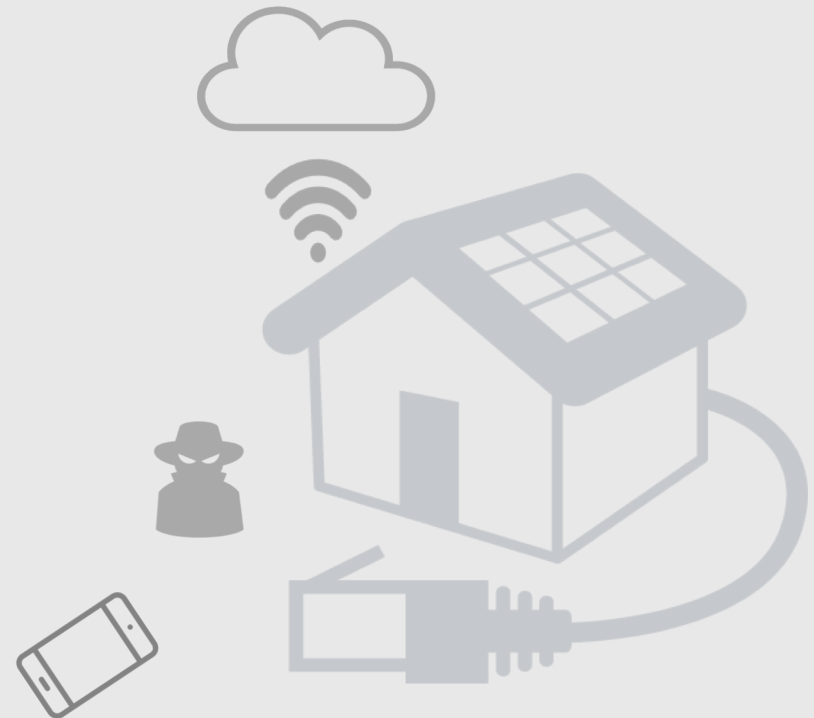# Functional Classification and Quantitative Analysis of Smart Connected Home Devices

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INTERNET OF THINGS AND
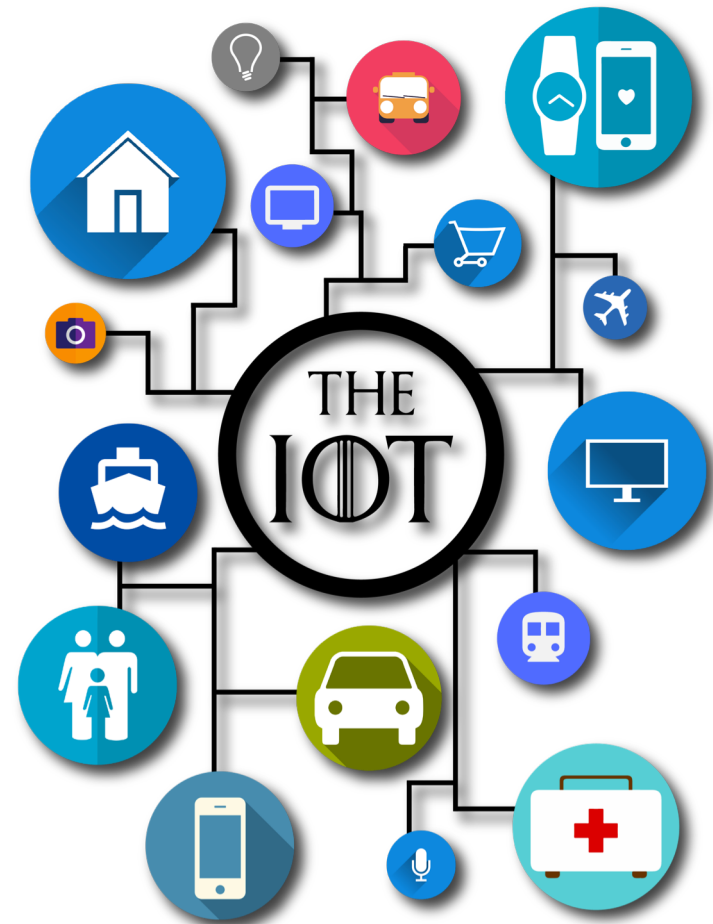PEOPLE RESEARCH CENTER

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ALARMS WITH IQ

AGENDA

THE INTERNET OF THINGS

- In 2017, there was an estimated 8.4 billion IoT devices

- Recent surveys estimate the number of IoT devices to exceed 20 billion by 2020

- Consumer applications, e.g., the smart connected home, represent the largest user base

THE SMART CONNECTED HOME

- These devices – alongside the infrastructure supporting them – enable the smart connected home

SMART CONNECTED HOME DEVICES

What are the challenges and motivations of this study?

- The introduction of numerous and heterogenous devices, including multiple disciplines, complicates the efforts to understanding the smart home environment

- Such understanding is needed, e.g., to build a more robust, secure, and resilient smart home

RESEARCH OBJECTIVES

What are the main research objectives of this study?

