IoT Security and Privacy

INFR11158/11230 Usable Security and Privacy

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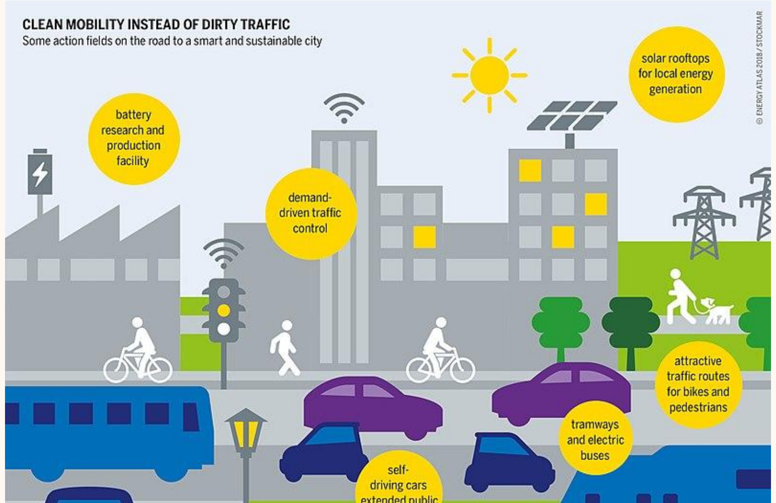
24/02/2026

THE UNIVERSITY of EDINBURGH

Overview

- IoT
- Take-home

What is the Internet of Things?


CLEAN MOBILITY INSTEAD OF DIRTY TRAFFIC
Some action fields on the road to a smart and sustainable city
© ENERGY ATLAS 2018 / STOCKMAR
solar rooftops for local energy generation
battery research and production facility
demand-driven traffic control
attractive traffic routes for bikes and pedestrians
tramways and electric buses
self-driving cars extended public transport
charging stations for individual vehicles

Smart city

Data-driven agriculture (taken in Madison, Wisconsin during my first PhD research)

Fitness tracker

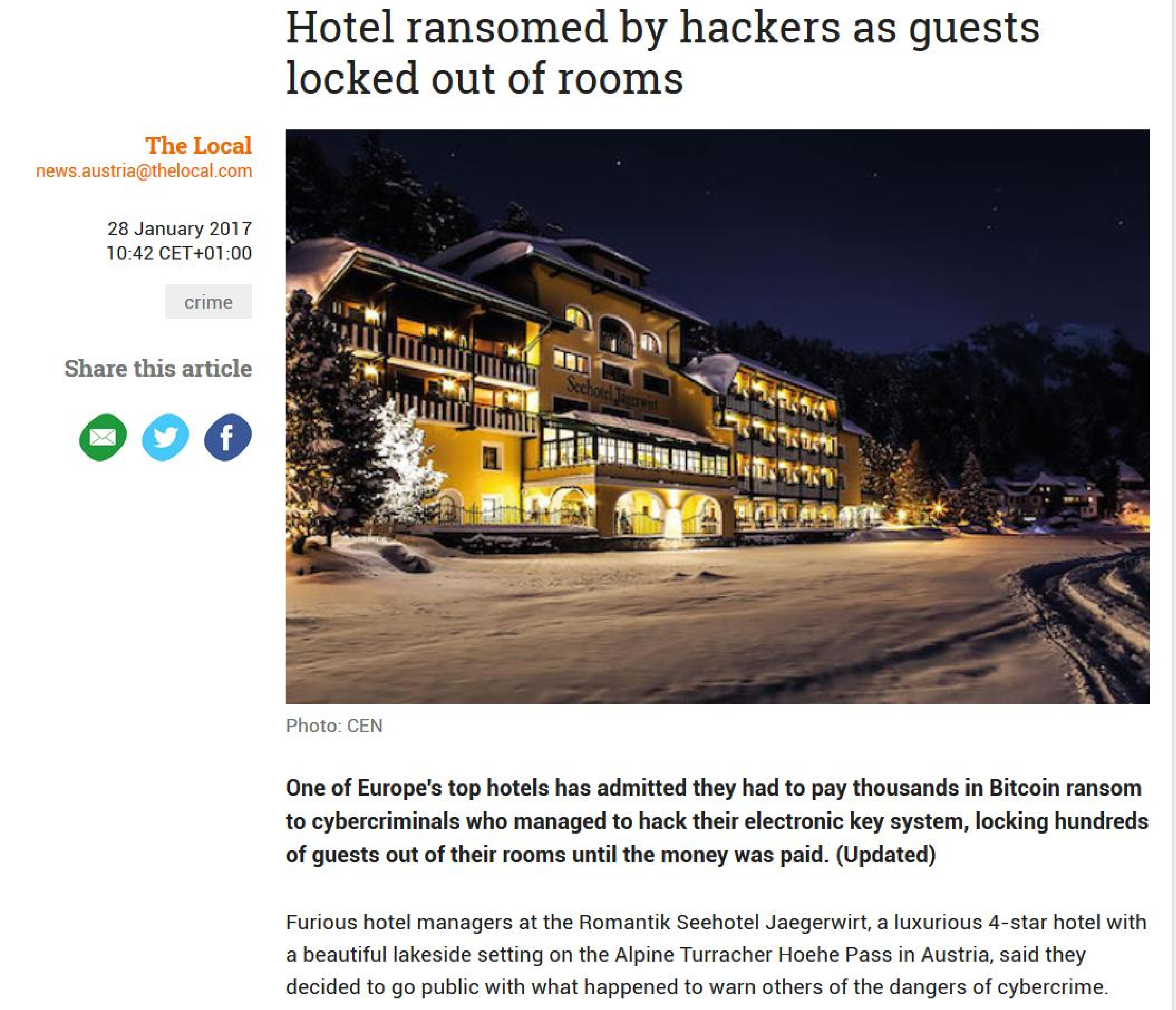
Hello Barbie
HELLO HELLO HELLO
PRESS BELT & TALK
WARNING:
CHOKING HAZARD
WIFI INTERNET CONNECTION AND WIFI ENABLED SMART DEVICE REQUIRED
6+
Google play
NETCAM
belkin
ring
ring VIDEO DOORBELL
SEE & SPEAK WITH VISITORS
MOTION DETECTION
WI-FI CONNECTED
WORKS WITH iOS, ANDROID & WINDOWS 10 DEVICES
Try me!
ANNKE
HD 720P Video Monitoring
For home, pets, baby, seniors and business.
Sparkle I
ANNKE
Wi-Fi
netatmo
The Weather Station for Smartphone
La Station Météo pour Smartphone
fitbit
Balance Wi-Fi intelligente
Bilancia intelligente Wi-Fi
Intelligente WLAN-Waage
Báscula inteligente Wi-Fi
75.1
PIXSTAR
FotoConnect XD Wi-Fi 10.4"
Instantly receive photos from those you love
from anywhere in the world
RATIO 4/3
Email
Internet

Introducing
echo studio
"Alexa, play the Best of 3D Music
amazon music
SiriusXM
npr
PHILIPS hue
ADT
Press the mic off button to disconnect the microphones

“Internet of Things”

- Previously known as:
  - Ubiquitous computing
  - Ambient computing
- Idea is that the computers are embedded into the world around people, effectively pushing computation into the surrounding infrastructure, rather than in devices we carry around.
- Large issues:
  - Privacy
  - Security
  - Trust
  - Battery
  - Computational power

