Smartphones are the key!

On the constraints of mobile computing in cloud avoidance

Rémy Raes
Spirals/WIDE research teams
Inria Lille

July 6th, 2026

Inria

Université de Lille


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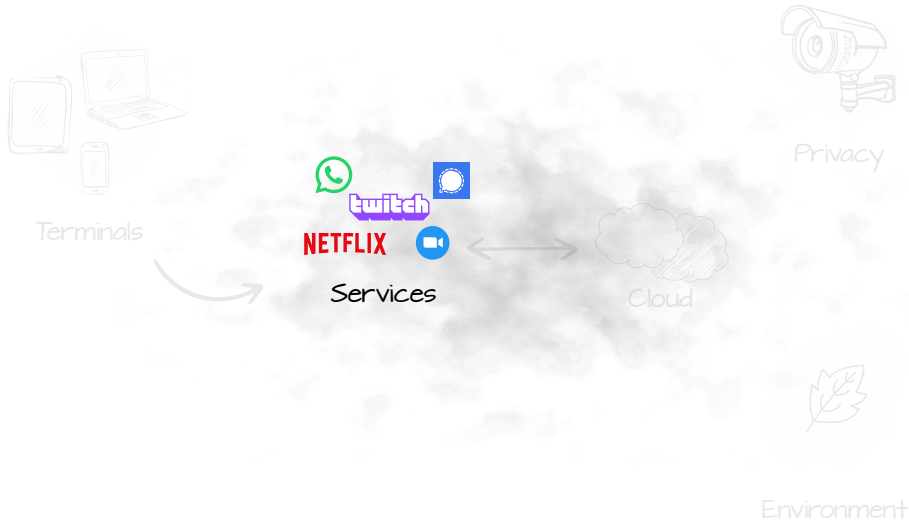
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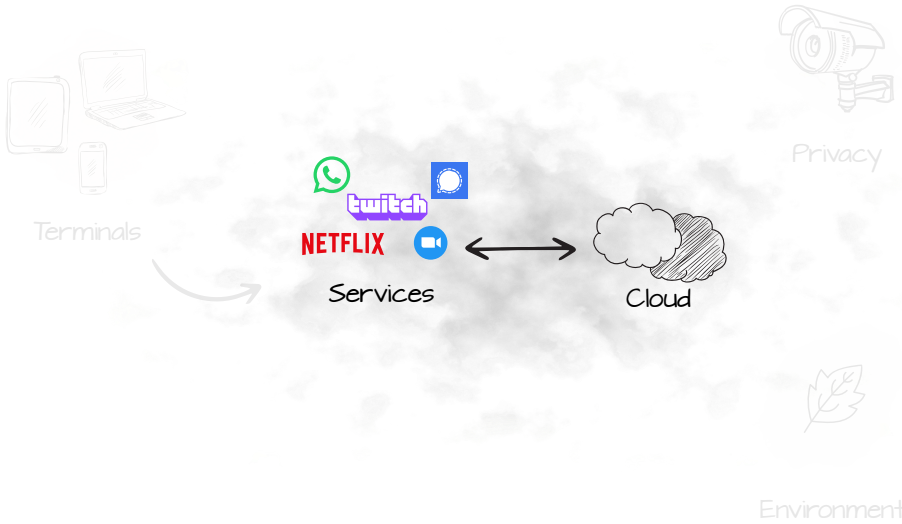
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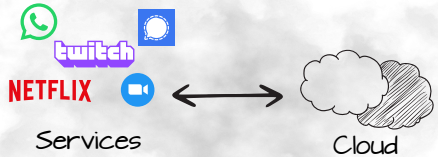

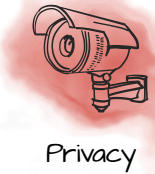

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54% of data in the cloud is sensitive, up from 47% last year.

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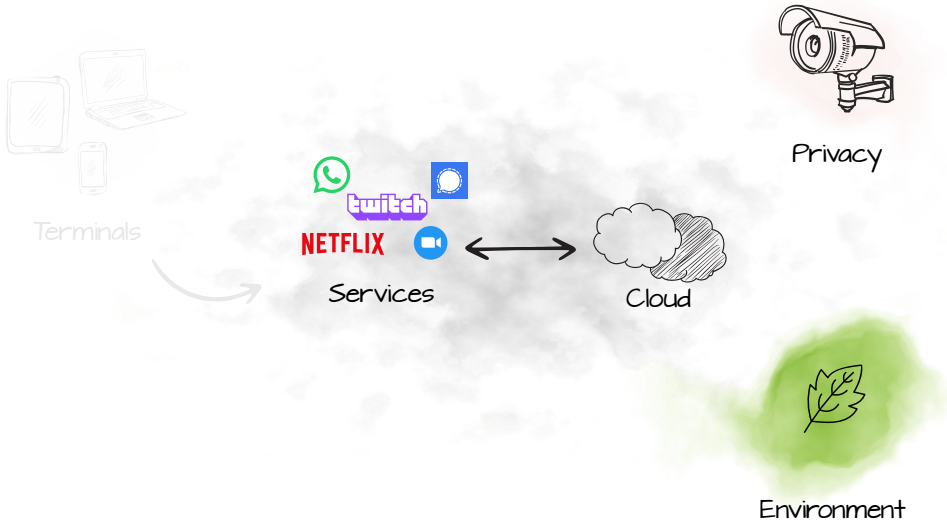
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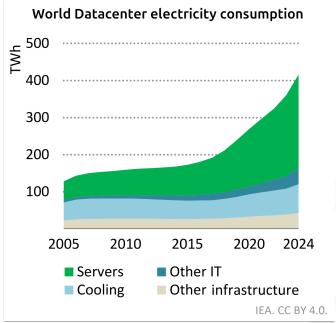

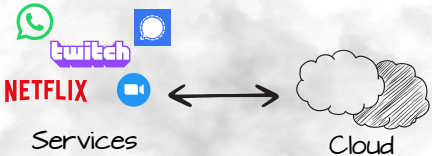

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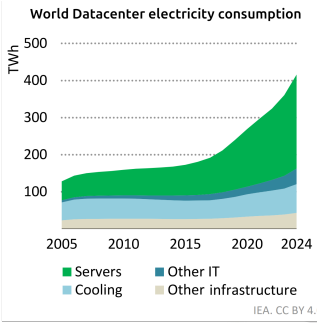

