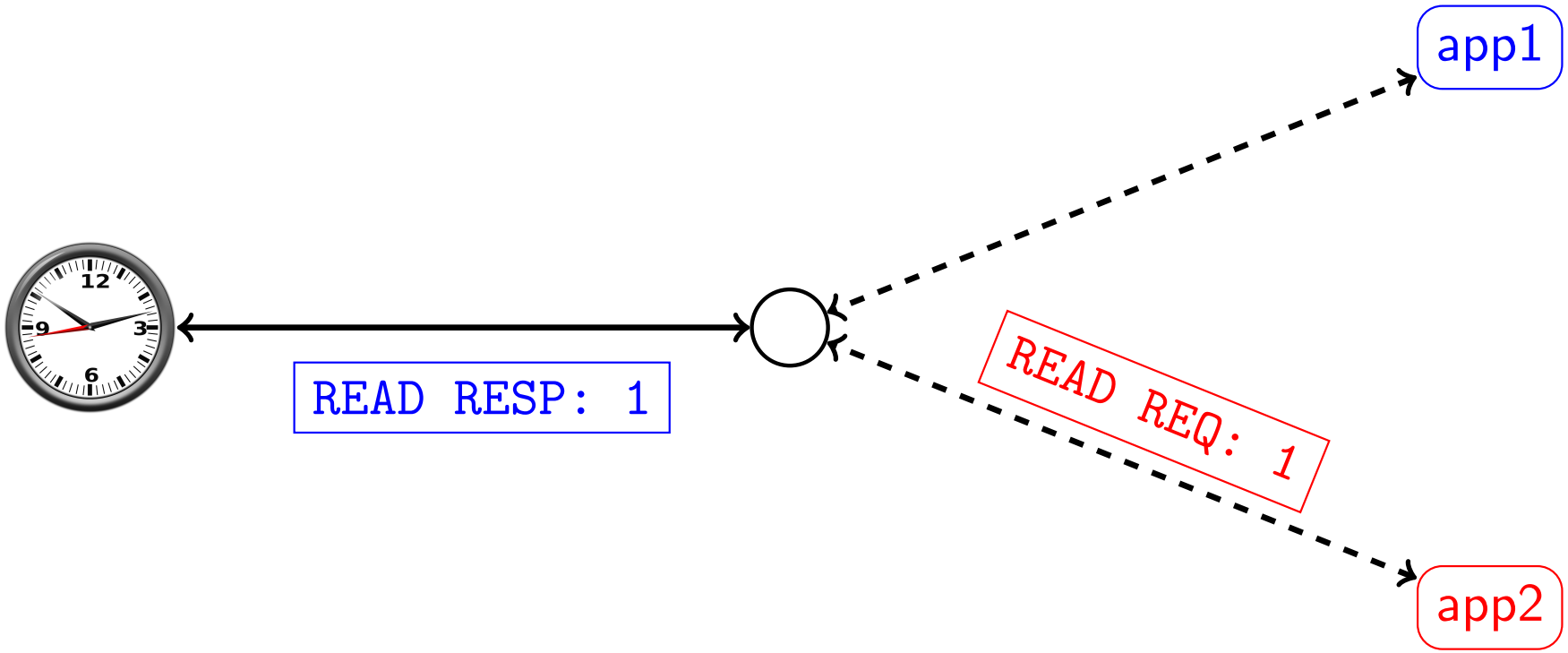

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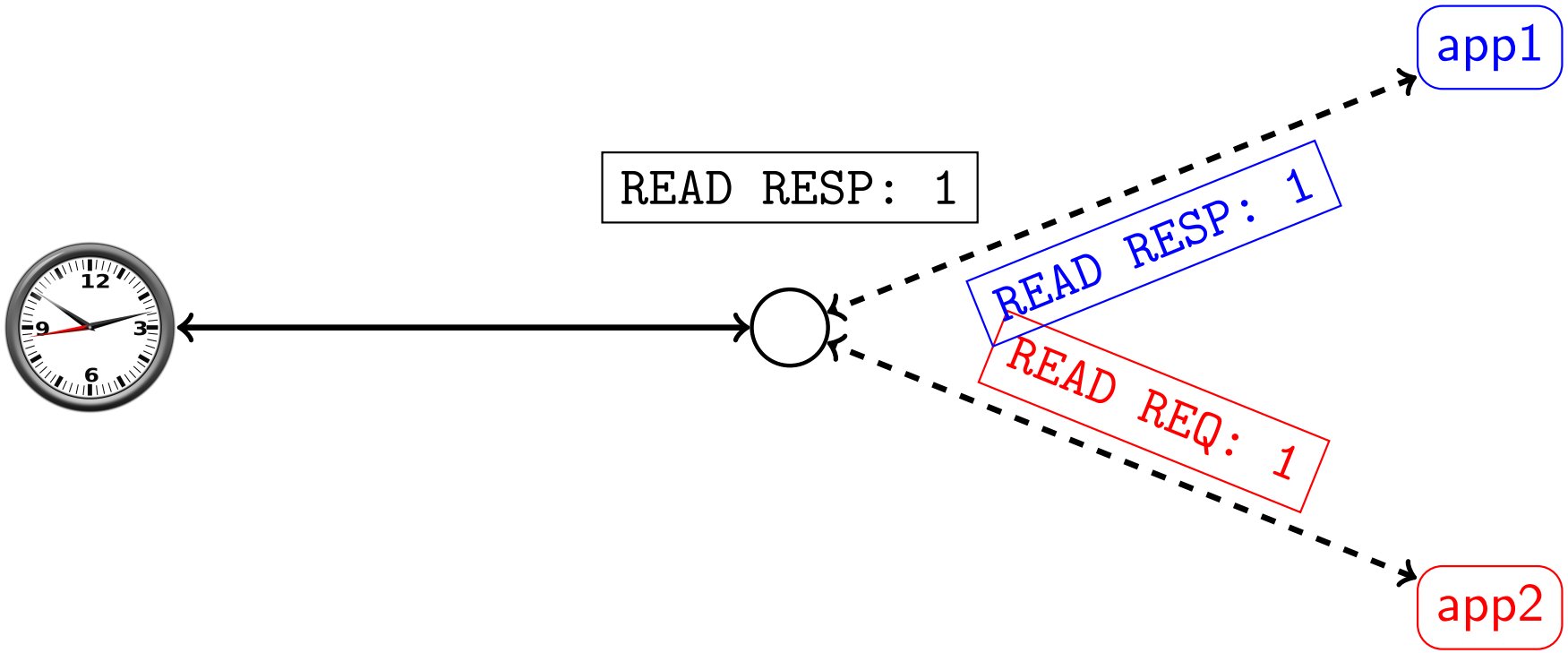