Security and privacy issues in IoT



Hotel ransomed by hackers as guests locked out of rooms

The Local
news.austria@thelocal.com

28 January 2017
10:42 CET+01:00

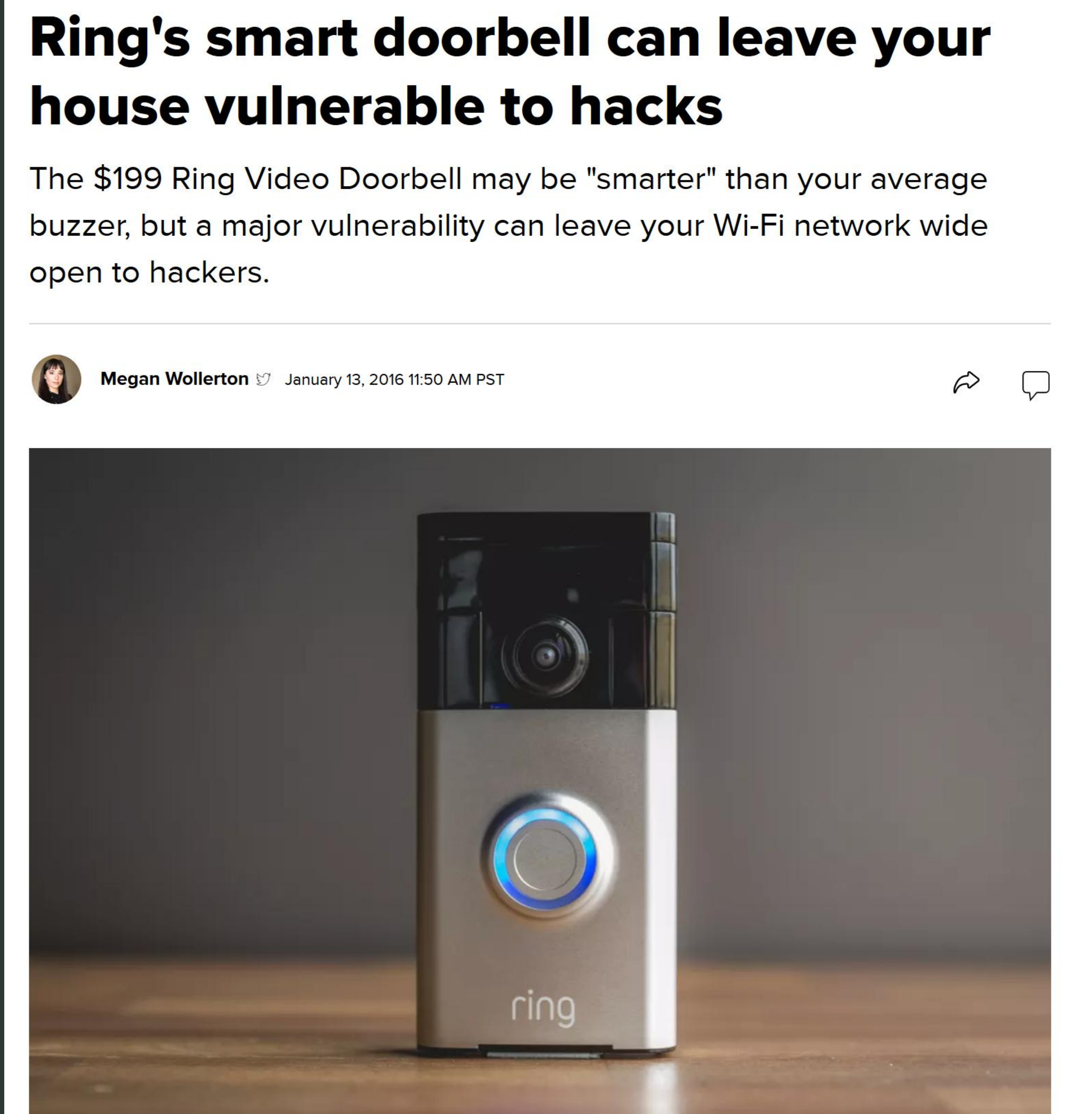
crime

Share this article

Photo: CEN

One of Europe's top hotels has admitted they had to pay thousands in Bitcoin ransom to cybercriminals who managed to hack their electronic key system, locking hundreds of guests out of their rooms until the money was paid. (Updated)

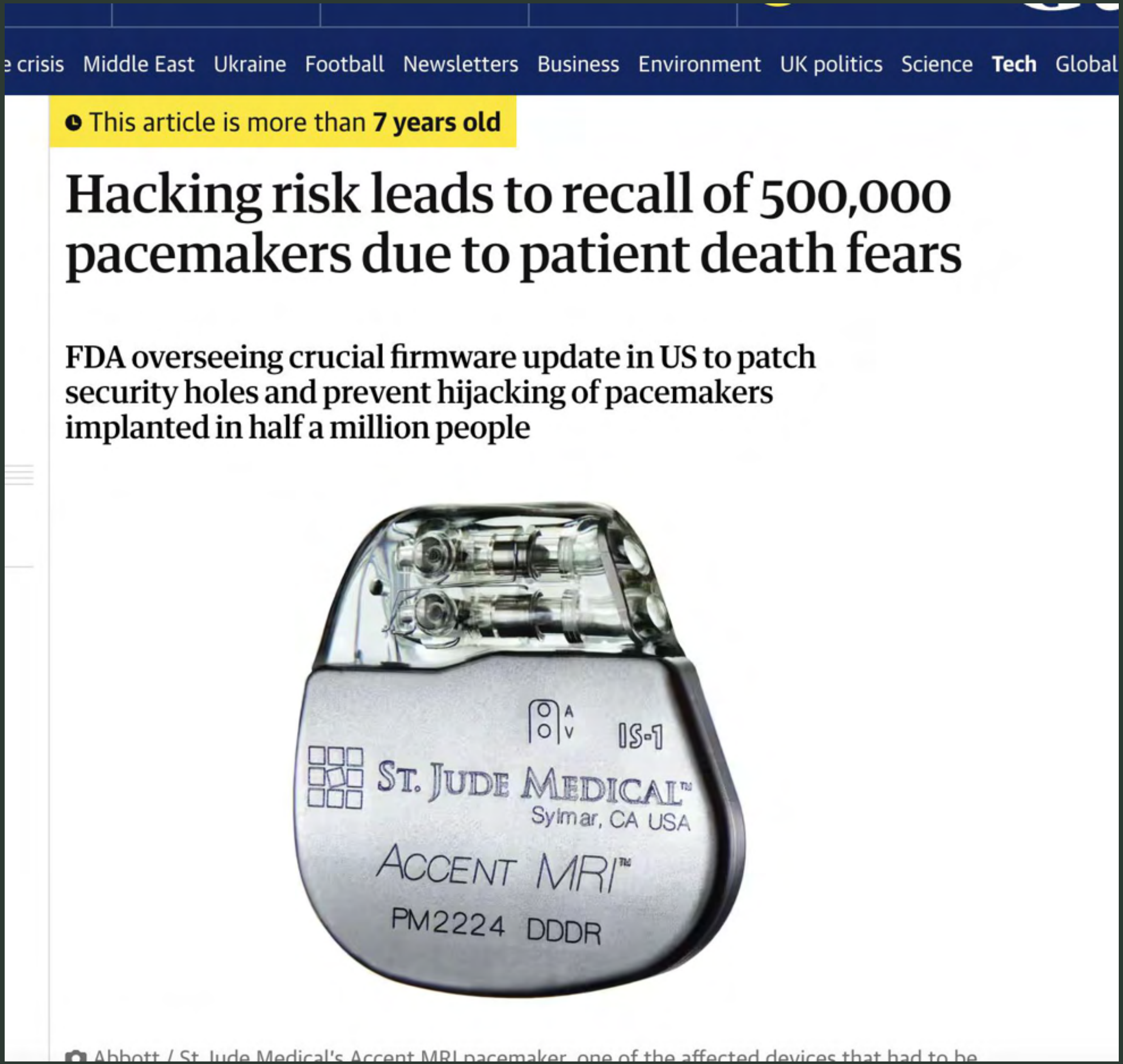
Furious hotel managers at the Romantik Seehotel Jaegerwirt, a luxurious 4-star hotel with a beautiful lakeside setting on the Alpine Turracher Hoehe Pass in Austria, said they decided to go public with what happened to warn others of the dangers of cybercrime.