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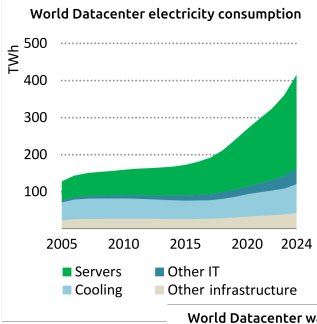

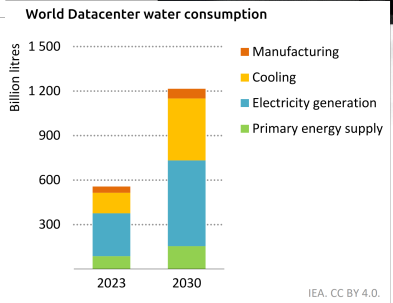

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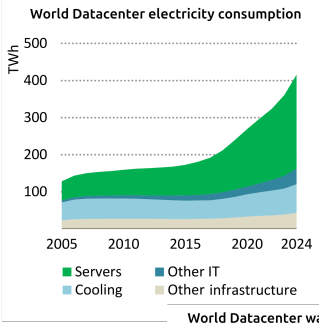

'I can't drink the water' - life next to a US data centre

10 July 2025

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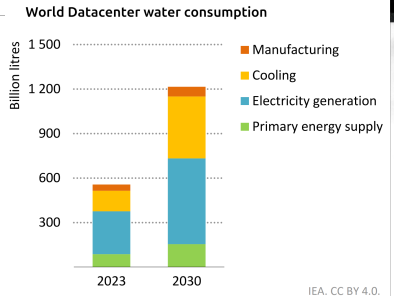
Michelle Fleury & Nathalie Jimenez

North America business correspondent & Business reporter, Georgia



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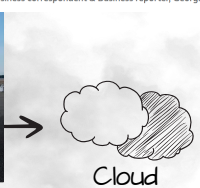
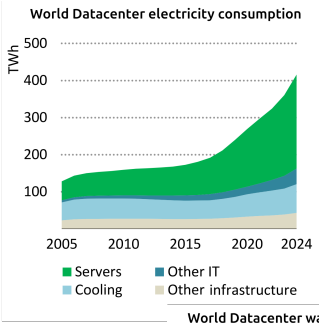




'I can't drink the water' - life next to a US data centre

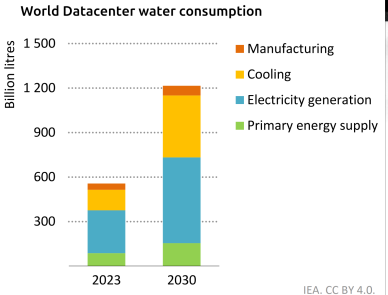
We Need to Talk About AI's Impact on Public Health ›

Data-center pollution is linked to asthma, heart attacks, and more

BY ADAM WIERMAN SHAOLEI REN | 01 MAY 2025 | 5 MIN READ

Adam Wierman is the Carl F. Braun professor of computing and mathematical sciences at Caltech.

Shaolei Ren is an associate professor of electrical and computer engineering at the University of California, Riverside.



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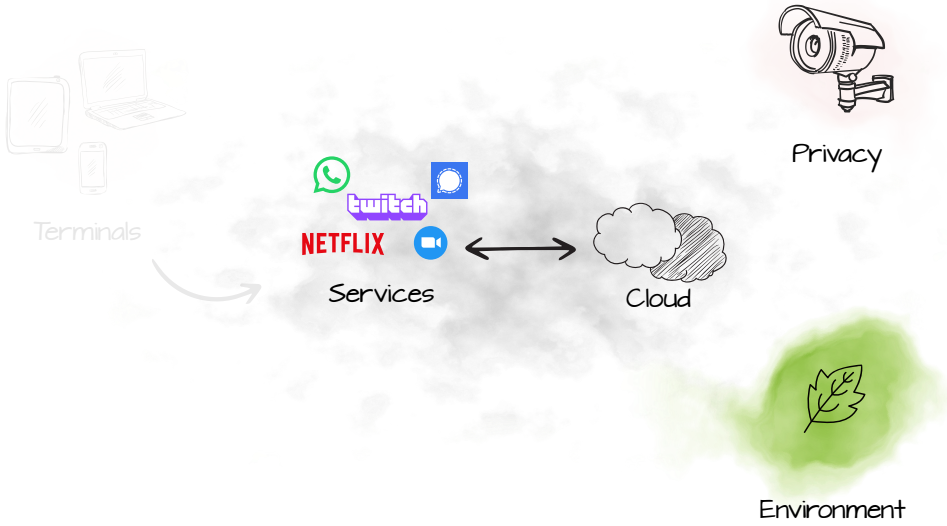
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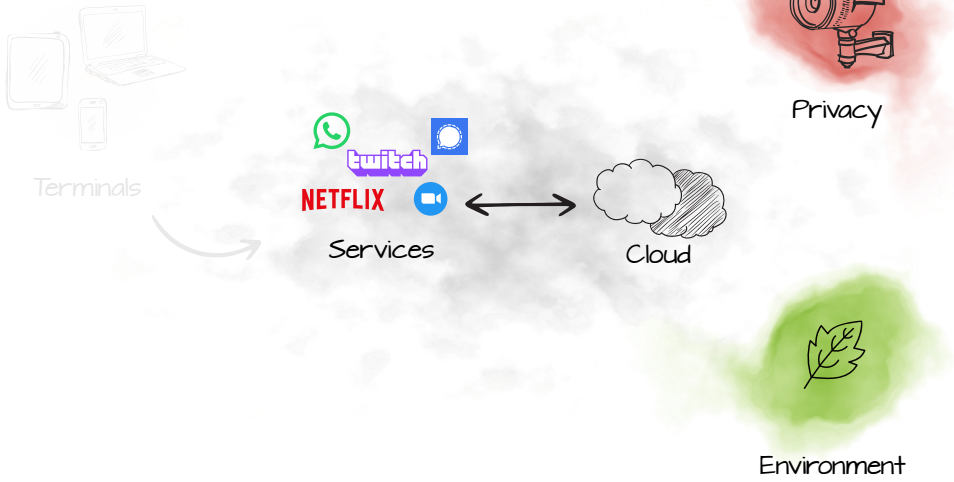
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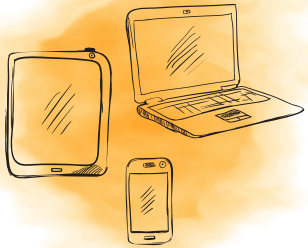