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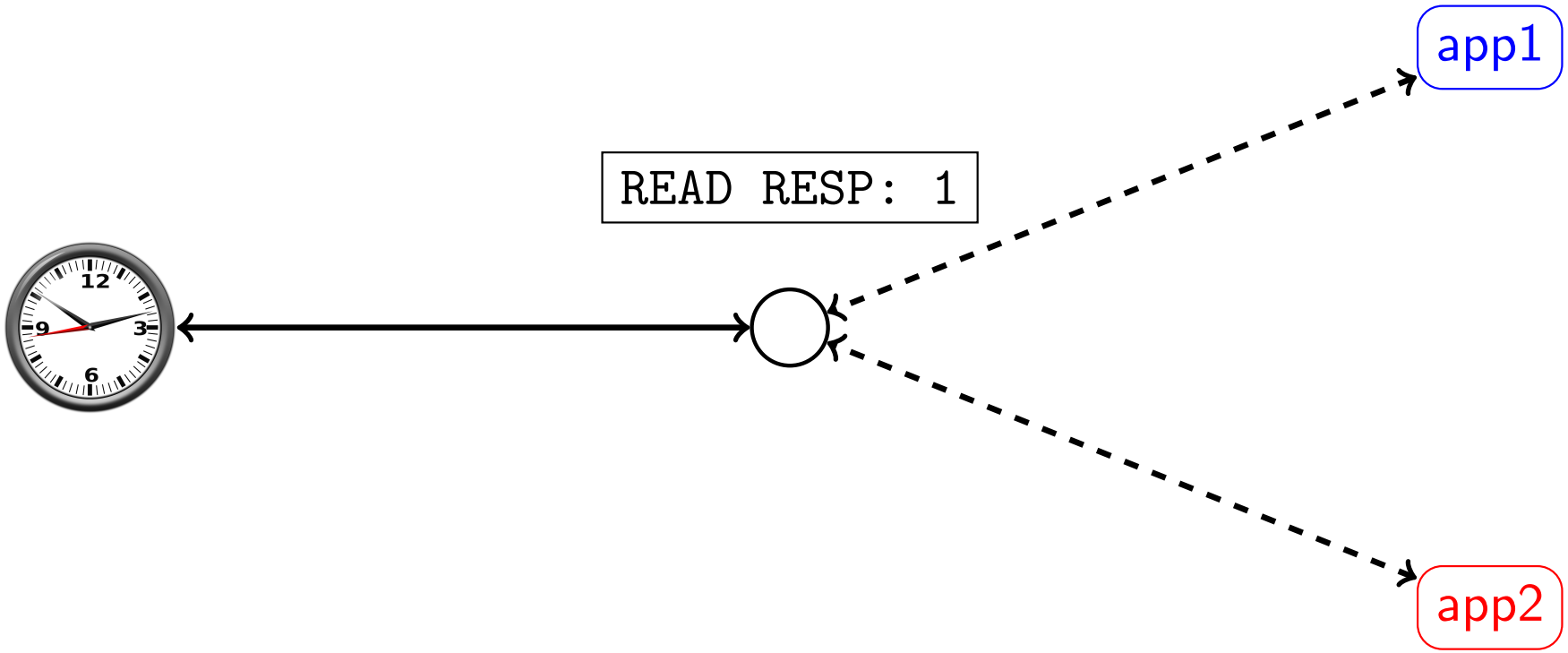

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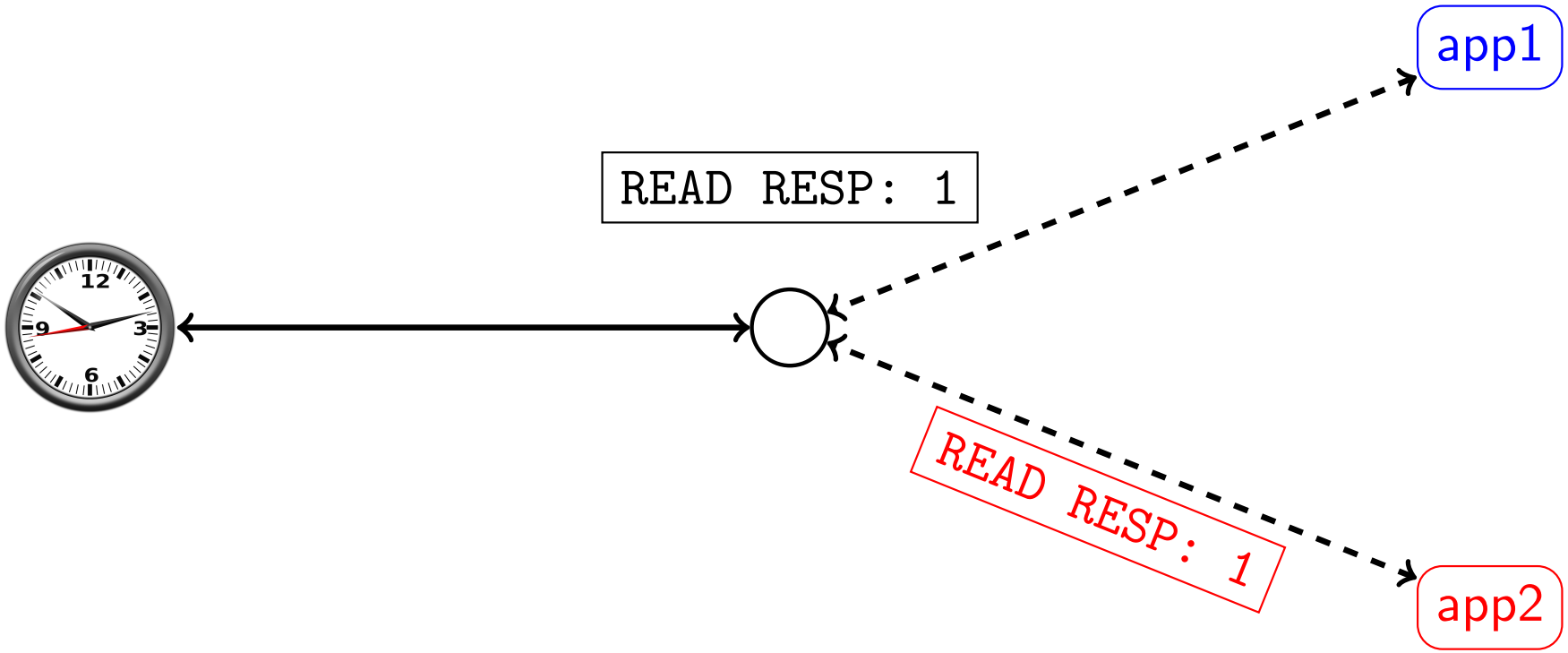
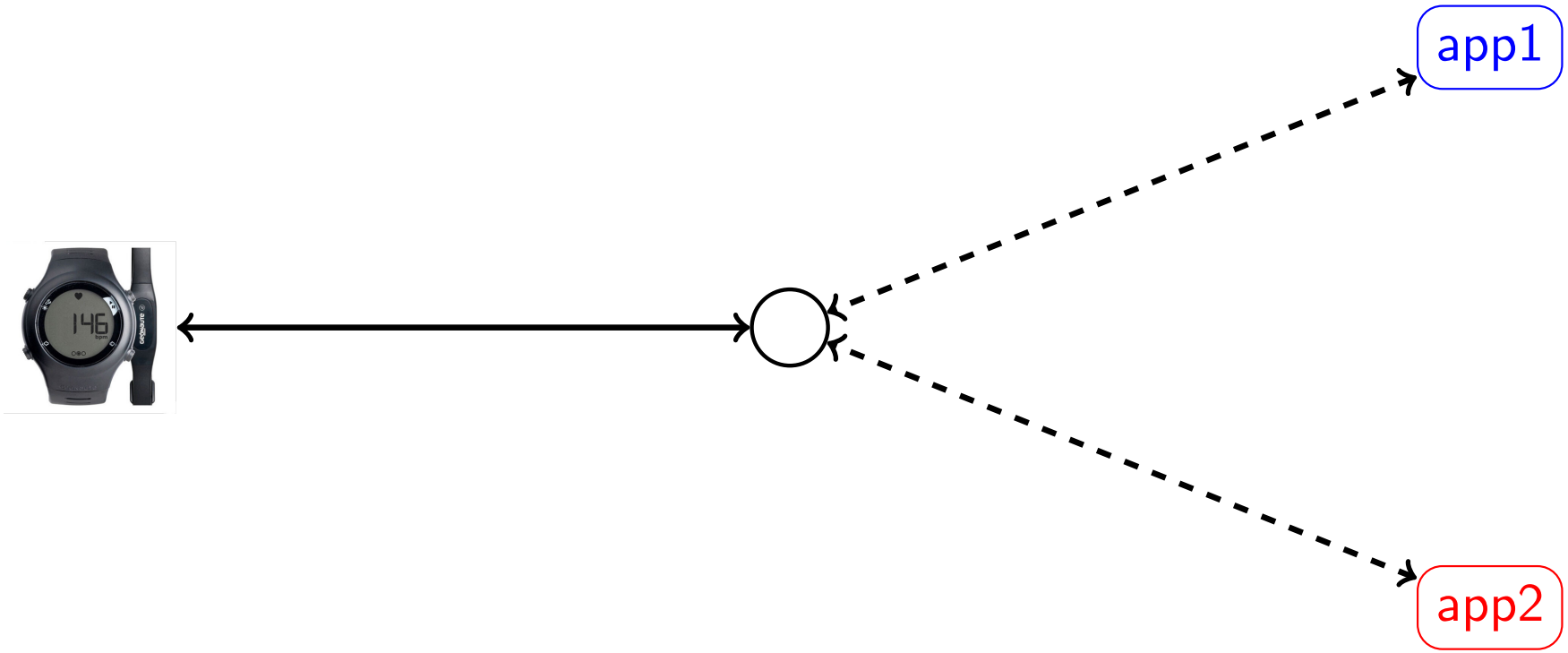