Ring's smart doorbell can leave your house vulnerable to hacks

The $199 Ring Video Doorbell may be "smarter" than your average buzzer, but a major vulnerability can leave your Wi-Fi network wide open to hackers.

Megan Wollerton January 13, 2016 11:50 AM PST



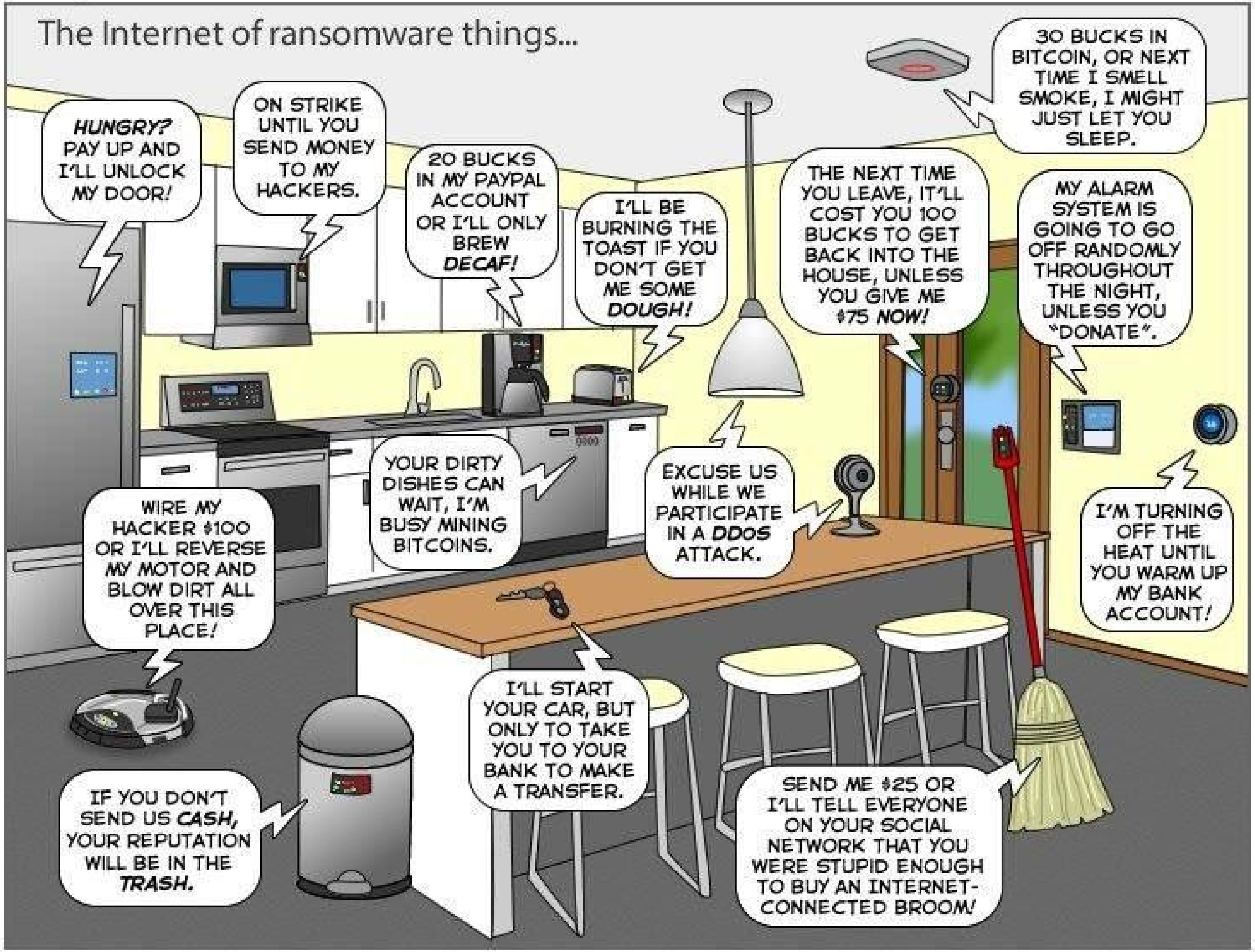
This article is more than **7 years old**

Hacking risk leads to recall of 500,000 pacemakers due to patient death fears

FDA overseeing crucial firmware update in US to patch security holes and prevent hijacking of pacemakers implanted in half a million people

Abbott / St Jude Medical's Accent MRI pacemaker, one of the affected devices that had to be

The Joy of Tech™ by Nitrozac & Snaggy


The Internet of ransomware things...
HUNGRY? PAY UP AND I'LL UNLOCK MY DOOR!
ON STRIKE UNTIL YOU SEND MONEY TO MY HACKERS.
20 BUCKS IN MY PAYPAL ACCOUNT OR I'LL ONLY BREW DECAF!
I'LL BE BURNING THE TOAST IF YOU DON'T GET ME SOME DOUGH!
THE NEXT TIME YOU LEAVE, IT'LL COST YOU 100 BUCKS TO GET BACK INTO THE HOUSE, UNLESS YOU GIVE ME $75 NOW!
30 BUCKS IN BITCOIN, OR NEXT TIME I SMELL SMOKE, I MIGHT JUST LET YOU SLEEP.
MY ALARM SYSTEM IS GOING TO GO OFF RANDOMLY THROUGHOUT THE NIGHT, UNLESS YOU "DONATE".
YOUR DIRTY DISHES CAN WAIT, I'M BUSY MINING BITCOINS.
EXCUSE US WHILE WE PARTICIPATE IN A DDOS ATTACK.
I'M TURNING OFF THE HEAT UNTIL YOU WARM UP MY BANK ACCOUNT!
WIRE MY HACKER $100 OR I'LL REVERSE MY MOTOR AND BLOW DIRT ALL OVER THIS PLACE!
I'LL START YOUR CAR, BUT ONLY TO TAKE YOU TO YOUR BANK TO MAKE A TRANSFER.
IF YOU DON'T SEND US CASH, YOUR REPUTATION WILL BE IN THE TRASH.
SEND ME $25 OR I'LL TELL EVERYONE ON YOUR SOCIAL NETWORK THAT YOU WERE STUPID ENOUGH TO BUY AN INTERNET-CONNECTED BROOM!

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Why don’t people protect themselves?