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2. FLInD

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3. INTACT

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4. Survey
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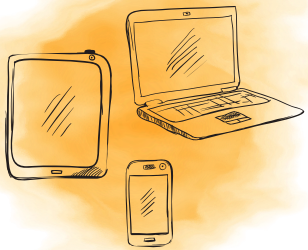

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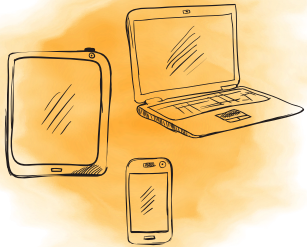

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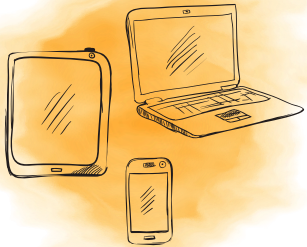

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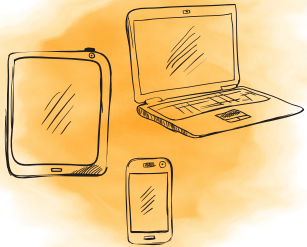

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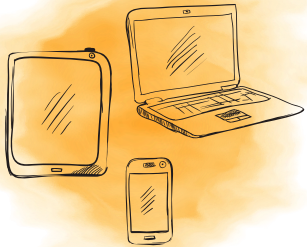

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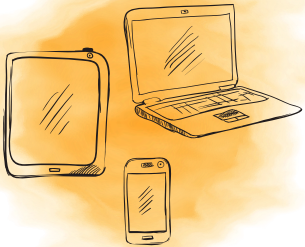

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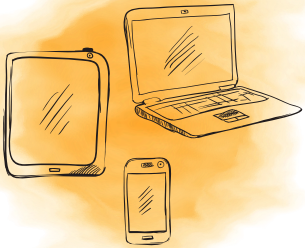

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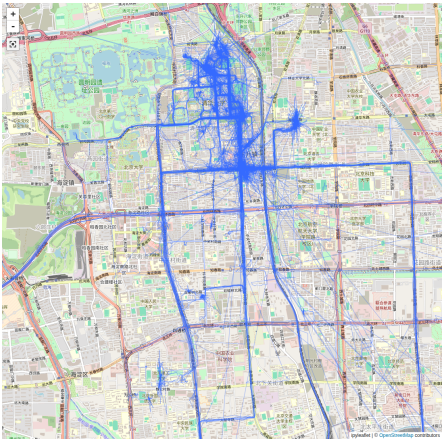
The location data case

- Location data is heavy (500MB/day)
- Location data is sensitive
- Can be mined to extract **Points of Interest** *(POIs)*
- Storage competitors exist: SQLite, SWAB, Greycat
  - But they're not satisfying



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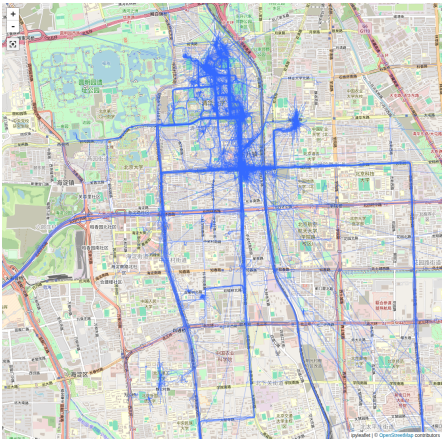

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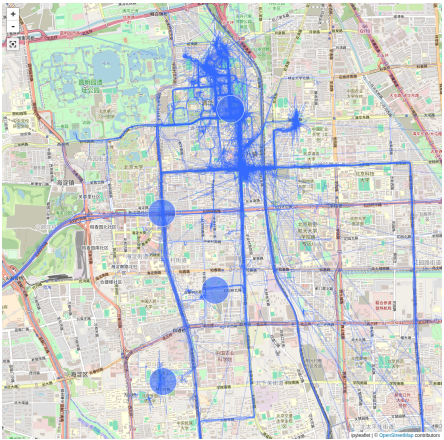

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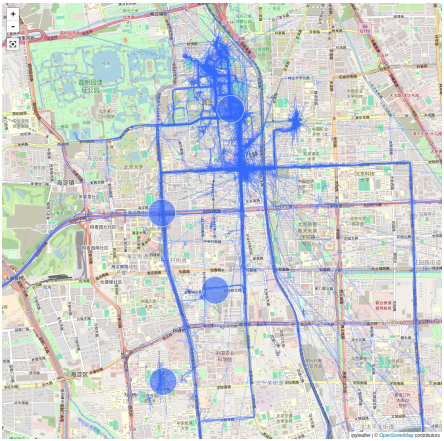

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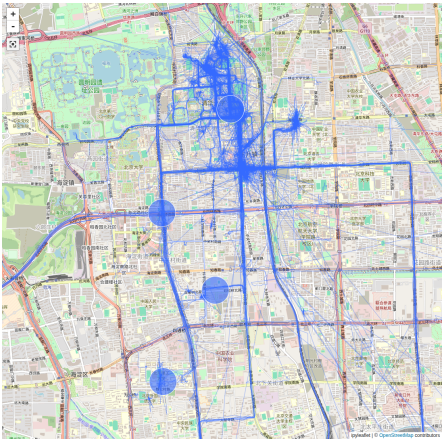

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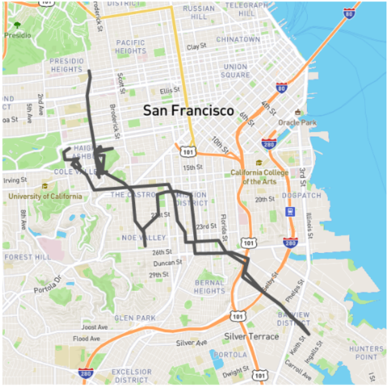