Handling Subscriptions



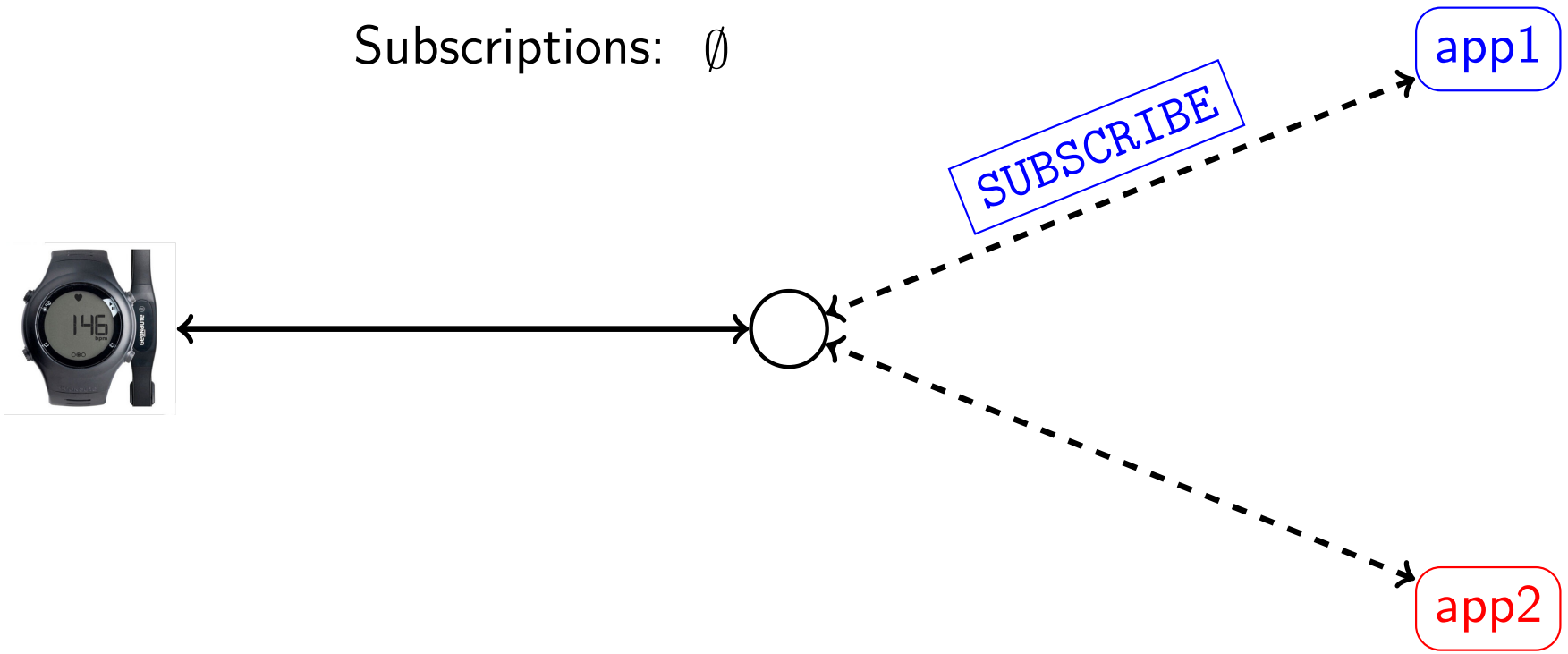
Handling Subscriptions

Subscriptions: $\emptyset$

app1

app2

Handling Subscriptions



Handling Subscriptions

Subscriptions: app1

app1

app2

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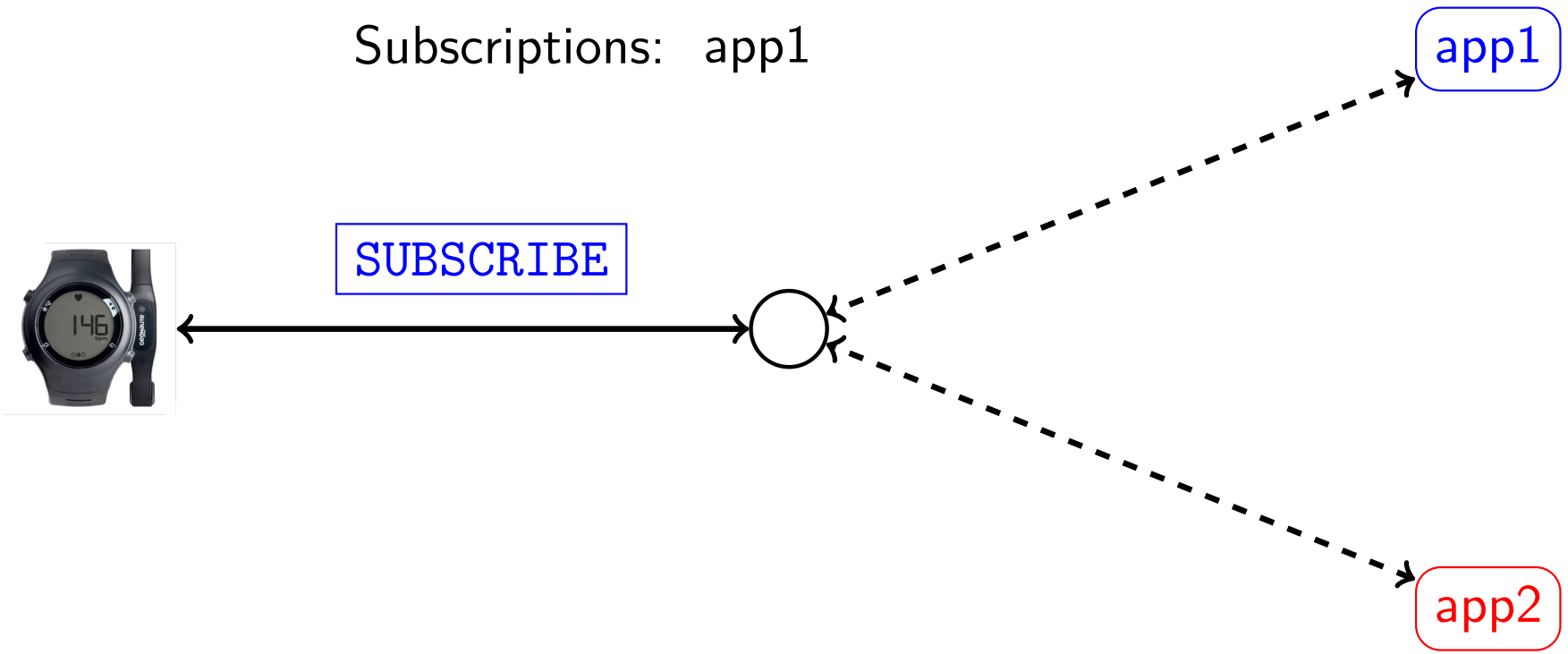