- *Organize the smart home devices in a logical and coherent manner*

  - ➢ Provide homogeneity and order within the existing diversity

- *Perform a quantitative analysis of these devices in terms of their functionality and capabilities*

  - ➢ Identify areas that are growing in adoption rate, new trends, topics, etc.

RESEARCH OBJECTIVES

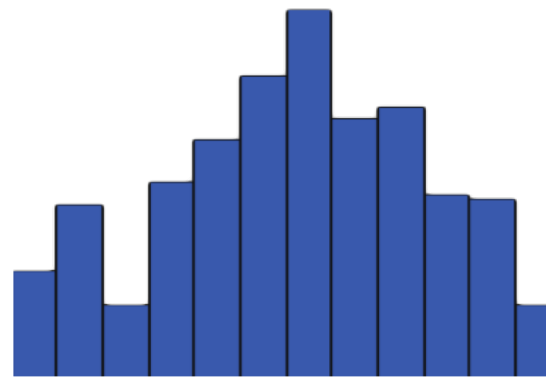What are the main research objectives of this study?

1 HIERARCHICAL TAXONOMY
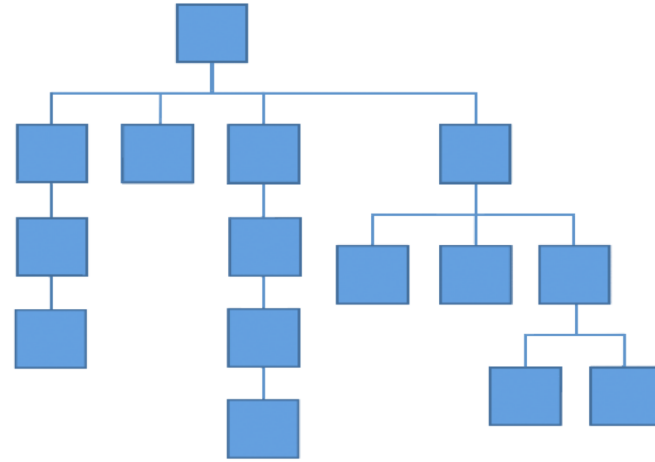
- *Organize the smart home devices in a logical and coherent manner*

2 DESCRIPTIVE STATISTICS

- *Identify areas that are growing in adoption rate, new trends, topics, etc.*

RELATED WORK

What is the existing work related to IoT and smart home devices classification?

- Functionality
  - ➢ *E.g., ITU classification*

  Data-carrying device
  Data-capturing device
  Sensing/actuating device
  General device

- Data
  - ➢ *E.g., Imagination Technologies Limited*

  M2M data
  Audio
  Audio/Video

- Resources
  - ➢ *E.g., RFC 7228*

  Class 0
  Class 1
  Class 2

- Interaction
  - ➢ *E.g., Moawad et al.*

  Level 0
  Level 1
  Level 2
  Level 3

MAIN OBSERVATIONS

What are the main observations drawn from reviewing the existing work?

- Conceptual models
  - ➤ *Ignore complexity and heterogeneity of actual setups*

....

- Machine-oriented classifications
  - ➤ *Not mainly intended for the human as the analyst/operator*

....

- Functionality and capabilities
  - ➤ *Mostly theoretical and capabilities are often not identified and/or measured*

....

- In our proposal we address the above issues

SMART CONNECTED HOME SETUP

What makes up a typical smart home setup?