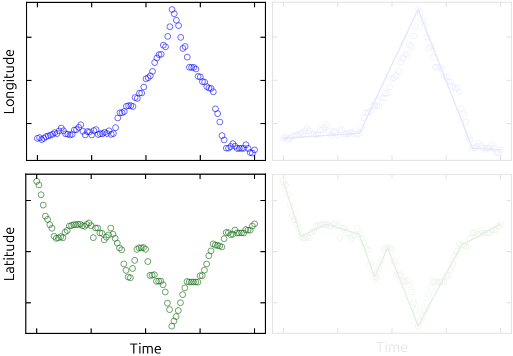

Rémy Raes, Olivier Ruas, Adrien Luxey-Bitri, Romain Rouvoy. Compact Storage of Data Streams in Mobile Devices. *DAIS'24 - 24th International Conference on Distributed Applications and Interoperable Systems, Jun 2024, Groningen, Netherlands.* **(hal-04535716v3)**

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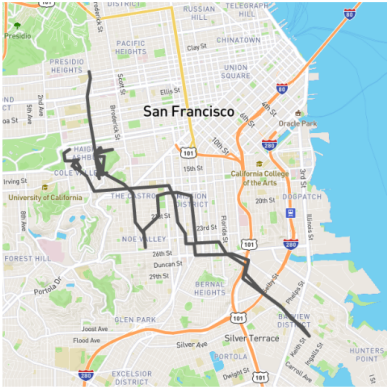

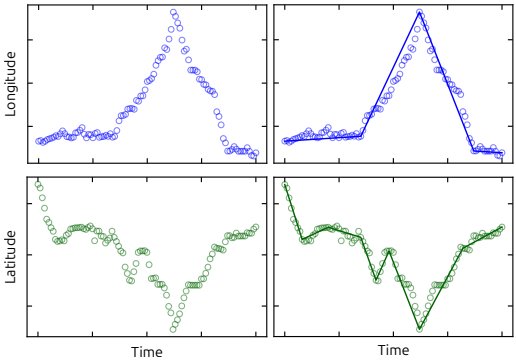

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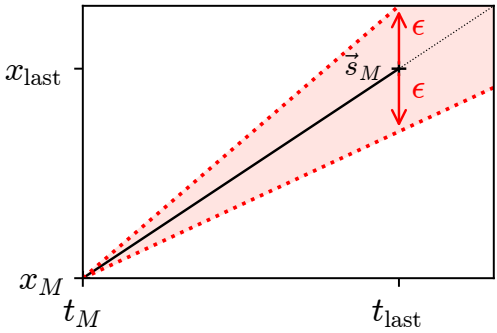
- List of piecewise linear approximations
- Capture as many points as possible per linear segment
- Data approximation through error tolerance



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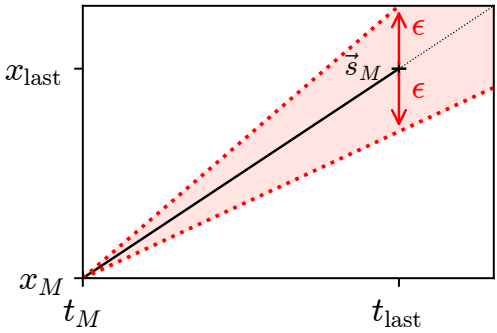

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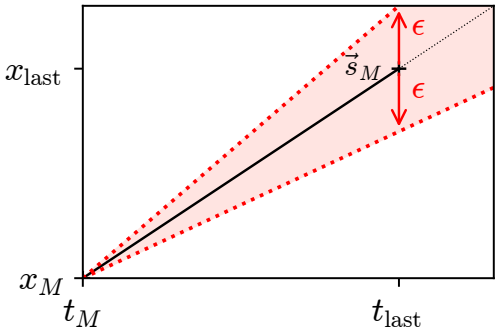

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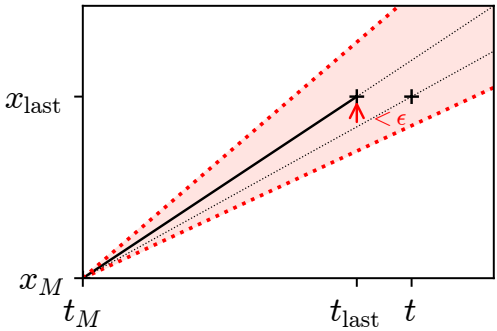

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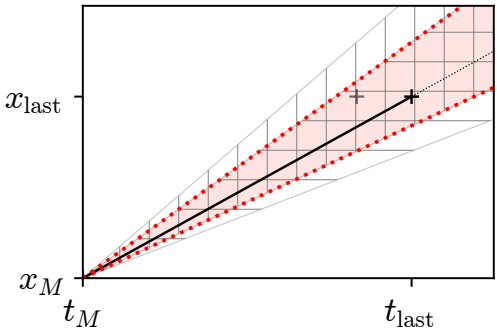

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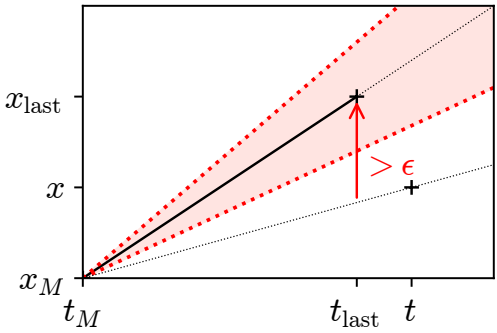
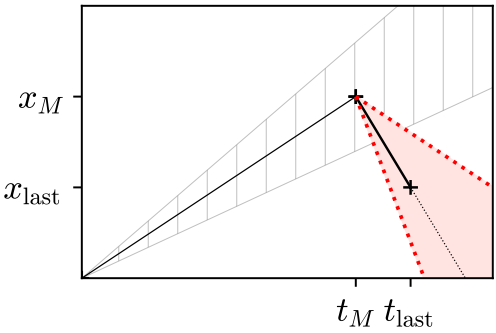


Fast Linear Interpolation (FLI)

- List of piecewise linear approximations
- Capture as many points as possible per linear segment
- Data approximation through error tolerance



FLI evaluation protocol

- Competitors
  - SQLite
  - SWAB
  - Greycat
- Input data
  - Synthetic data
  - Accelerometer data
  - Cabspotting dataset (GPS, San Francisco)
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- ϵ definition
  - 1×10^{-3} by default
  - Up to 2×10^{-3}