1. People are not **aware** of the risks or protection mechanisms.

2. People cannot **use** the available protection mechanisms.

3. People do not **care** about security and privacy.

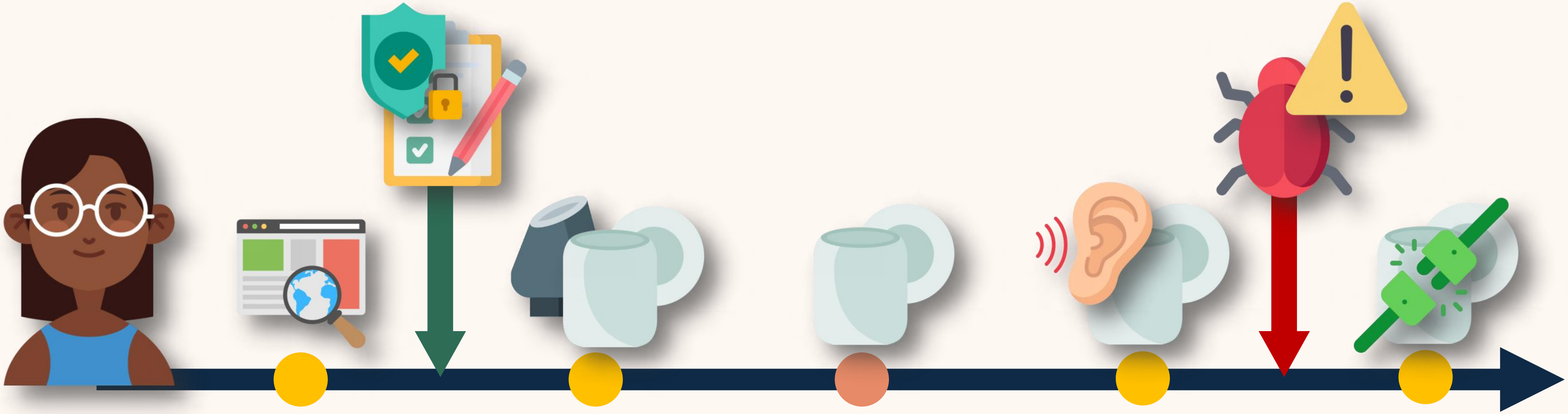
Lemon markets

Security and privacy in IoT is currently a lemon market.

People with purchasing power cannot differentiate between a “good” device and a “bad” one

Are the arguments above still valid today?

User awareness == secure behavior?



Information search
Product comparison
Purchase
In use
Abandonment

Prior Work

S&P perception

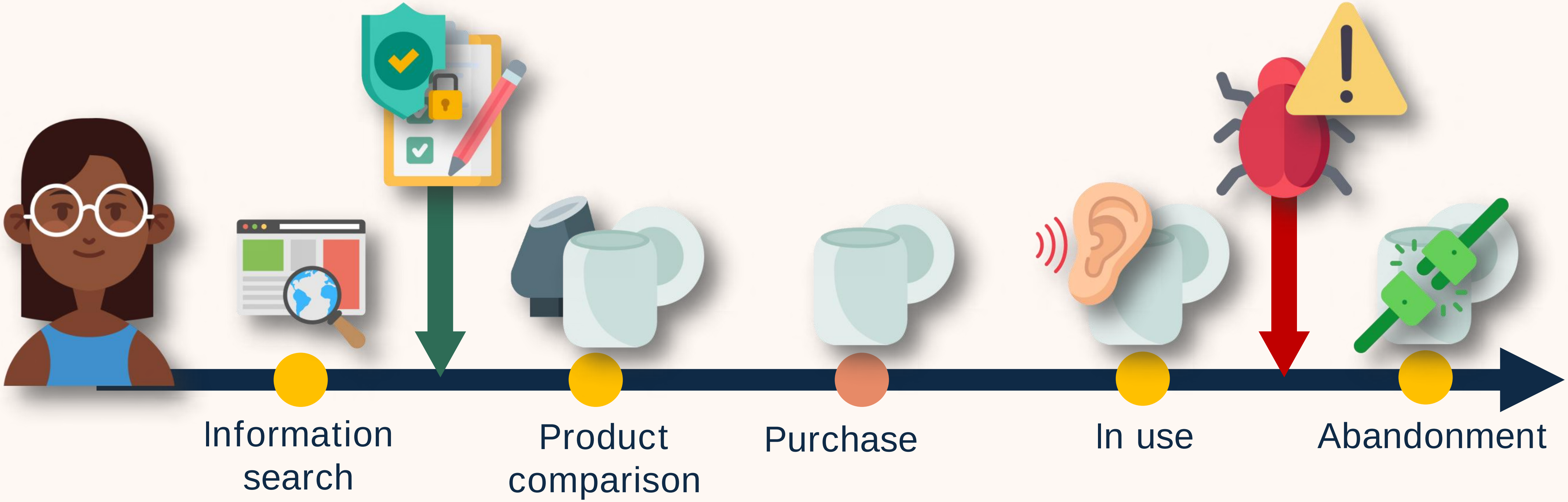
S&P attitudes

Smart home adoption

End user security and privacy concerns with smart homes. Eric Zeng, Shrirang Mare, and Franziska Roesner. In *SOUPS*, 2017

Privacy Indexes: A Survey of Westin's Studies. Ponnurangam Kumaraguru and Lorrie Faith Cranor. In *CMU-ISRI*, 2005

Which privacy and security attributes most impact consumers' risk perception and willingness to purchase IoT devices? Pardis Emami-Naeini, Janarth Dheenadhayalan, Yuvraj Agarwal, and Lorrie Faith Cranor. In *IEEE S&P*, 2021



Information search

Product comparison

Purchase

In use

Abandonment

How do users develop security and privacy attitudes organically?

Method Overview

Reddit online discussion

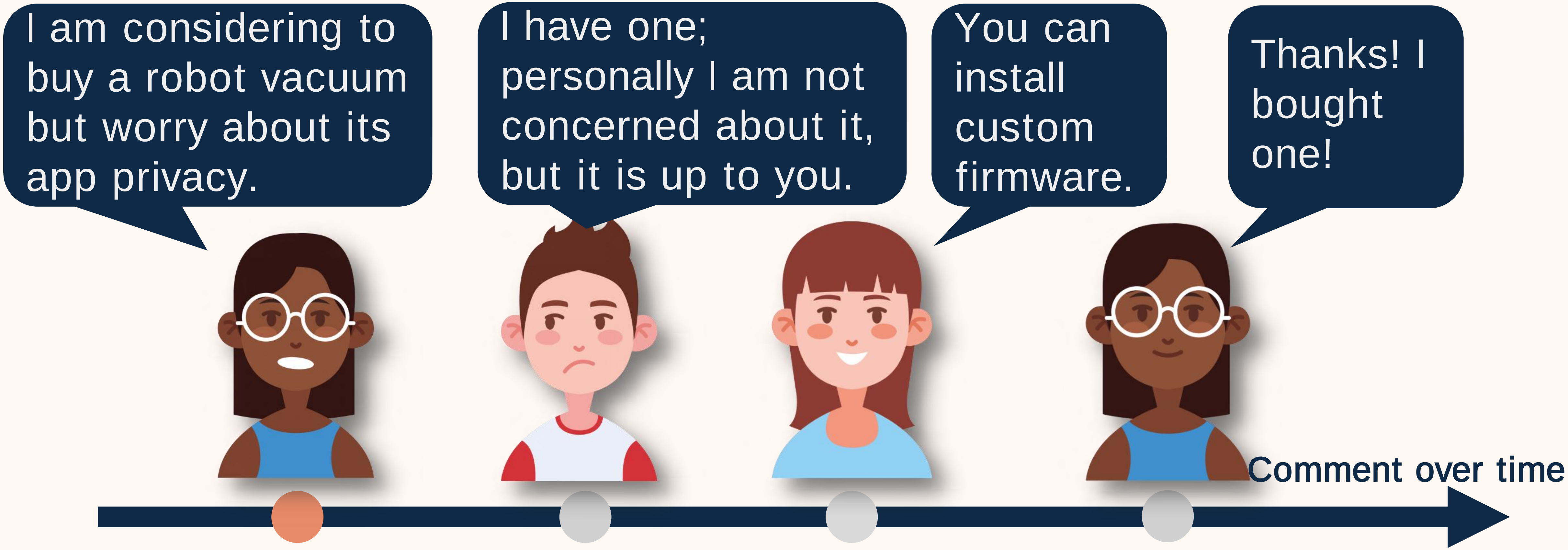
NLP-assisted sampling

Qualitative content analysis

r/homeautomation
2.2M users as of 05/2023

- **Over time** throughout adoption process
- **Non-intrusive** observation
- Diverse **interactive discussion**