- A typical smart home setup consists of devices, services, end-users, and supporting infrastructure
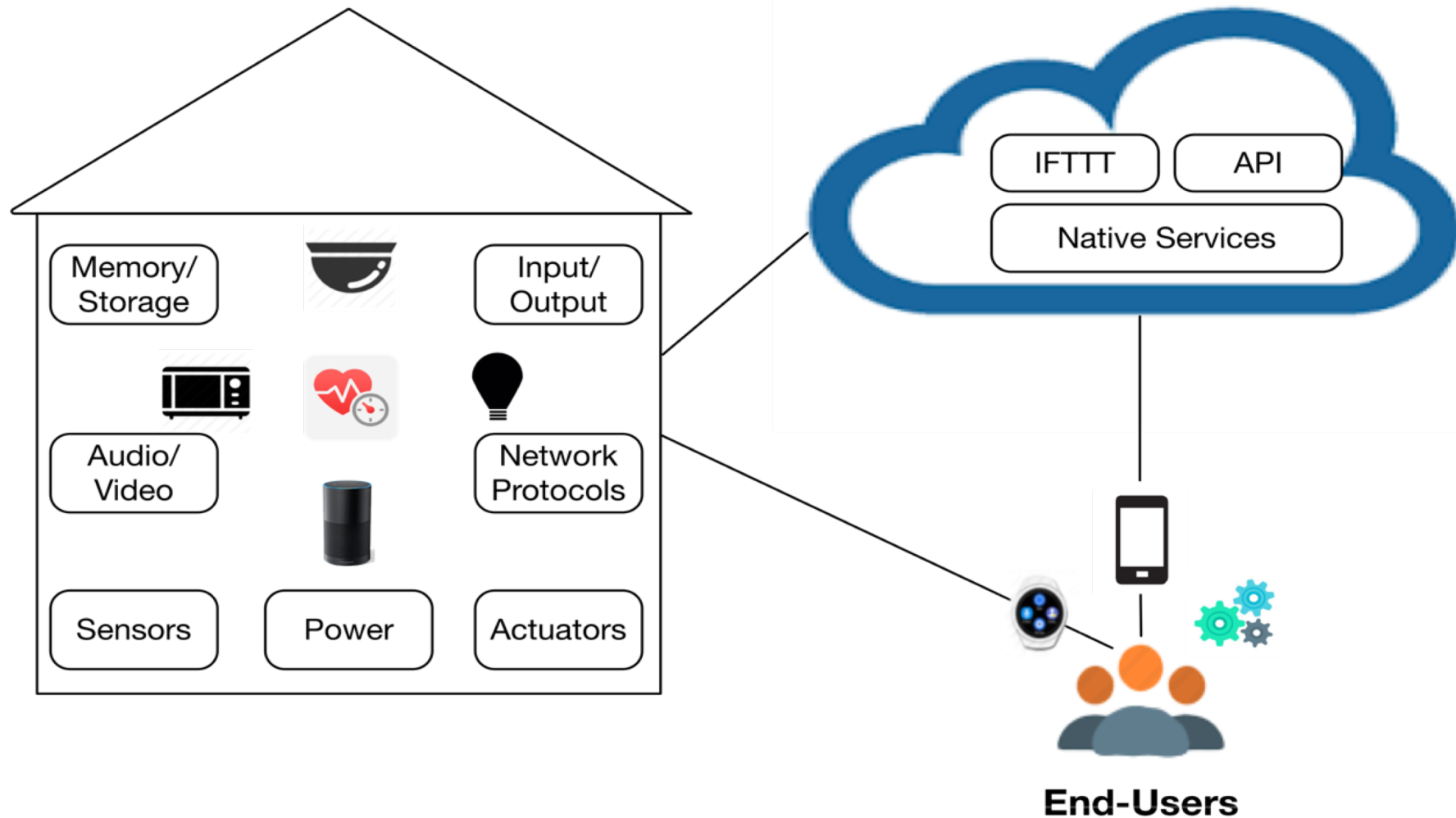
RESEARCH AIMS

What are the main research aims?

- Effectively we want to:

1 ORGANIZE SMART HOME DEVICES
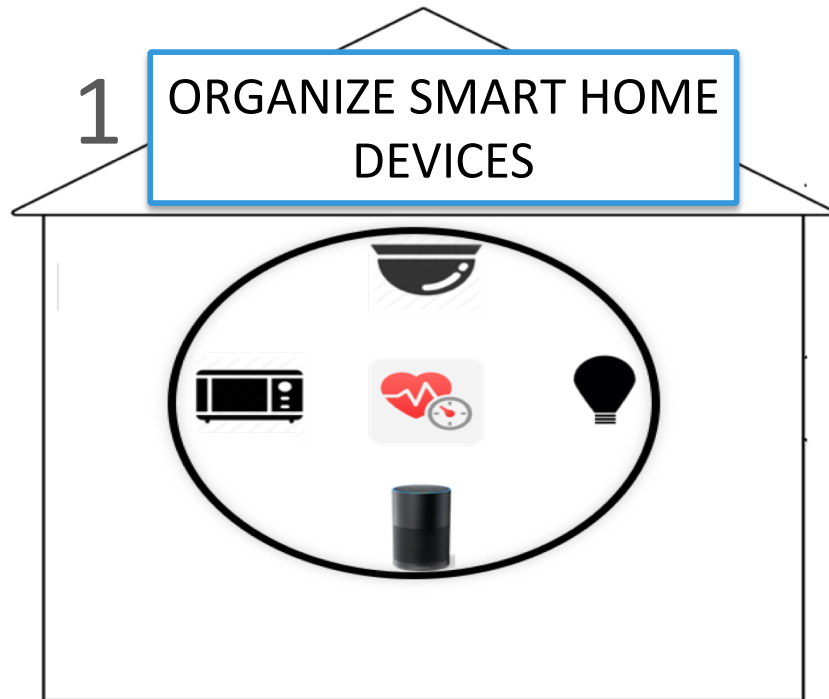
2 SURVEY CAPABILITIES

API	Gateway
IFTTT	Cloud
Wireless	Wired
Sensors	Actuators
Battery	Remote
Web browser	Smart phone

RESEARCH METHODOLOGY

What is the adopted research methodology?