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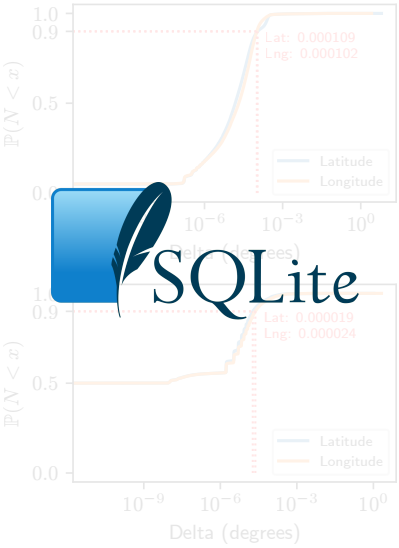

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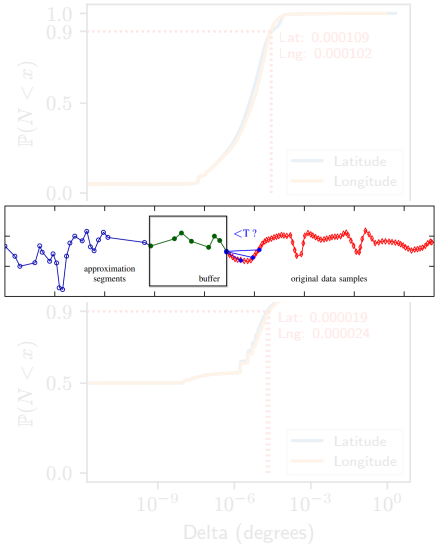

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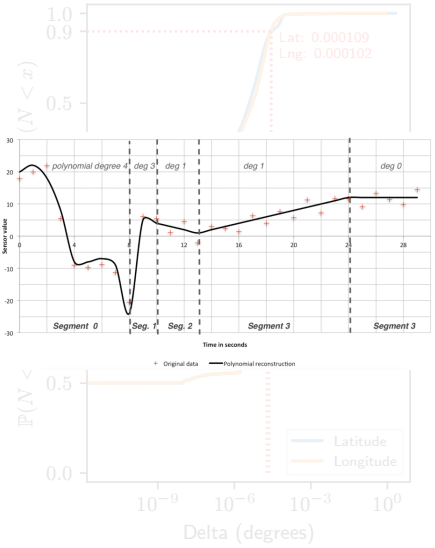

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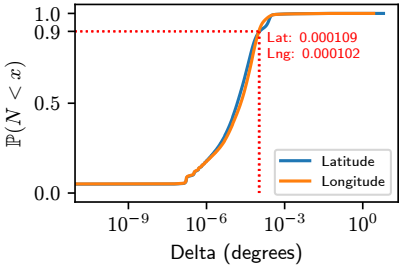

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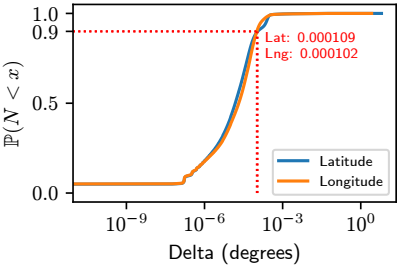

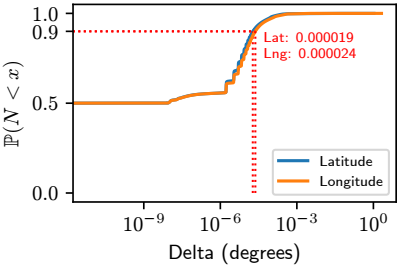

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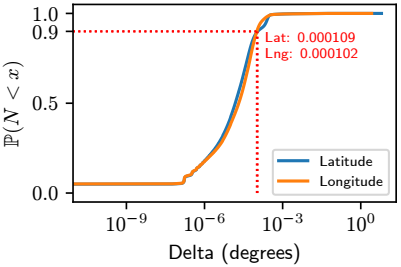

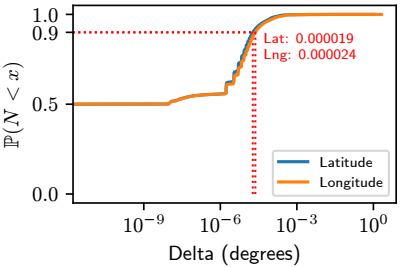

FLI RESULTS

- Faster than competitors
- Substantial compression gains
  - CABSPOTTING: from **388MB** to **307MB** (-21%)
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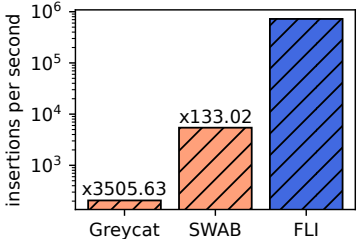

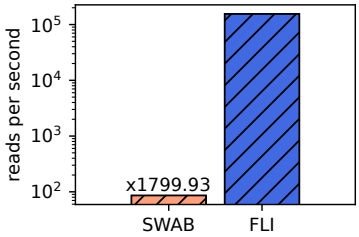

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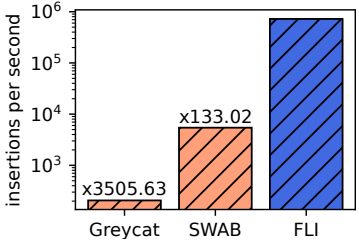

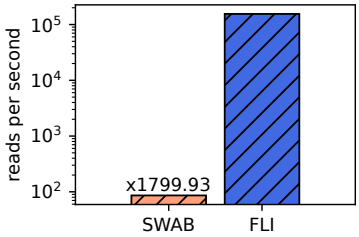

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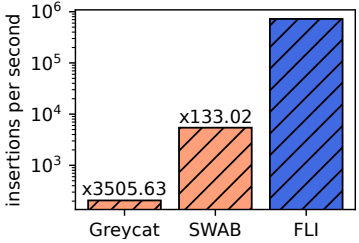

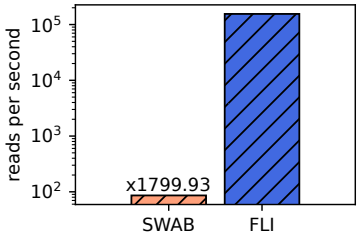

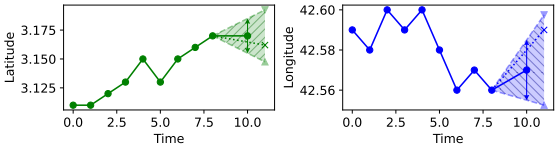

- FLI is suboptimal for storing multivariate time series
- Exploit relation between dimensions