Online Discussion on Reddit


I am considering to buy a robot vacuum but worry about its app privacy.
I have one; personally I am not concerned about it, but it is up to you.
You can install custom firmware.
Thanks! I bought one!
Comment over time

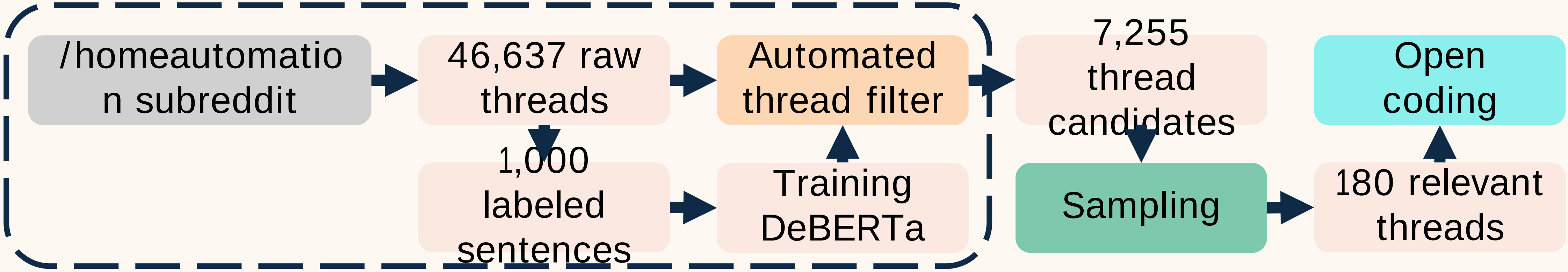
Research Questions

How users think of S&P issues (**considerations**)

How users react to S&P issues (**attitudes**)

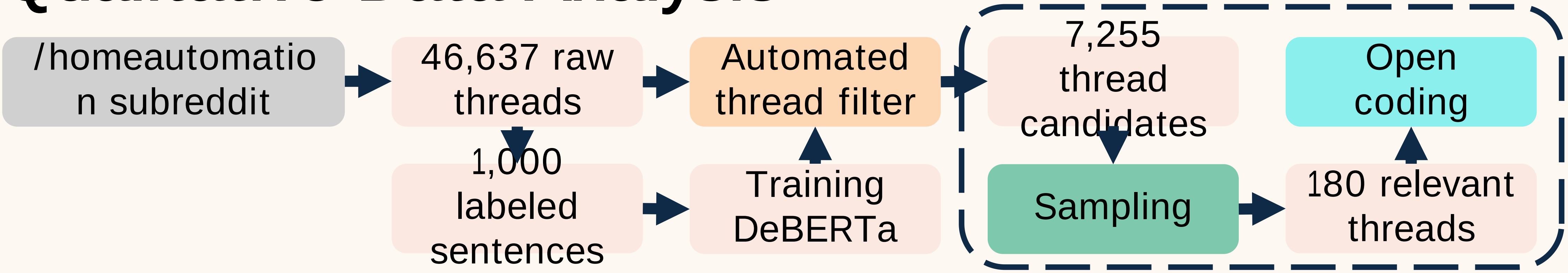
How **online discussion influences** users

NLP-Assisted Data Collection

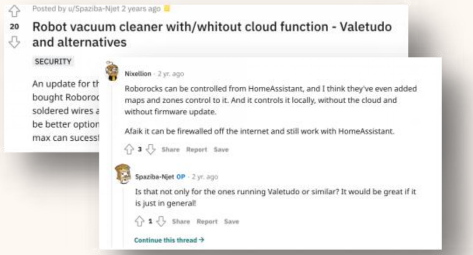


- Collected **46,637 raw threads** between 2010 and 2021
- Built a **natural language processing classifier** to identify relevant threads, incorporating diverse S&P terminology
- Sampled and coded **180 threads** with 4,957 comments until data saturation from 7,255 candidates

Qualitative Data Analysis



- Our team with broad knowledge (S&P, computer science and engineering, information science, psychology, and legal studies) performed **qualitative coding** and **thematic analysis**
- Inter-rater reliability = 0.74 (substantial)


Posted by u/Spaziba-Njet 2 years ago

20

Robot vacuum cleaner with/whitout cloud function - Valetudo and alternatives

SECURITY

An update for th
bought Roboroc
soldered wires a
be better option
max can sucessf

Nixellion · 2 yr. ago

Roborocks can be controlled from HomeAssistant, and I think they've even added maps and zones control to it. And it controls it locally, without the cloud and without firmware update.

Afaik it can be firewalled off the internet and still work with HomeAssistant.

3 Share Report Save

Spaziba-Njet OP · 2 yr. ago

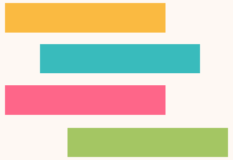
Is that not only for the ones running Valetudo or similar? It would be great if it is just in general!

1 Share Report Save

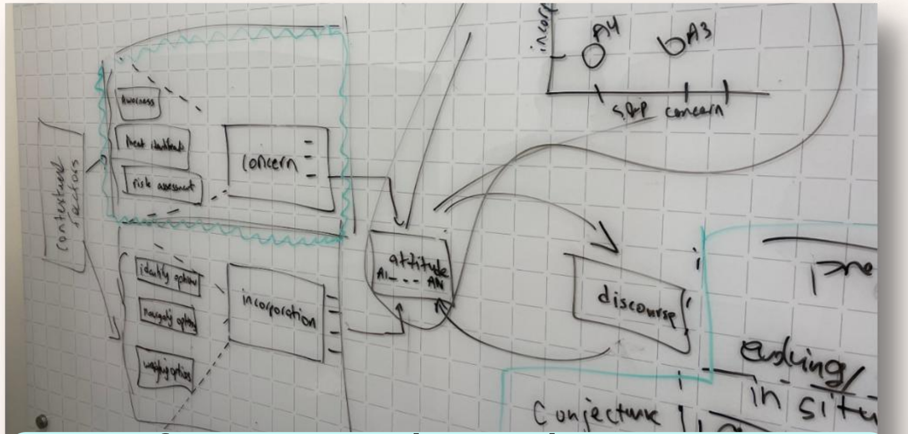
Continue this thread →

Reddit comments

Themes



Codes



Our framework under construction (2021)

Findings: Contextual Factors Related to S&P

Am I still **in the refund period?**

Product factors

S&P features

They have **blatant disregard for the ethical responsibility** when they have access to such sensitive data.