1 Data Collection

- Gathering actual products and their technical specification

2 Data Processing

- Extract the capabilities of devices

3 Data Analysis

- Build taxonomy and compute statistics
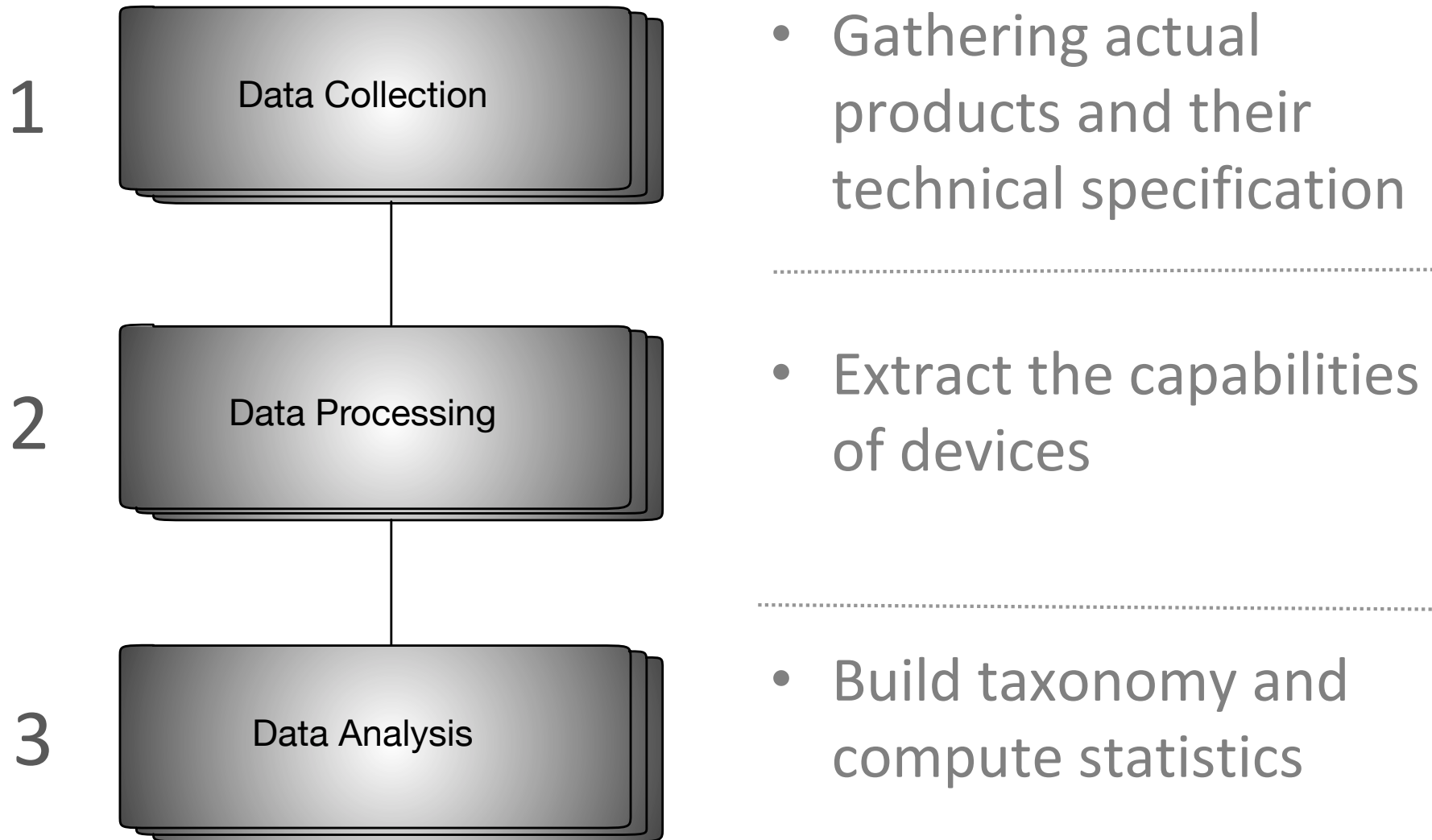
DATA COLLECTION

What data sources were used for collecting data?

- Using SmartHomeDB as data source

- SmartHomeDB is an online platform focusing on smart connected home devices

- During the data collection exercise it featured 1193 devices belonging to 87 different device types

DATA COLLECTION

How was the data collected?