Rémy Raes, Romain Rouvoy, François Taïani, Adrien Luxey-Bitri, Davide Frey. Less is More: a Lossy Storage Middleware for Multivariate Time Series. **(hal-05547600)**

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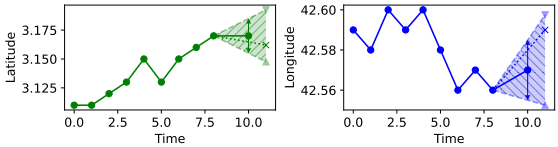

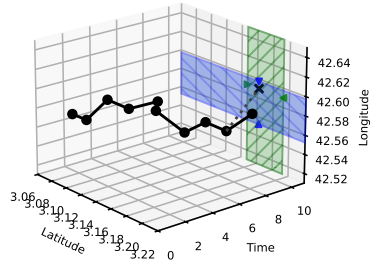

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Evaluation protocol

- Impact of dimensions
  - The more captured dimensions…
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  - FLInD (all dimensions in one instance)
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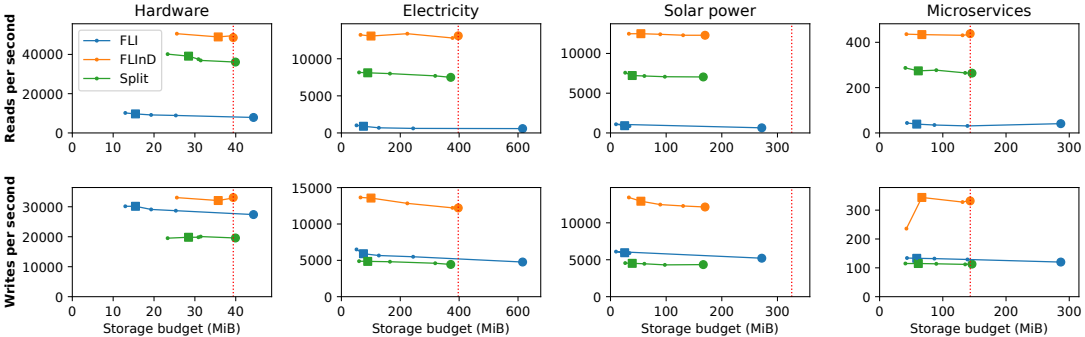
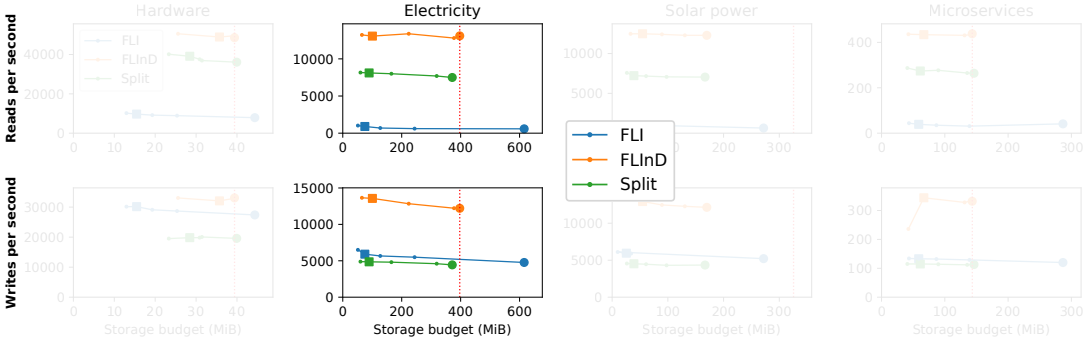


Figure: Read and write throughput VS storage budget of linear approximation competitors over several datasets.



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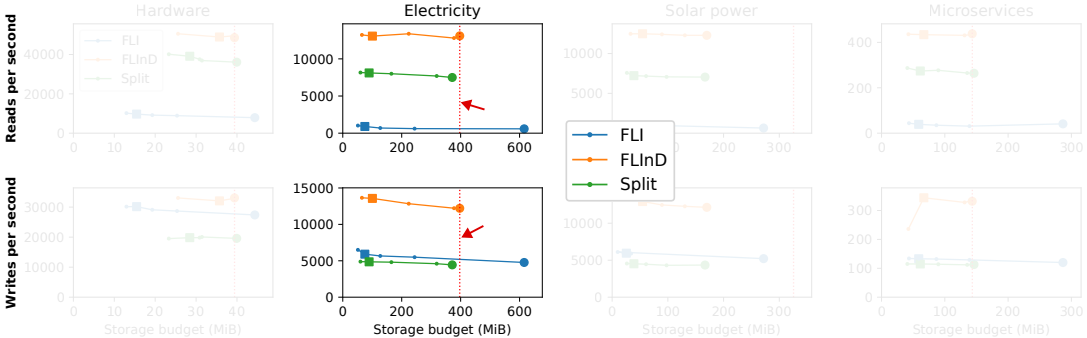

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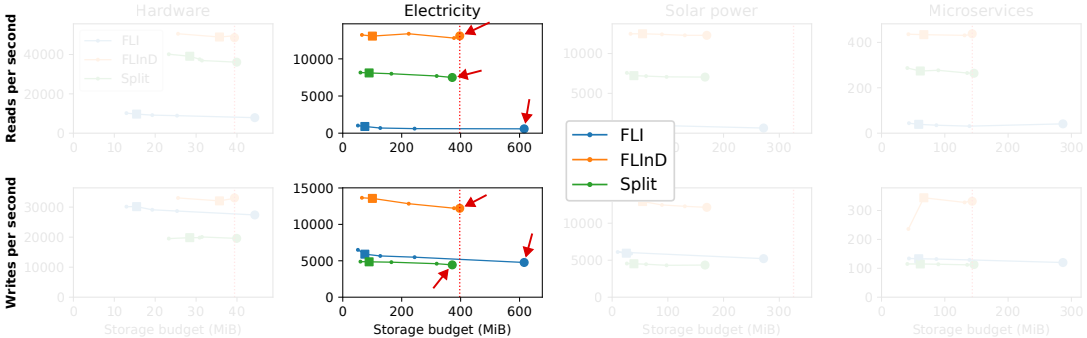