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app1

app2

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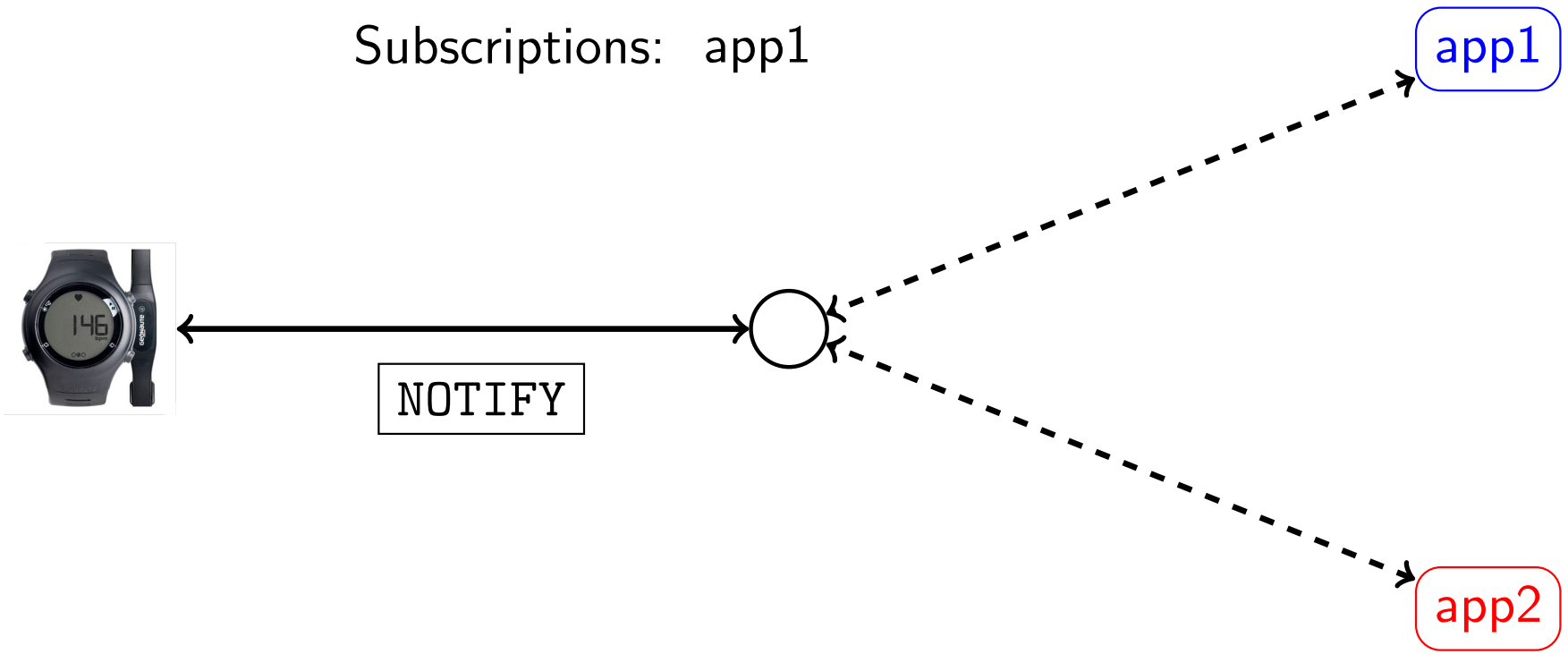
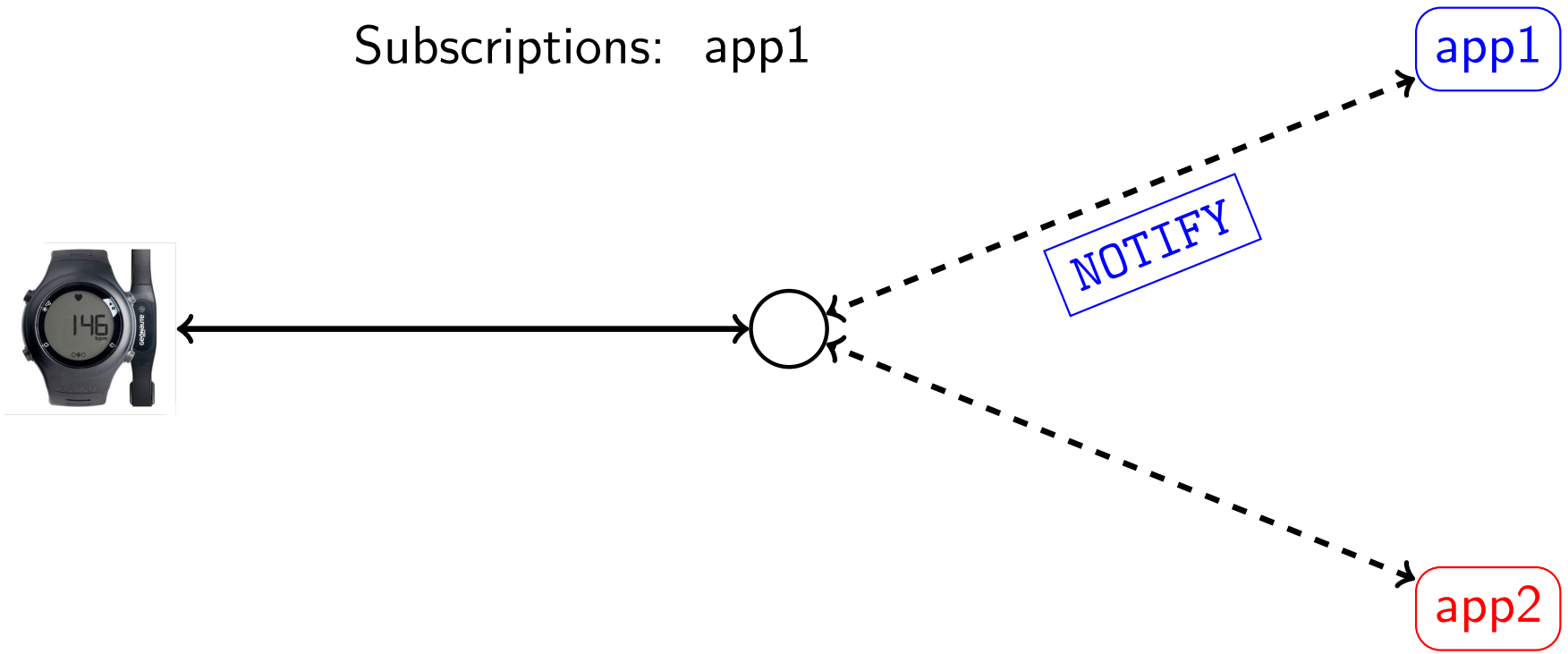