- Crawling the entire SmartHomeDB

```
curl -sL 'http://www.smarthomedb.com/product/amazon-fire-tv-(2nd-gen)/p1565'
curl -sL 'http://www.smarthomedb.com/product/ring-video-doorbell/p898'
curl -sL 'http://www.smarthomedb.com/product/ring-chime/p1322'
curl -sL 'http://www.smarthomedb.com/product/nest-learning-thermostat-(3rd-gen)/p1025'
curl -sL 'http://www.smarthomedb.com/product/arlo-2-hd-camera-security-system/p814'
curl -sL 'http://www.smarthomedb.com/product/sony-playstation-4-500gb/p1574'
curl -sL 'http://www.smarthomedb.com/product/chromecast/p1560'
curl -sL 'http://www.smarthomedb.com/product/sonos-play-1-compact-wireless-speaker/p106'
curl -sL 'http://www.smarthomedb.com/product/fitbit-aria-wi-fi-smart-scale/p96'
curl -sL 'http://www.smarthomedb.com/product/amcrest-prohd/p1221'
curl -sL 'http://www.smarthomedb.com/product/nest-cam/p973'
curl -sL 'http://www.smarthomedb.com/product/apple-tv-(4th-gen,-32gb)/p1248'
curl -sL 'http://www.smarthomedb.com/product/bose-soundlink-color-bluetooth-speaker/p1446'
curl -sL 'http://www.smarthomedb.com/product/ring-video-doorbell-pro/p1324'
curl -sL 'http://www.smarthomedb.com/product/jam-classic-speaker/p1553'
curl -sL 'http://www.smarthomedb.com/product/nest-learning-thermostat-(2nd-gen)/p88'
curl -sL 'http://www.smarthomedb.com/product/tp-link-wi-fi-smart-plug/p1118'
curl -sL 'http://www.smarthomedb.com/product/tp-link-wi-fi-smart-plug-with-energy-monitoring/p1117'
curl -sL 'http://www.smarthomedb.com/product/tp-link-smart-light-switch/p1458'
curl -sL 'http://www.smarthomedb.com/product/belkin-wemo-switch/p464'
curl -sL 'http://www.smarthomedb.com/product/sonos-play-5-wireless-speaker/p438'
curl -sL 'http://www.smarthomedb.com/product/sonos-play-3-wireless-speaker/p436'
curl -sL 'http://www.smarthomedb.com/product/amazon-tap-alexa-enabled/p1253'
curl -sL 'http://www.smarthomedb.com/product/roku-streaming-stick/p1570'
curl -sL 'http://www.smarthomedb.com/product/sonos-playbar/p444'
curl -sL 'http://www.smarthomedb.com/product/ecobee3-homekit-enabled-thermostat/p1166'
curl -sL 'http://www.smarthomedb.com/product/fujikam-hd-camera/p200'
curl -sL 'http://www.smarthomedb.com/product/vimtag-vt-361-cloud-camera/p1411'
curl -sL 'http://www.smarthomedb.com/product/vimtag-b-1-outdoor-cloud-camera/p1413'
curl -sL 'http://www.smarthomedb.com/product/withings-smart-body-analyzer/p114'
```

DATA PROCESSING

How was data collected processed?

- Using web mining to extract the features (capabilities) of devices

- Effectively, this involved string searches within the collected HTML file

- Searches were done for a capability set consisting of 12 elements, e.g., wireless protocols, API support, Web browser access, etc.

- The end result of this was a 2D matrix consisting of rows representing actual devices and columns the capabilities of devices

DATA PROCESSING

How was data collected processed?

- Capabilities were represented as a binary vector, with 1 indicating that a capability is supported; 0 the contrary

Name	API	Cloud / Serve	Remote Acce	IFTTT	Gateway Fur	Wireless Cha	Wired Proto	Battery Oper	Smartphone	Web-browse
Amazon Fire TV Sti	0	1	0	0	1	1	1	1	1	0
Amazon Fire TV (2r	0	1	0	0	1	1	1	1	1	0
Ring Video Doorbel	0	1	1	1	1	1	0	1	1	0
Ring Chime	0	0	0	0	0	1	0	0	1	0
Nest Learning Ther	1	1	1	1	1	1	0	1	1	0
Arlo 2 HD Camera S	0	1	1	1	1	1	1	1	1	0
Sony PlayStation 4	0	1	0	0	1	1	1	0	1	0
Chromecast	0	1	0	0	1	1	1	0	1	0
SONOS PLAY: 1 Cor	0	0	0	0	1	1	1	0	1	0
Fitbit Aria Wi-Fi Sm	1	1	1	1	1	1	0	1	1	1
Amcrest ProHD	0	1	1	0	1	1	1	0	1	0
Nest Cam	0	1	1	1	1	1	0	0	1	0
Apple TV (4th Gen,	0	1	1	0	1	1	0	0	1	0
Bose SoundLink Co	0	0	0	0	1	1	0	1	0	0
Ring Video Doorbel	0	1	1	1	1	1	0	0	1	0
JAM Classic Speake	0	0	0	0	1	1	0	1	0	0
Nest Learning Ther	1	1	1	1	1	1	0	1	1	0
TP-LINK Wi-Fi Smar	0	1	1	0	1	1	0	0	1	0
TP-LINK Wi-Fi Smar	0	1	1	0	1	1	0	0	1	0
TP-Link Smart Light	0	1	1	0	1	1	0	0	1	0
Belkin WeMo Switc	0	1	1	1	1	1	0	0	1	0
SONOS PLAY: 5 Wir	0	0	0	0	1	1	1	0	1	0
SONOS PLAY: 3 Wir	0	0	0	0	1	1	1	0	1	0
Amazon Tap - Alexa	0	1	1	1	1	1	0	0	1	1
Roku Streaming Sti	0	1	0	0	1	1	1	1	1	0
SONOS PLAYBAR	0	0	0	0	1	1	1	0	1	0
ecobee3 HomeKit-e	0	1	1	1	1	1	0	0	1	1
Fujikam HD Camera	0	1	1	0	1	1	0	0	1	1
Vimtag VT-361 Clou	0	1	1	0	1	1	1	0	1	0
Vimtag B-1 Outdoo	0	1	1	0	1	1	1	0	1	0

DATA ANALYSIS

How was data analysis performed?