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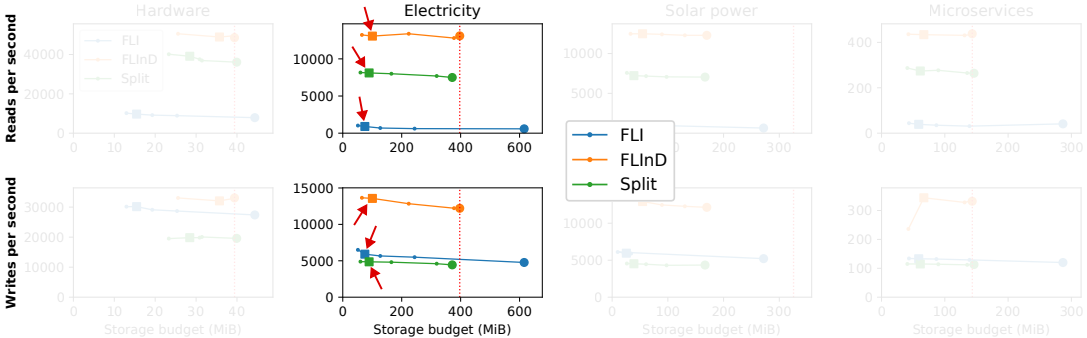

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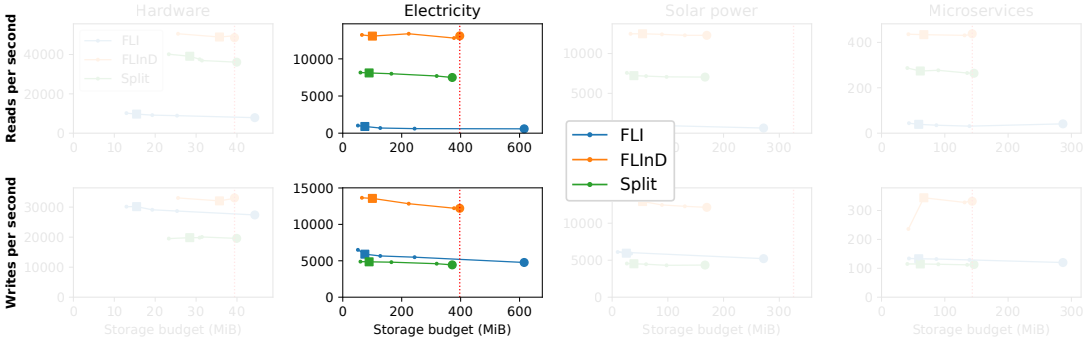

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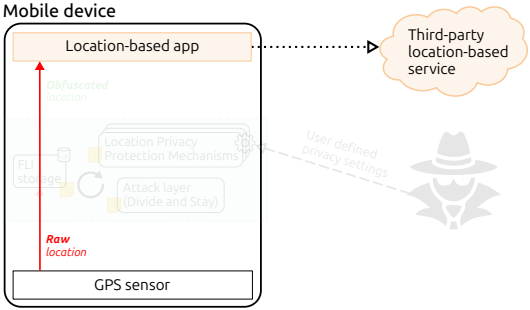
Local privacy audit

- INTACT: *in situ* location protection



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2. Local **protection** mechanisms
3. Local **attack** algorithms

- Locally **ensure data is safe** *before* sharing it

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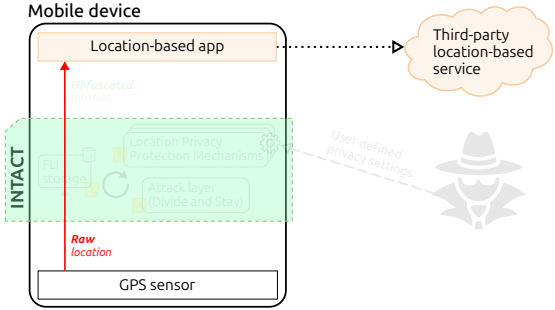

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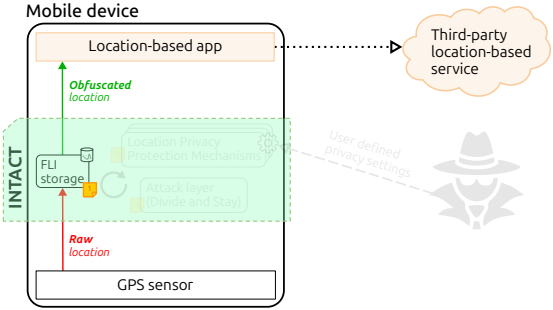

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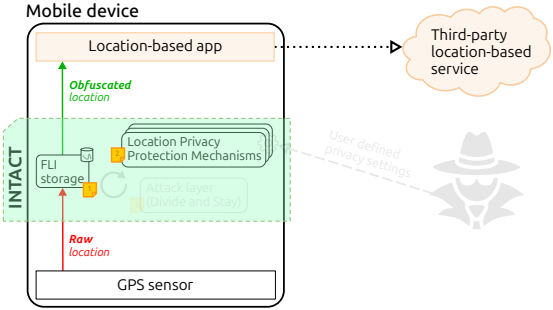

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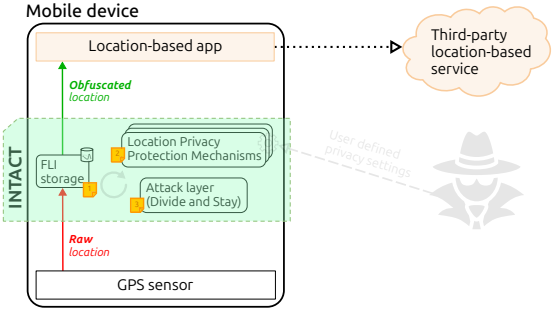

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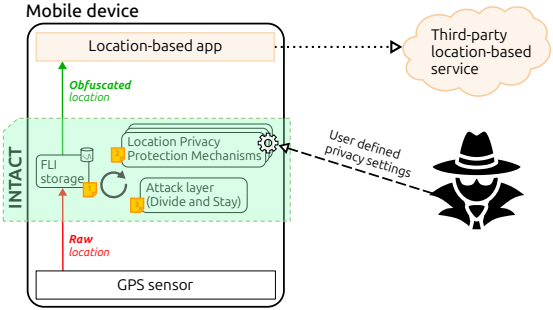

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- Implementation of the LPPM
- Execution time of a second

Figure: Toy example of the Promesse LPPM in action.