Adoption phases

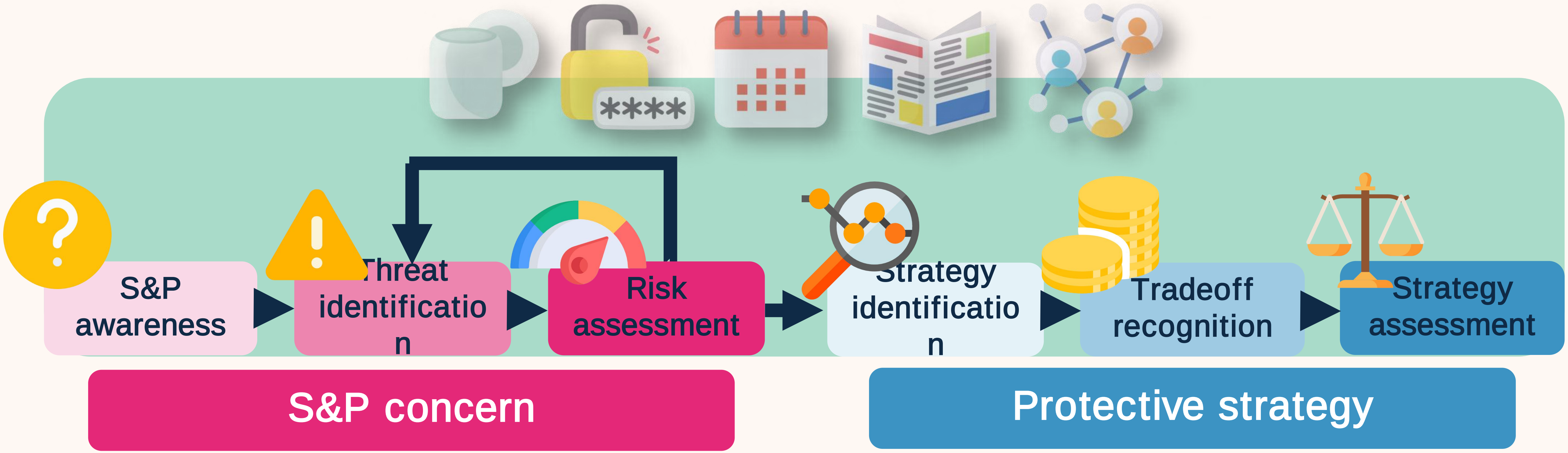
Auxiliary information

Relevant stakeholders

They **are highly incentivized to keep it safe** and not sell it.

Users’ understanding and requirements differ and are constraint by diverse contextual factors

Findings: S&P Considerations



Users develop S&P concerns and protective strategies overtime and reflectively

Findings: S&P Concern - S&P Awareness

- **Contextual factors** contribute to awareness

[MQTT] may expose something on your Internet

- Awareness evolves based on **changing** contextual factors

Yeah i had gotten a discounted nest thermostat from my power company but after seeing their reluctance to let me access *my own data* i returned it

Findings: S&P Concern – Threat Identification

- Technical expertise affects **vulnerability assessment**

I assume Z-Wave doesn't suffer from this problem due to the certification process? Or are there attack vectors that could be leveraged against that particular tech?

Insufficient understanding may lead to overestimation or underestimation of the threat

Findings: S&P Concern – Threat Identification

- **Preconceptions** (trust, reputation, reliability, etc.) shape users' views toward products and stakeholders

Not specifically for Xiaoyi, but it is quite common for low-priced Chinese brands to have embedded backdoors or privacy-invading snooping by the company

Redditors may show differing trust but a predominant distrust toward Chinese stakeholders

Findings: S&P Concern – Threat Identification

- Assumptions regarding stakeholders’ behaviors result in **different role assignments** (e.g., potential victim, adversary, and “good Samaritans”)

> Well Google records all your data, but they are highly incentivized to keep it safe and not sell it, because having exclusive access to it is their core business

Users assumptions on stakeholders’ roles and their dynamics differ

Findings: S&P Concern – Risk Assessment

- Users’ assumptions (e.g., resource and technical sophistication) about adversaries drive their **likelihood assessment** of risks (health, finances, physical and digital assets.)

> I can disable the system with a walkie talkie after using an SDR [software defined radio] to find the exact frequency the system is on and just blast it the entire time I’m in your house . . . $20 baofeng [radio] will kill simplisafe since it uses 433[MHz]

Users’ assumptions about adversaries are subjective

Findings: S&P Concern – Risk Assessment

- Users' valuation of users (children, elderly, etc.) and assets (sensitive data) influences their **severity assessment**

> I need to deal with sensitive HR [Human Resources] issues from home, all of which should never be recorded without consent of a third party

Users may have different valuations given the same threat model

S&P Considerations: Concerns

S&P awareness

Contextual factors contribute to awareness

Awareness evolves based on **changing factors**

Threat identification

Technical expertise affects vulnerability assess.

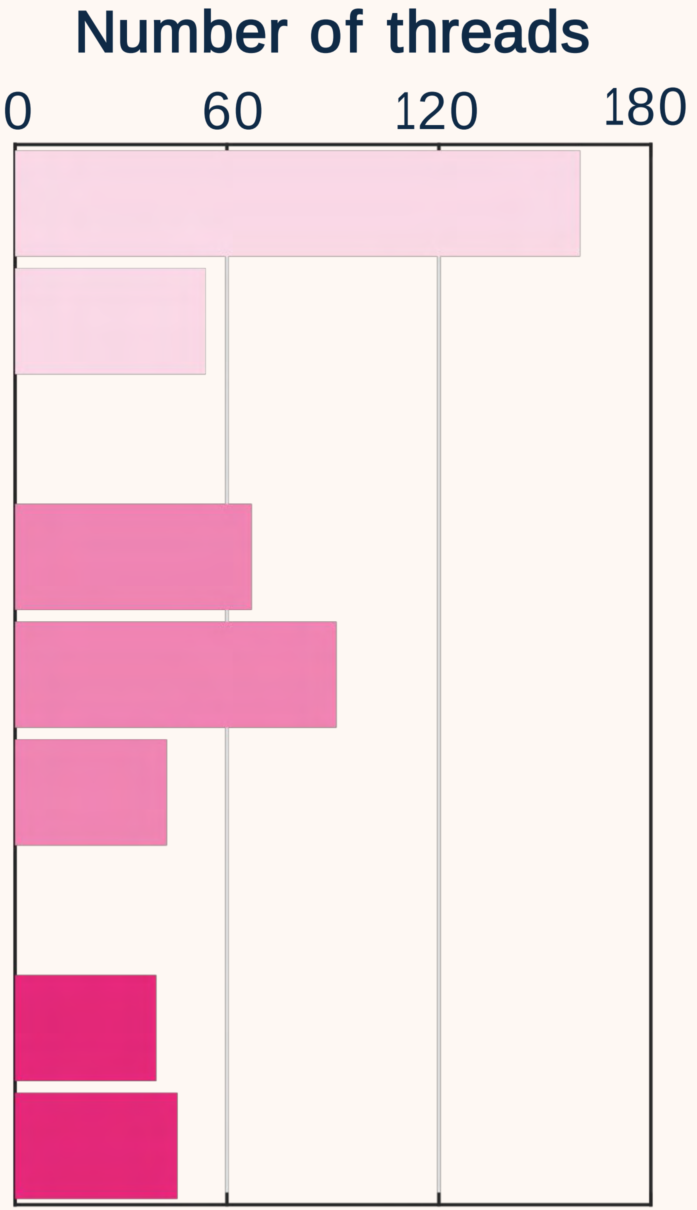
Preconceptions shape users’ views towards products and stakeholders