- The CSV was loaded into IBM SPSS for analysis

- First, a clustering variable was manually added (coded) to the dataset, representing the functional area the device is designed to provide

- Second, the actual computation of descriptive statistics on the dataset was performed

SMART HOME FUNCTIONAL AREAS

What are the device functional areas and their distribution?
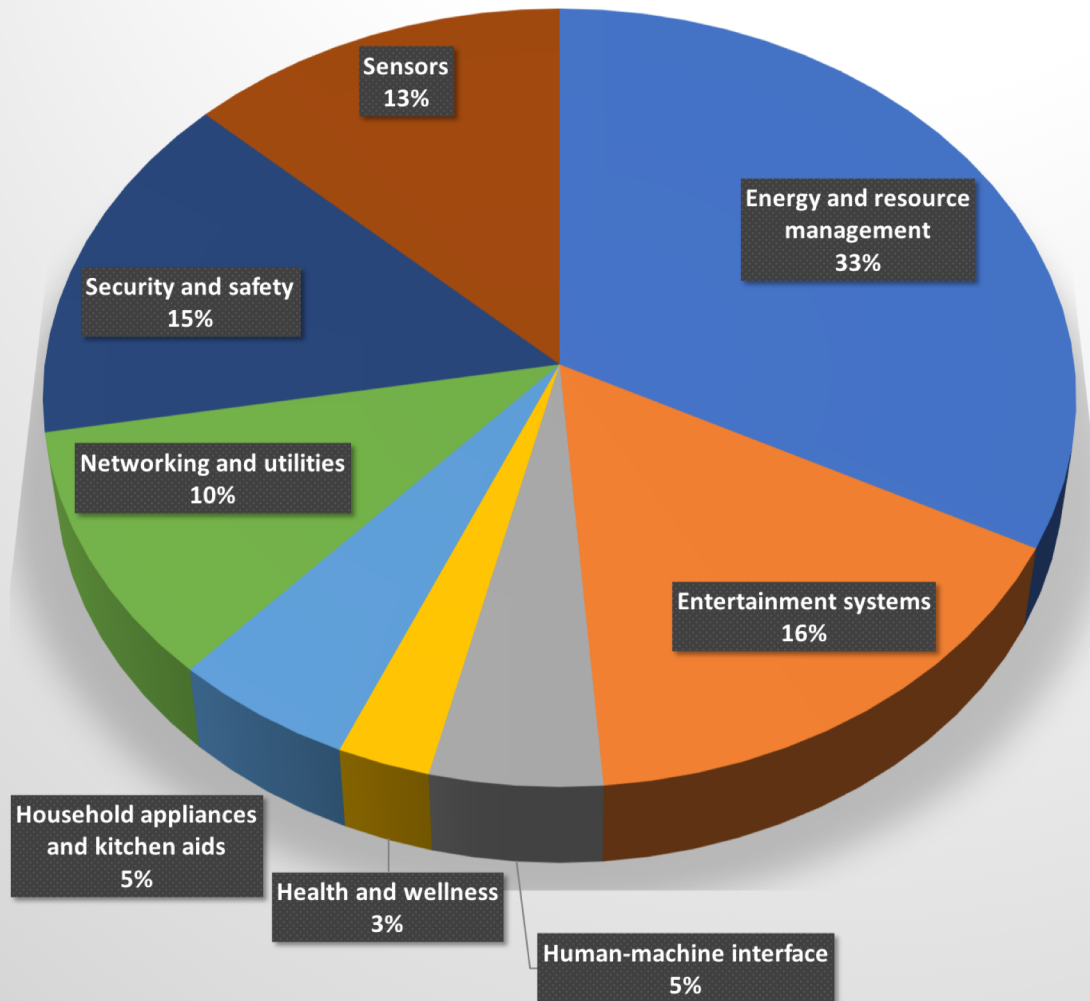
SMART HOME FUNCTIONAL CLASSIFICATION

What is the obtained hierarchical taxonomy?

Smart Connected Home Devices

- **Energy and Resource Management [389]**
  - Actuators/Motors
  - Climate Control
  - Lighting Systems
  - Metering Systems
  - Irrigation Controller [21]
  - Plug [74] / Power Outlet [15]

- **Entertainment Systems [193]**

- **Health and Wellness [32]**
  - Bed [3]
  - Blood Pressure Monitor [3]
  - Feeding Systems
  - Scale [20]

- **Networking and Utilities [125]**
  - Gateways
  - Wireless Signal Extender [10]
  - Infrared Controller [8]

- **Human-Machine Interface [60]**
  - Remote Control [51]
  - Voice Command Devices [9]

- **Household Appliances and Kitchen Aids [63]**
  - Portable Appliances
  - Stationary Appliances
  - Robotic Appliances

- **Security and Safety [176]**
  - Cloud Cameras [86]
  - Door Bell [10]
  - Siren [17] / Smoke Detector [16]
  - Tracker [11]
  - Smart Locks
    - Door Lock [35]
    - Pet Door [1]

- **Sensors [155]**

Full taxonomy is available in the paper

SMART HOME FUNCTIONAL AREAS

What is the most popular device across each functional area?