Handling Subscriptions



Handling Subscriptions

Subscriptions: app1

app1

app2

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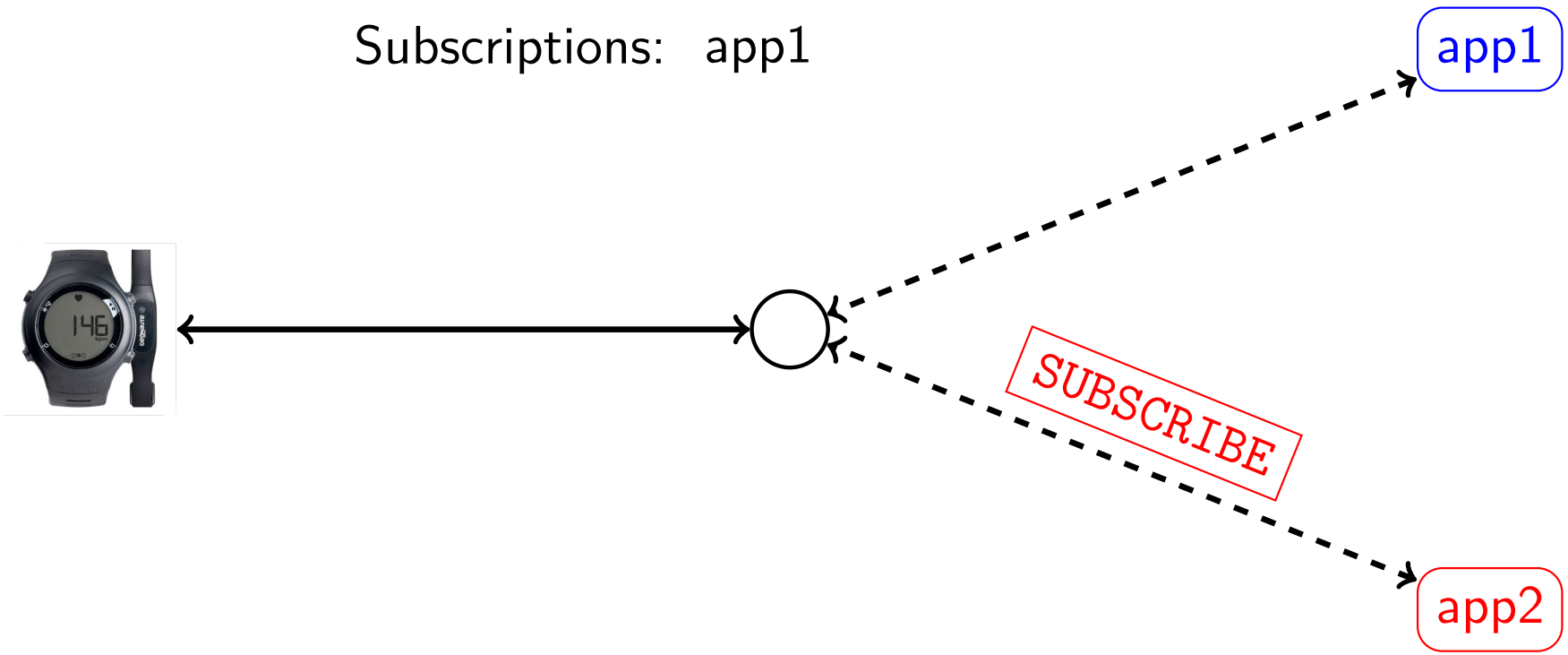

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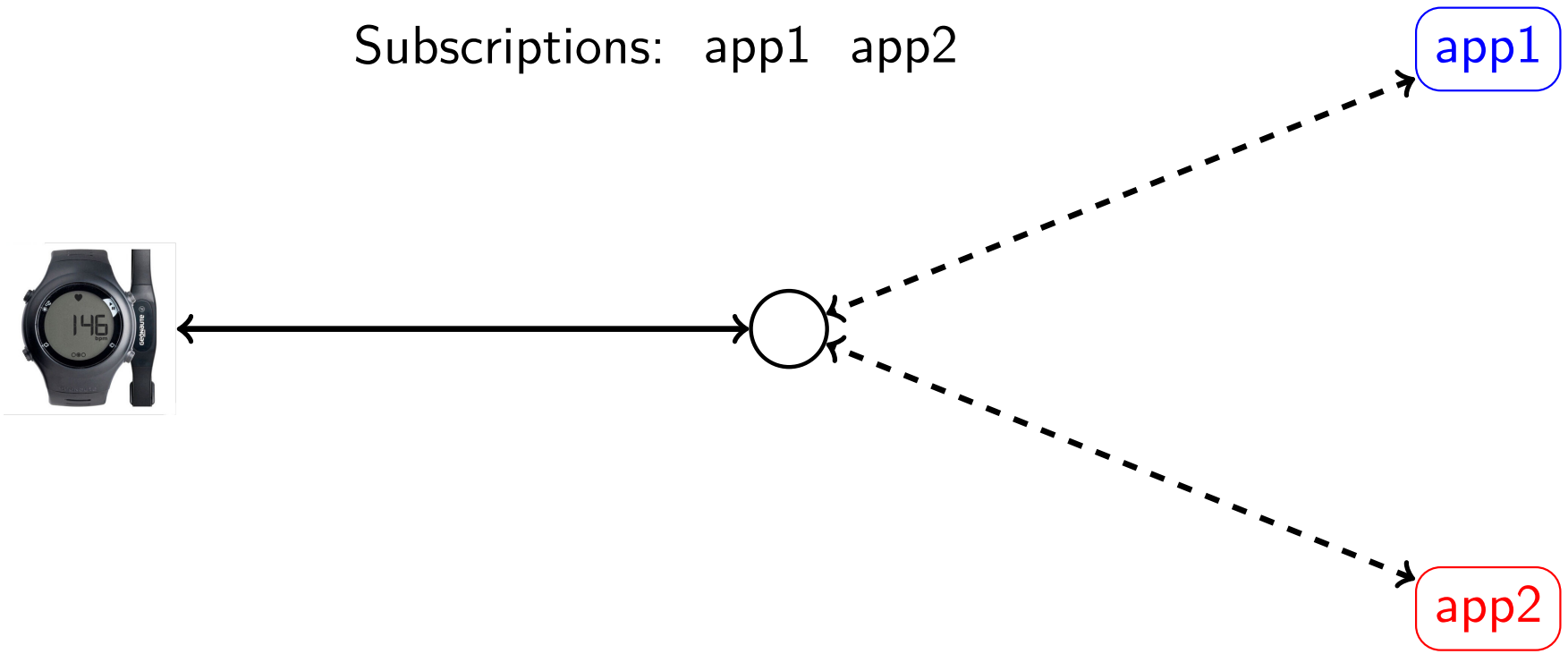