Assumptions regarding stakeholders’ behaviors results in different role assignments

Risk assessment

Users’ assumptions about adversaries drive their **likelihood** assessment

Users’ valuation of users and assets influences their **severity** assessment



Findings: Protective Strategies – Strategy Identification

- Users leverage **information sources** (buying guide, online discussion, etc.) to identify protective strategies.
- Contextual factors (e.g., availability of privacy option) **constrain the scope** of strategies

[the control] is buried in the app

Users may not have a complete understanding of the contextual factors

Findings: Protective Strategies – Tradeoff Recognition

- Price and technical effort inform **cost awareness**
- **Benefits of strategies** stand on the security and perceived improvements in use cases

Actually if you know python writing a voice assistant capable of controlling your house and doing other basic functions is a matter of a couple days

Cost and benefits are subject to personal circumstances

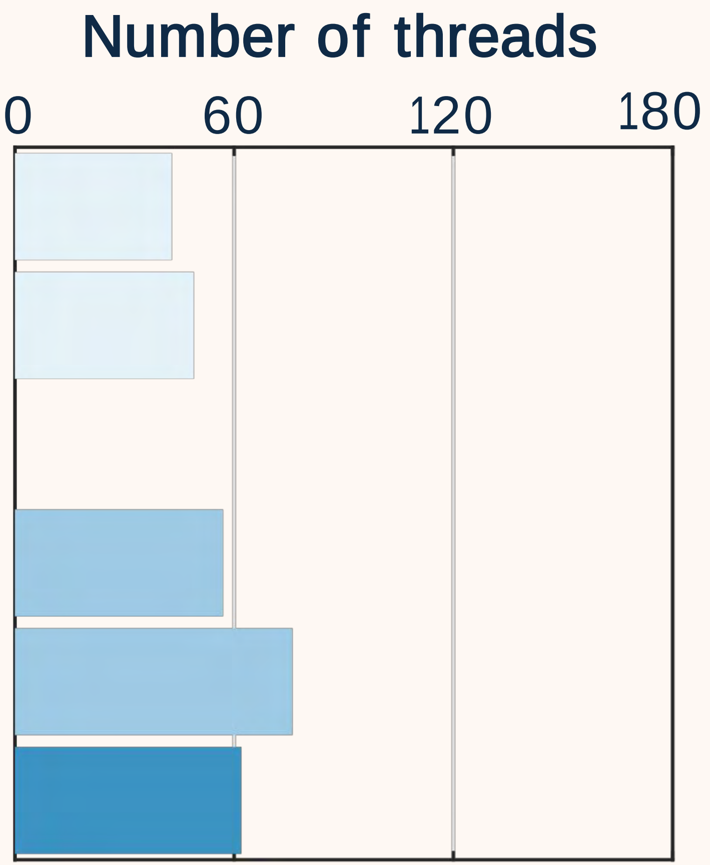
Findings: Protective Strategies – Strategy Assessment

- Whether the benefits overweigh the cost?

I agree that Homeseer’s interface is not the prettiest one around, but so far it does far and away more, is stable, and exposes the “nerd knobs” needed to do darn near anything including secure z-wave

S&P Considerations: Protective Strategies

- **Strategy identification**
  - Users leverage **info. sources** to identify protective strategies
  - Contextual factors **constrain the scope** of strategies
- **Threat identification**
  - Price and technical effort inform **cost awareness**
  - **Benefits of strategies** stand on the S&P and perceived improvements in use cases
- Strategy assessment



Findings: S&P Attitudes

But I **don’t really care about people** eavesdropping me.

Dismissiveness
44/255 users

Incorporating protective strategies

I’d definitely like to hear what other people have to say.

Exploration (111/255 users)

People are **walking around with a cellphone 24/7!**

Resignation (13/255

I value convenience over complete privacy

Positive pragmatism (71/255 users)

Personally I would and have layered the devices in 3 layers for security...

Devotion (65/255 users)

Low ⟷ High

Concern

Findings: S&P Attitudes

So far I’ve decompiled the app and found that it uses Ayla Networks IoT platform. Oh and the Cipher Suite for added security

the last thing I want to do on the weekend is fiddle with Raspberry Pi

Exploration/Devotion

Pragmatism with high tech competence

Users’ attitudes are contextual and evolve, despite preconception

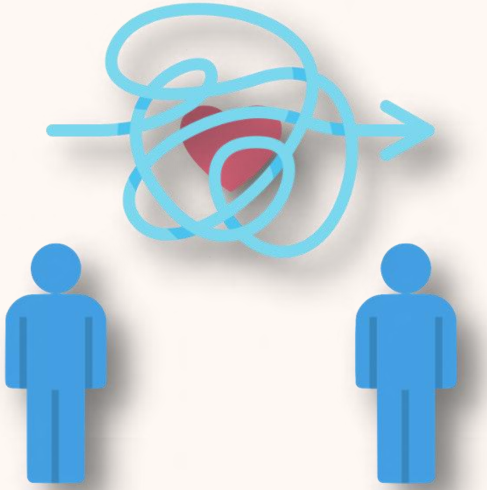
Findings: Influences of Online S&P Discussion

Resolving ambiguity

I believe this was resolved in 2016 with a new version (**see this news [url]**)

Developing attitudes

UPDATE: I took a hybrid approach. I setup a separate gmail…



Influencing environment

Am I weird for thinking it’s weird that someone would have access…

Findings: Resolving Ambiguity

- Collaborative exploration through elaboration
- Transfer of personal experience to a new context
- Supplementary information as evidence

> In my TPLink router, I have an option to block internal IP addresses from accessing the internet. Would it still work at all if it had NO connection

Users helped each other through iterations of discussion

Findings: Developing Attitudes

- The discourse affects S&P concerns
- The discourse informs alternative strategies

Edit: You’re right, I wasn’t scammed, but if it is a scam, someone else could easily fall for this

UPDATE: I took a hybrid approach. I setup a gmail account for the house and moved all accounts to it. I removed one of my Wink Relays...