Plugs

> Energy and resource management

Audio speakers

> Entertainment systems

Cloud cameras

> Security and Safety

Scales

> Health and Wellness

Remote controls

> Human-machine interface

Gateways/Hubs

> Networking and utilities

Vacuum cleaners

> Household appliances and kitchen aids

Door sensors

> Sensors

SMART HOME DEVICE CAPABILITIES

What capabilities were surveyed?

Device
- Gateway
- Battery
- Sensors
- Actuators

Communication
- Wireless
- Wired
- Cloud/Server

Software
- API
- IFTTT

Accessibility
- Smartphone
- Web browser
- Remote access

DEVICE CAPABILITIES

What are the core device features?

Legend: ■ Gateway functionality ■ Battery source ■ Integrated sensors ■ Integrated actuators

Category	Gateway functionality	Battery source	Integrated sensors	Integrated actuators
E&RM	51.7	10.8	20.8	48.1
E	99	40.9	0.5	51.8
H&W	100	78.1	84.4	0
H&K	100	49.2	3.2	15.9
N&U	98.4	13.6	8.8	15.2
S&S	71.6	49.4	70.5	38.6
HMI	51.7	76.7	16.7	8.3
S	27.7	86.5	100	0.6
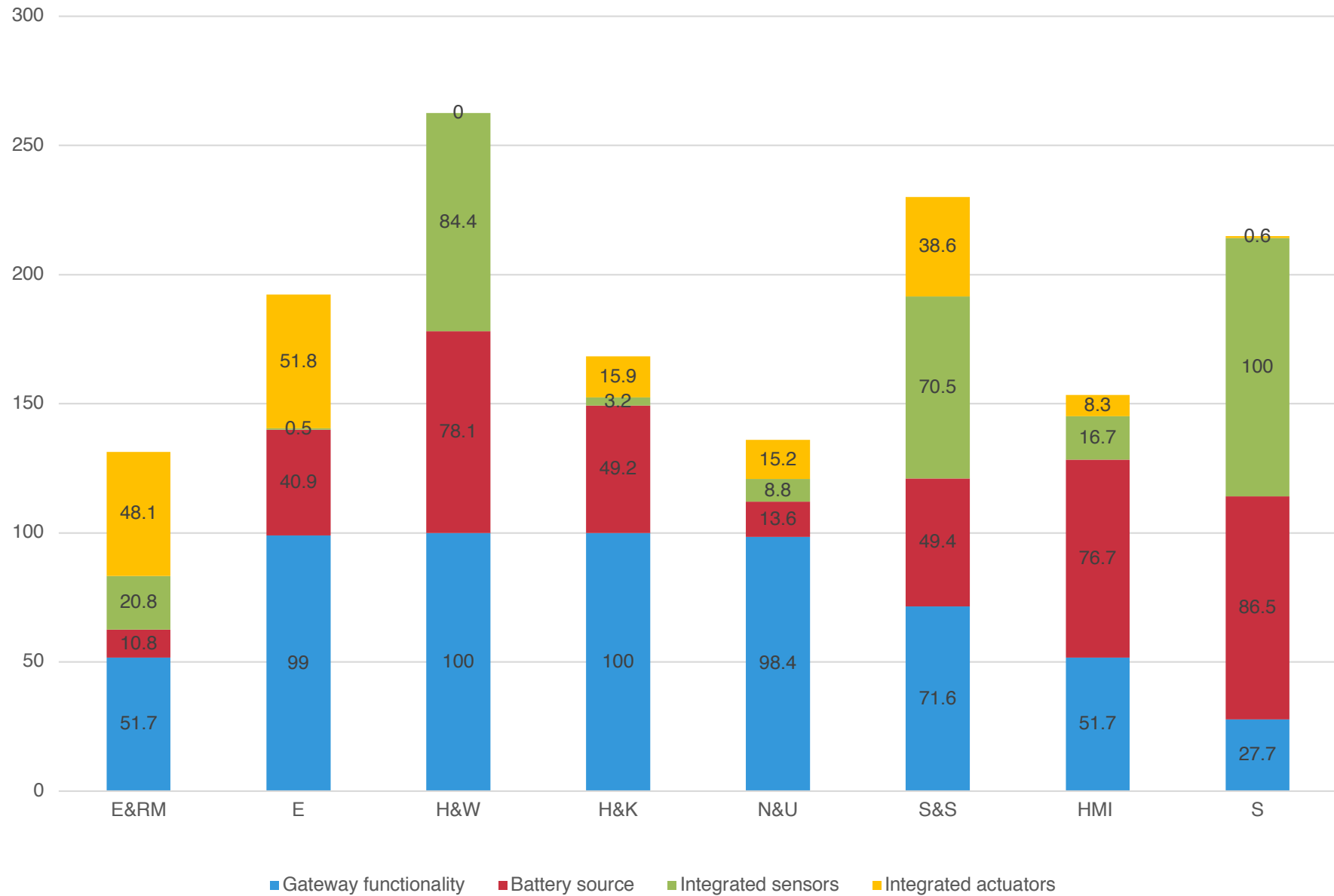
OTHER CAPABILITIES

What are the characteristics of some other features that were surveyed?