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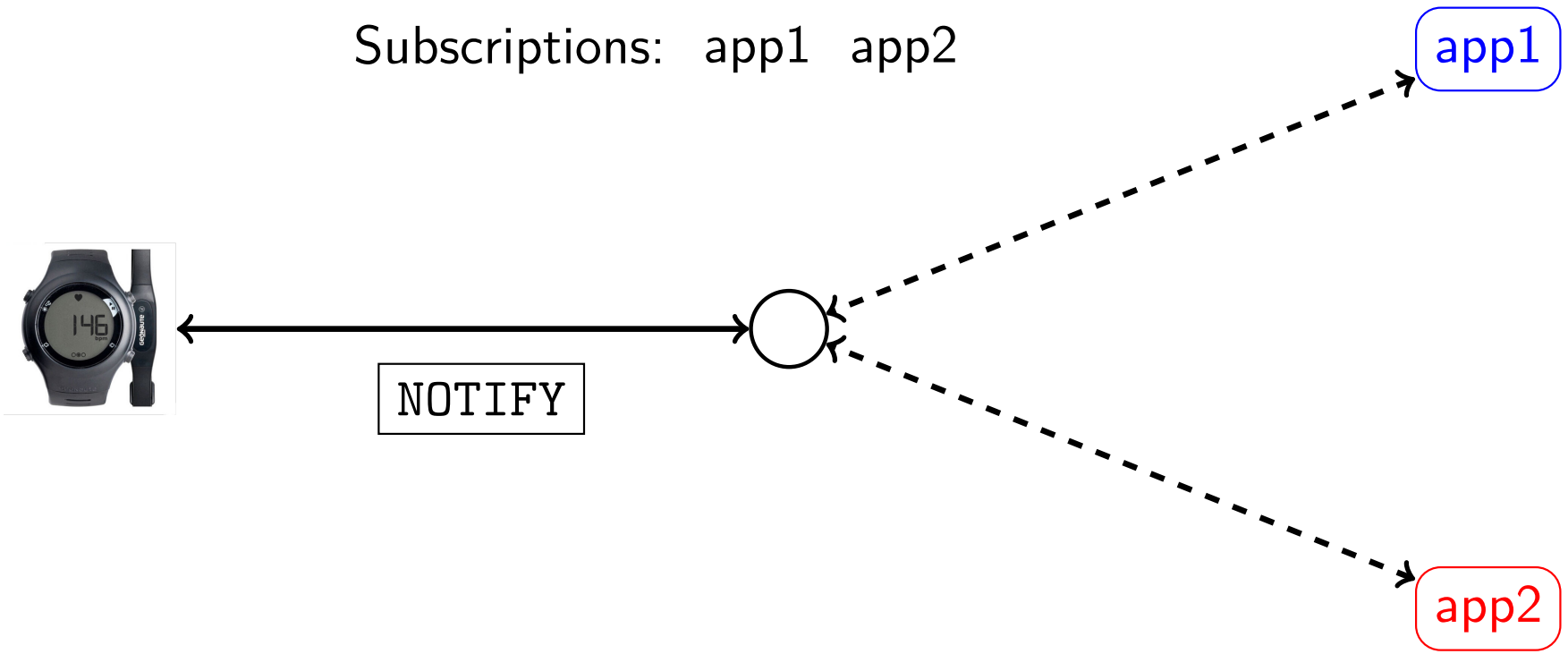

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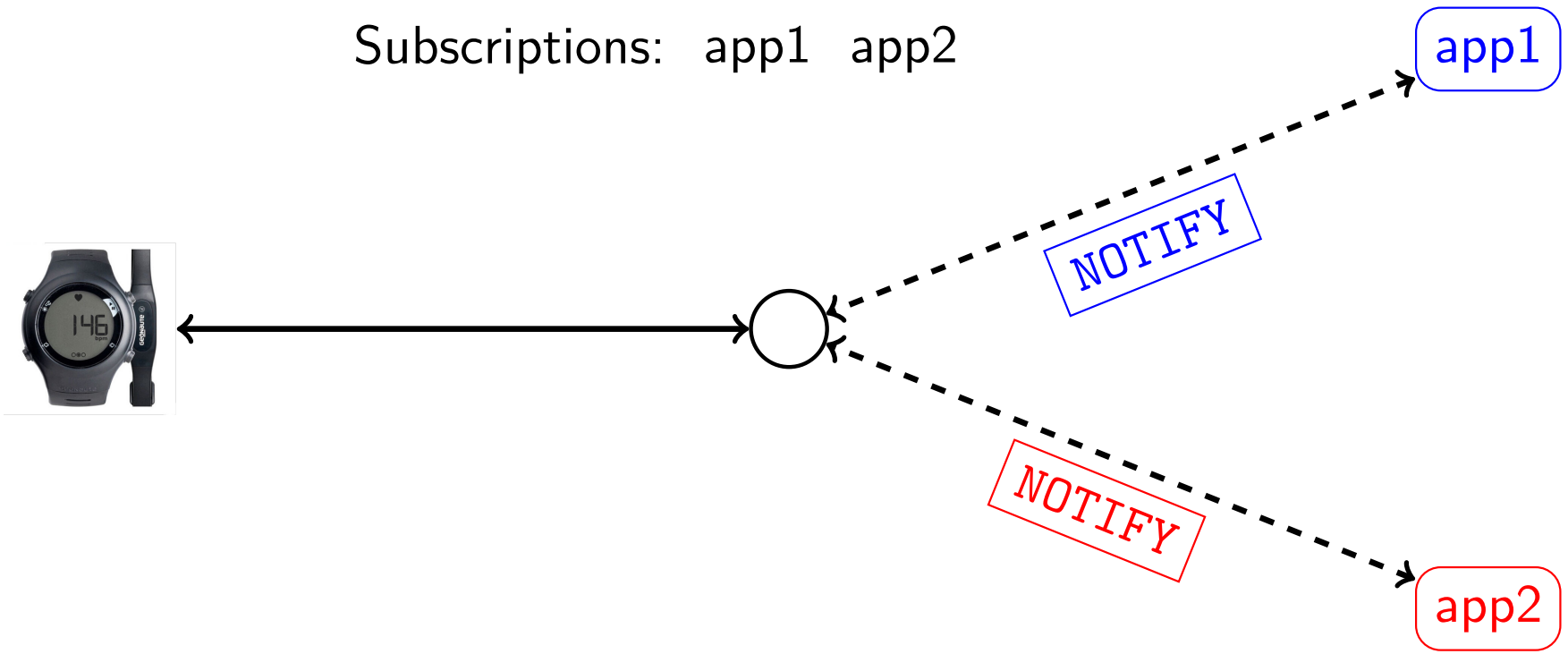

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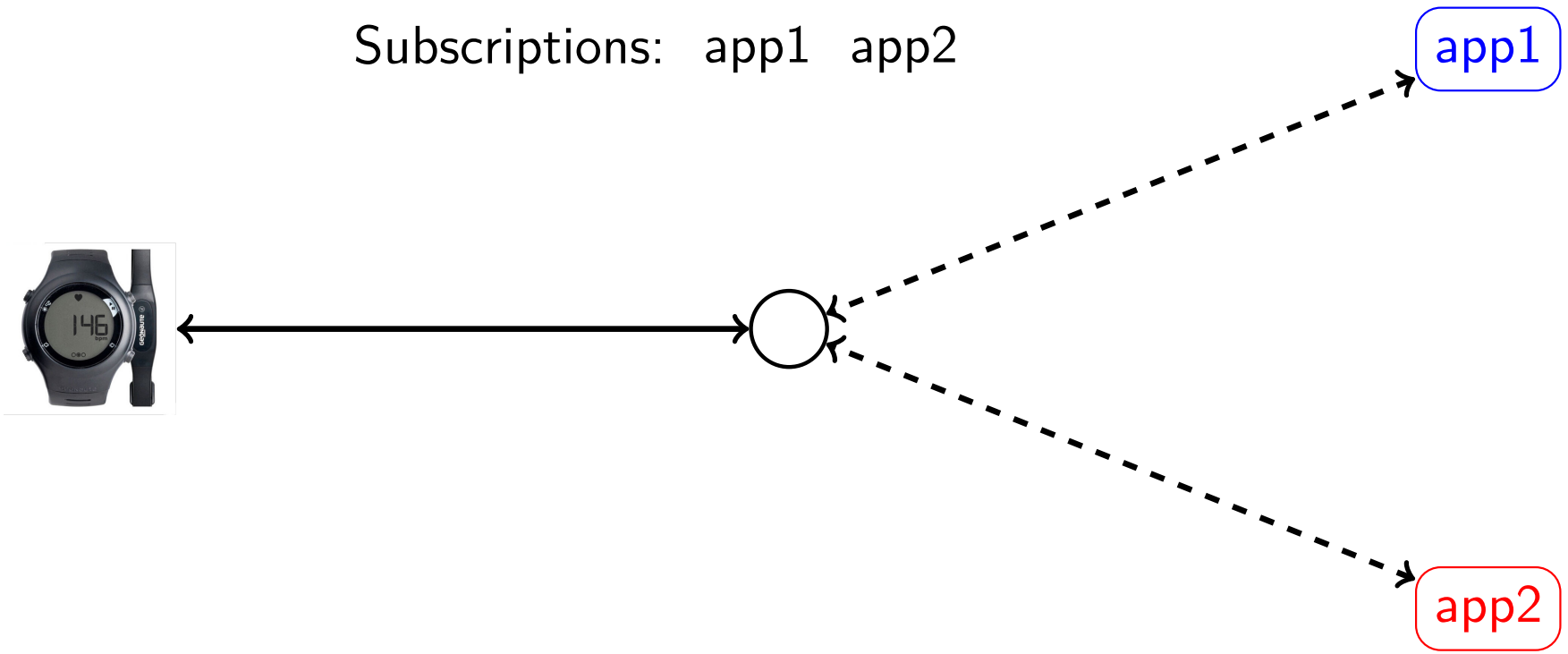