Users benefit from the online discussion in making decisions

Findings: Influencing Environment

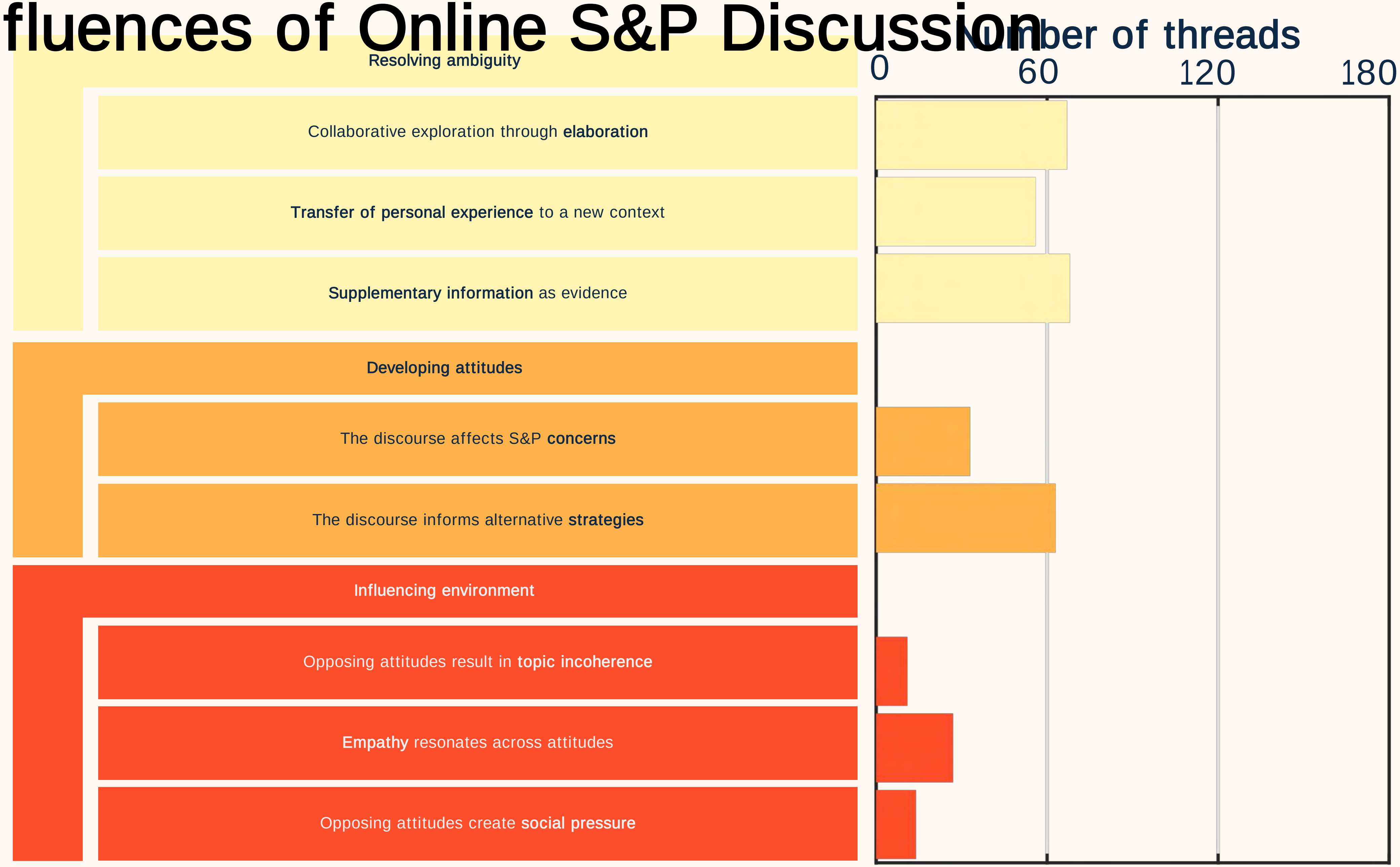
- Opposing attitudes result in topic incoherence
- Empathy resonates across attitudes
- Opposing attitudes create social pressure

... our son managed to get the Google Home Mini to recognize his ‘HEY GOOGLE!!’ this morning. People with small children and voice recognition Help

Am I weird for thinking it’s weird that someone would potentially have access to control many things in my home through that echo?

S&P information in discussion can be difficult to access and assess

Influences of Online S&P Discussion

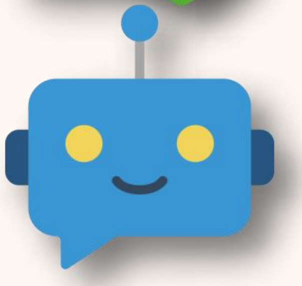


Recommendations: Design and Practice

1. Incorporate users’ **diverse considerations**

2. Support **attitude development** in real life

3. Improve access to **credible S&P info.** online



Recommendations: Design and Practice

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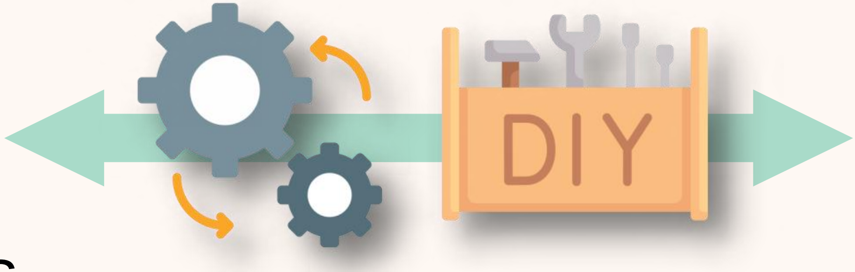


- Inform users about smart home operations and practices in a transparent and understandable manner
- Make S&P protective strategies available and flexible for products
- Accommodate considerations of different users, e.g., tech-savvy vs. novice, for specific use cases (e.g., by tech caregiving)

Recommendations: Design and Practice

2 Support **attitude development** in real life

- Nudge users’ S&P attitudes with physical metaphors (privacy labels and more?)
- Deploy S&P nudges at scale through automated assessment of smart home products.

Recommendations: Design and Practice

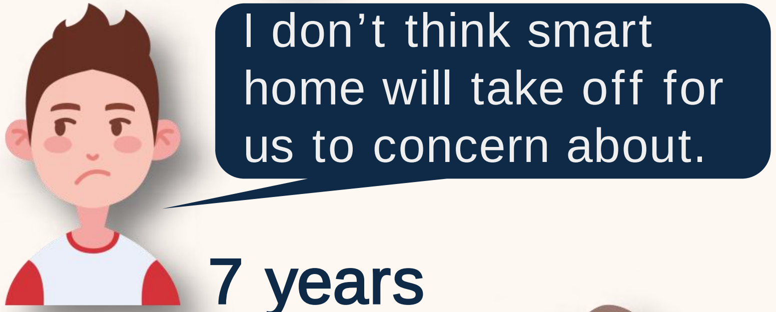
3 Improve access to **credible S&P info.** online

- Highlight the access to credible S&P information and sources (e.g., Wiki and security advice)
- Help mediate S&P discussion by detecting misinformation and moderation

Recommendations: Research Direction

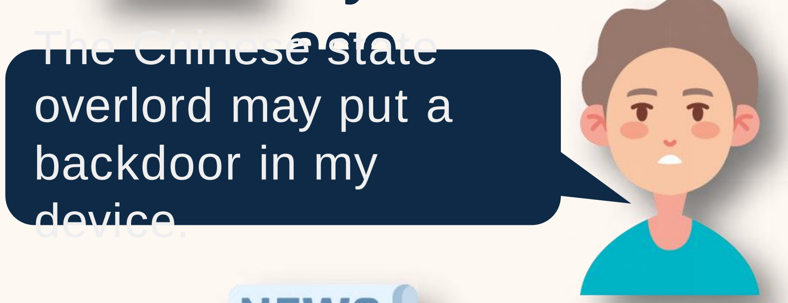
1. Study users' dynamic and context-dependent S&P **attitudes across domains**

2. Study users' attitudes **longitudinally at a community level**


I don't think smart home will take off for us to concern about.

7 years ago

3. Investigate the underlying **geopolitical and cultural influences** on S&P attitudes



4. Understand how different S&P **information sources online** impact users

Take-home

- Vetrivel, S., Bouwmeester, B., van Eeten, M. and Gañán, C.H., 2024. {IoT} Market Dynamics: An Analysis of Device Sales, Security and Privacy Signals, and their Interactions. In *33rd USENIX Security Symposium (USENIX Security 24)* (pp. 7031-7048).
- Do, Y., Arora, N., Mirzazadeh, A., Moon, I., Xu, E., Zhang, Z., Abowd, G.D. and Das, S., 2023. Powering for privacy: improving user trust in smart speaker microphones with intentional powering and perceptible assurance. In *32nd USENIX Security Symposium (USENIX Security 23)* (pp. 2473-2490).