Legend: API, IFTTT, Web browser accessibility, Smartphone accessibility, Remote access

Category	API	IFTTT	Web browser accessibility	Smartphone accessibility	Remote access
E&RM	3.6	15.4	12.6	63.2	78.7
E	0			95.3	3.6
H&W	6.3	12.5	18.8	84.4	65.6
H&K	3.2	7.9	0	57.1	49.2
N&U	5.6	21.6	22.4	76.8	79.2
S&S	2.3	15.9	9.7	69.9	90.9
HMI	1.7	15	18.3	50	26.7
S	3.2	12.9	17.4	56.8	91
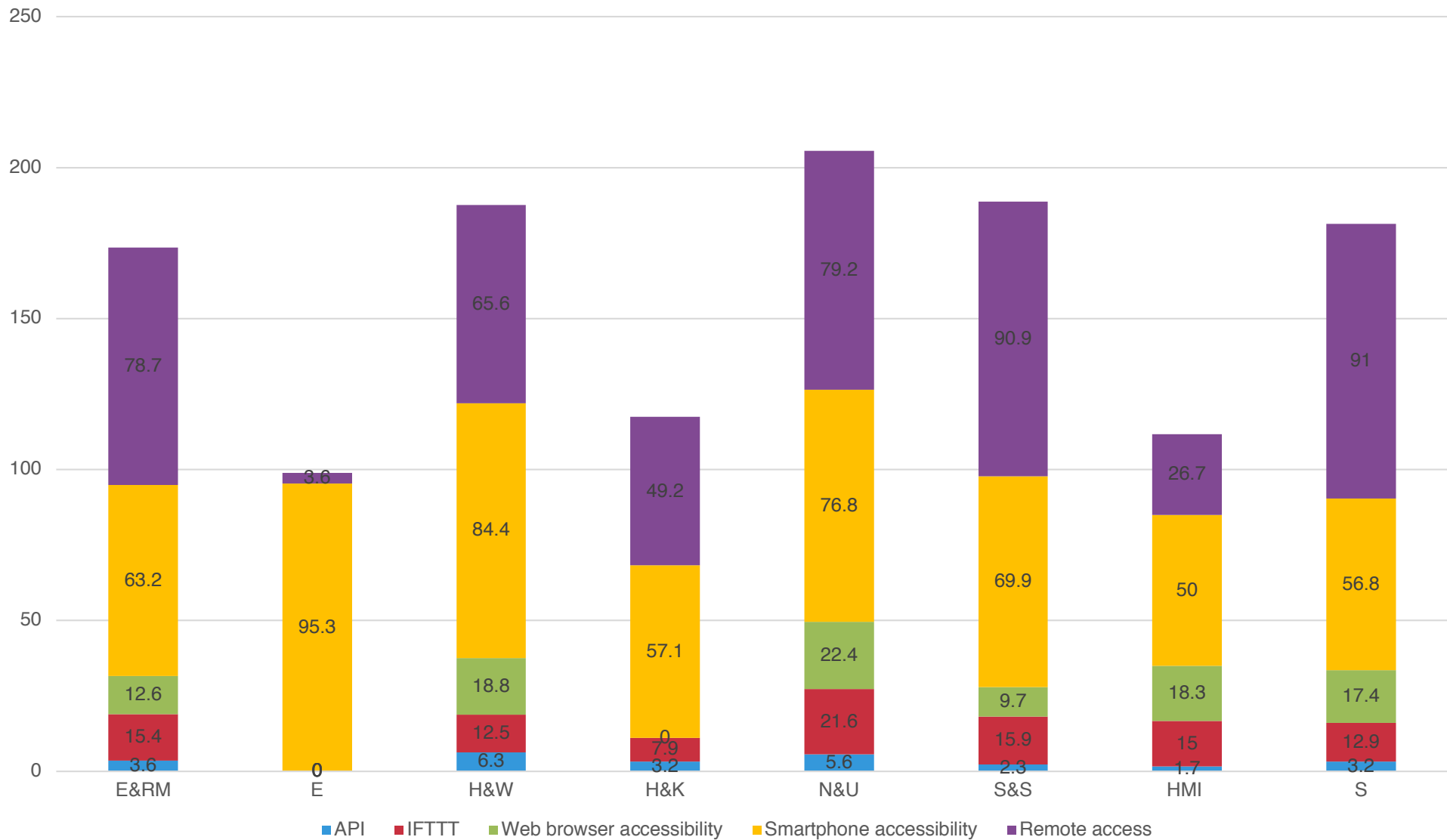
CLOSING REMARKS

- Proposed a generic classification consisting of 8 functional areas and 12 capabilities

- This was done by mining the technical specification of 1193 commercial devices

- Analyzed the entire spectrum of devices in terms of their capabilities per func. area

- Can be used to bridge the communication between researchers and practitioners and as a basis for generalization and common solutions

FUTURE WORK

What are some possible avenues for future work?

- Identify representative devices

- Show interoperable devices

- Conduct quantitative risk assessment

Thank you for your attention!

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