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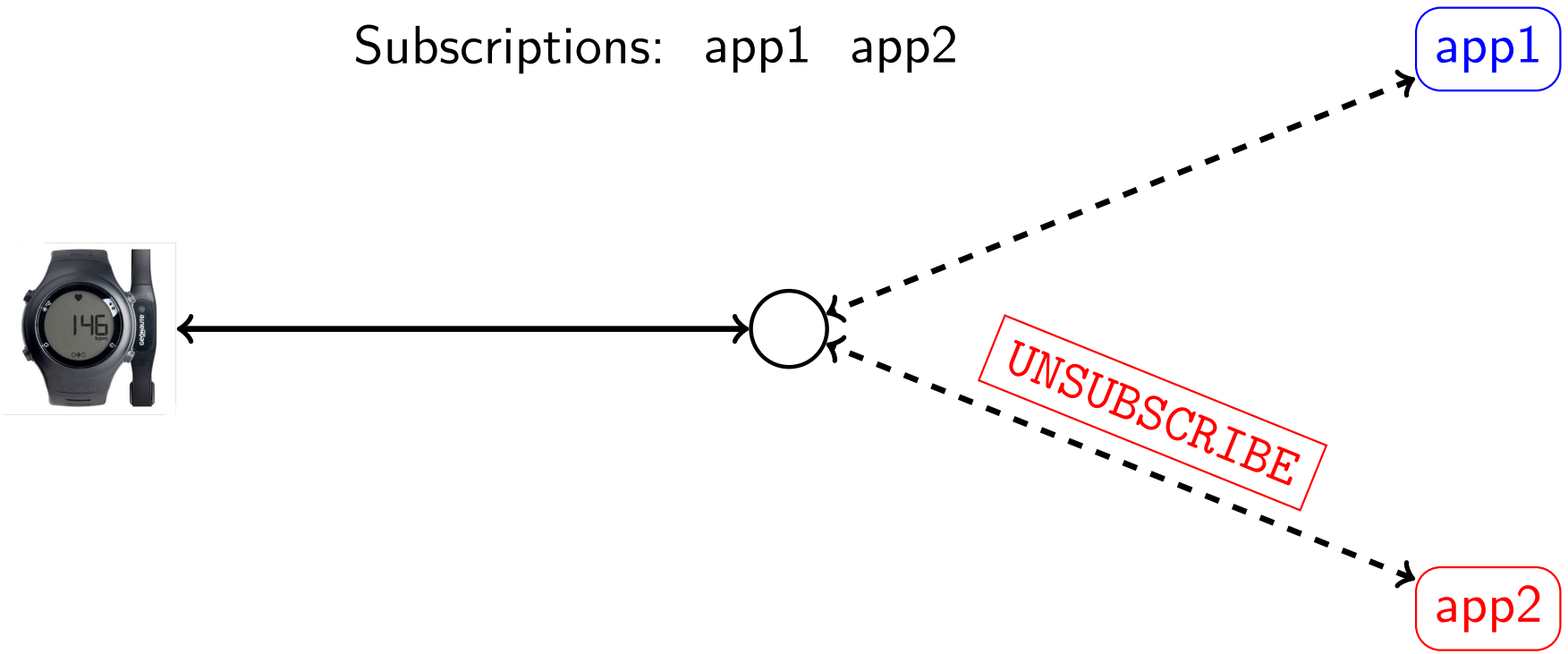

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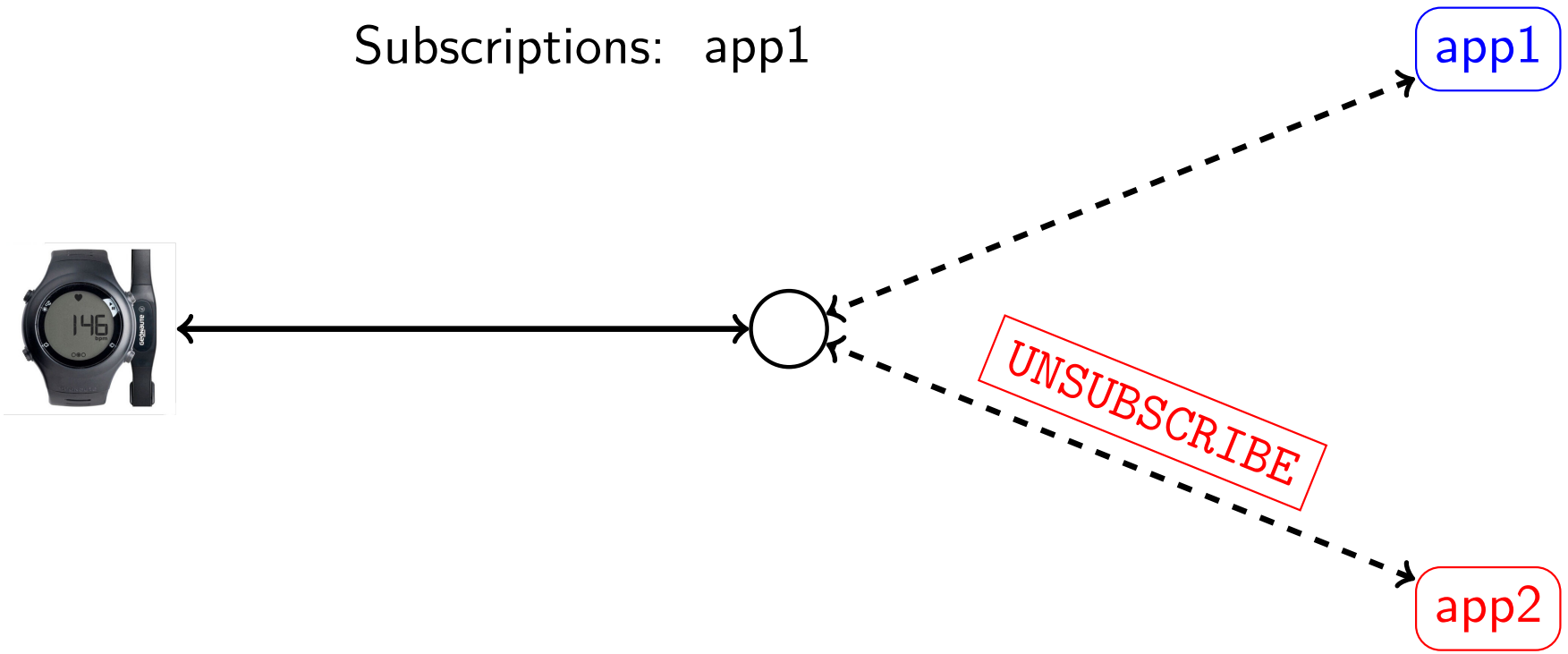

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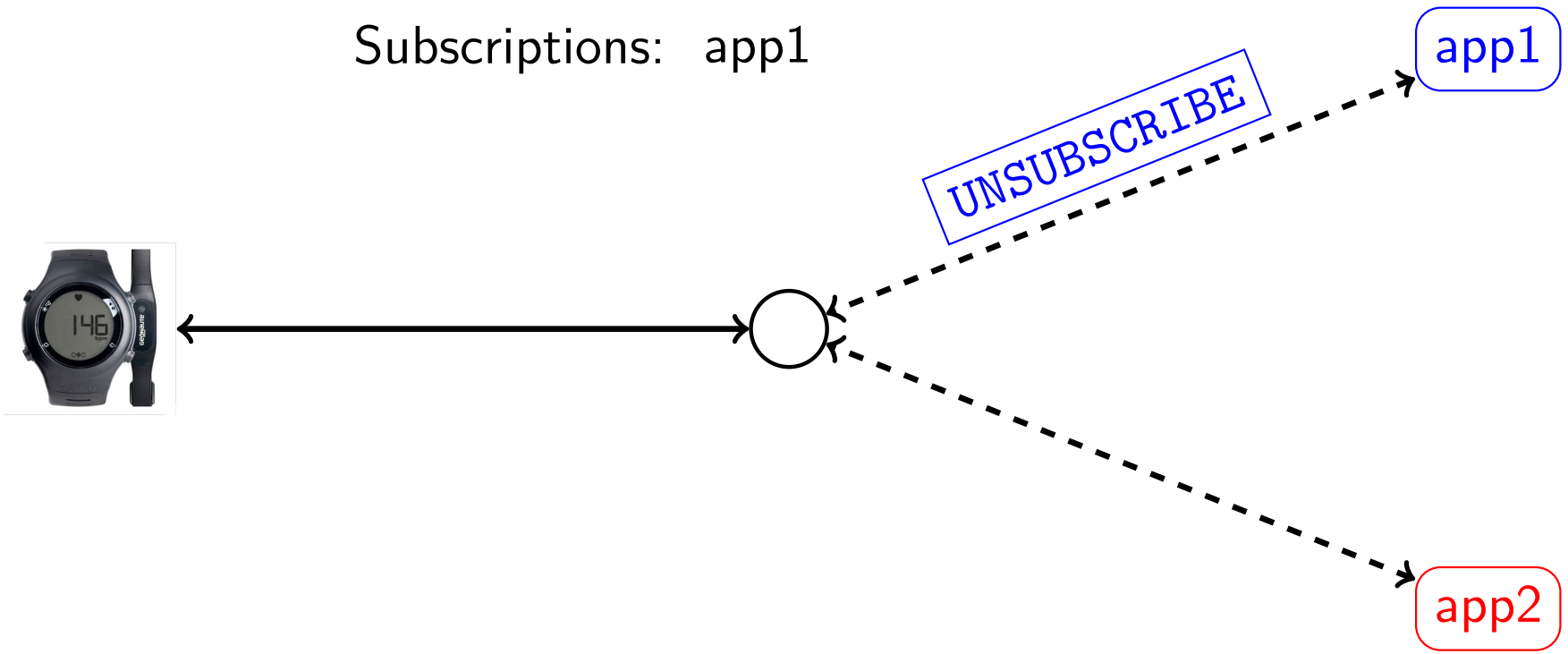

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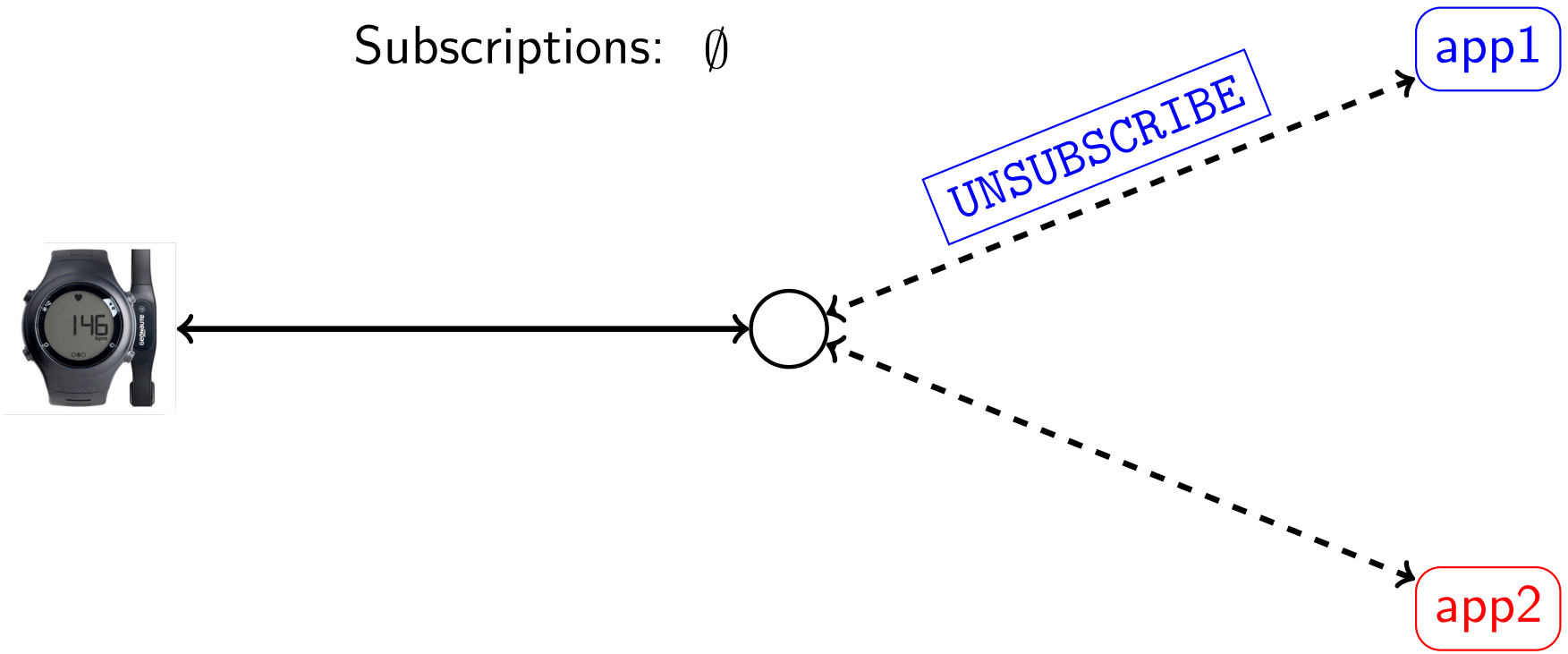

Handling Subscriptions

Subscriptions: $\emptyset$

UNSUBSCRIBE

app1

app2

Performance: Caching