Attack: Divide&Stay

- POI-attack optimisation
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Figure: Distances distribution of modelled to closest raw POIs on Cabspotting.

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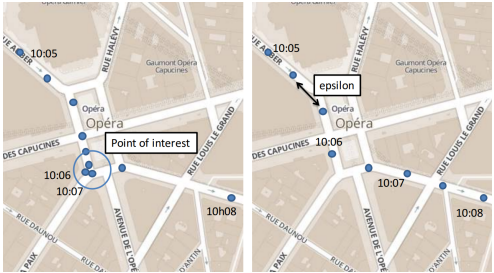

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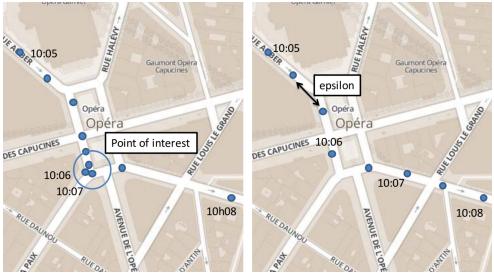

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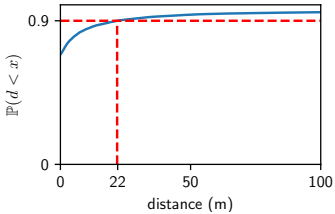

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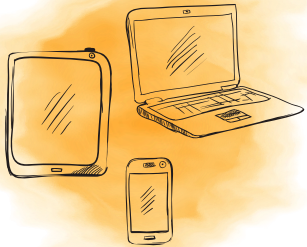

Terminals

Computing

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Energy

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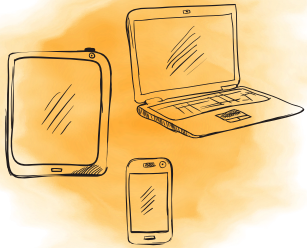

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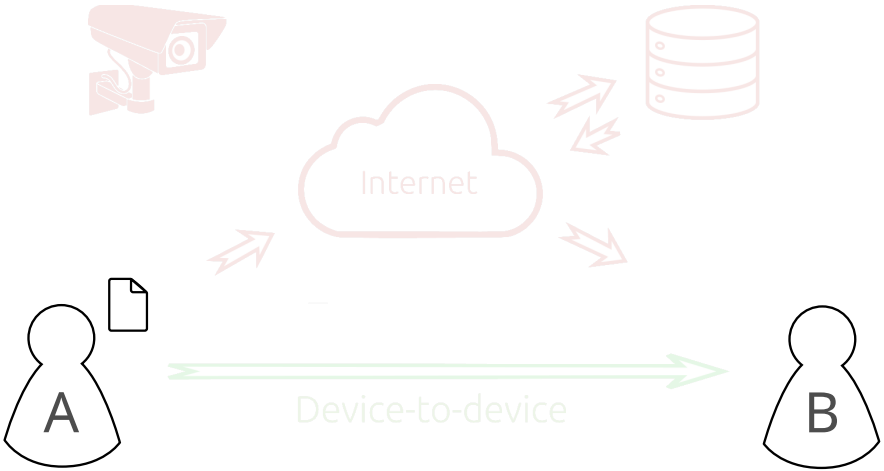

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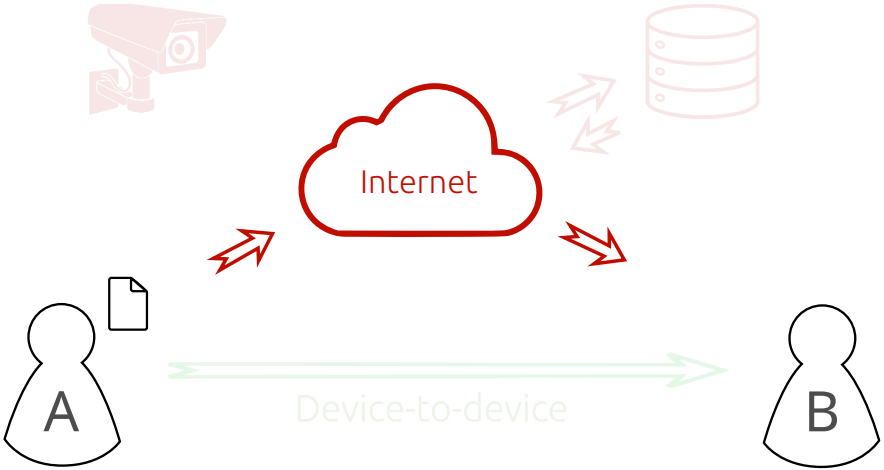

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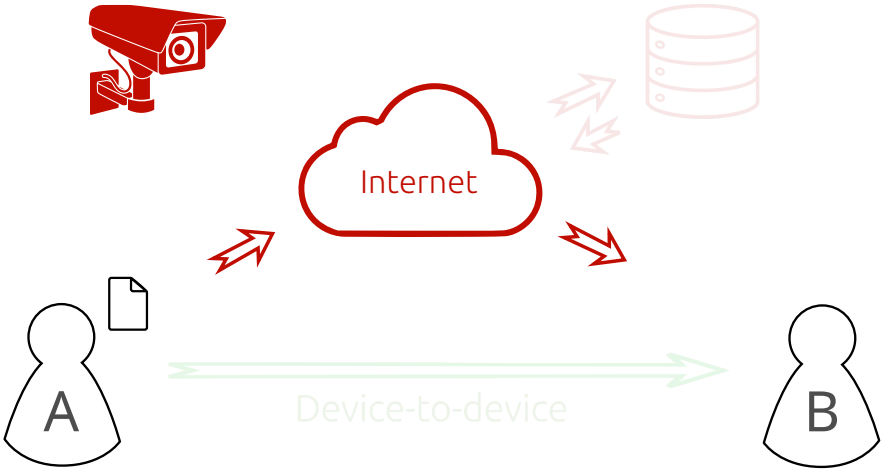

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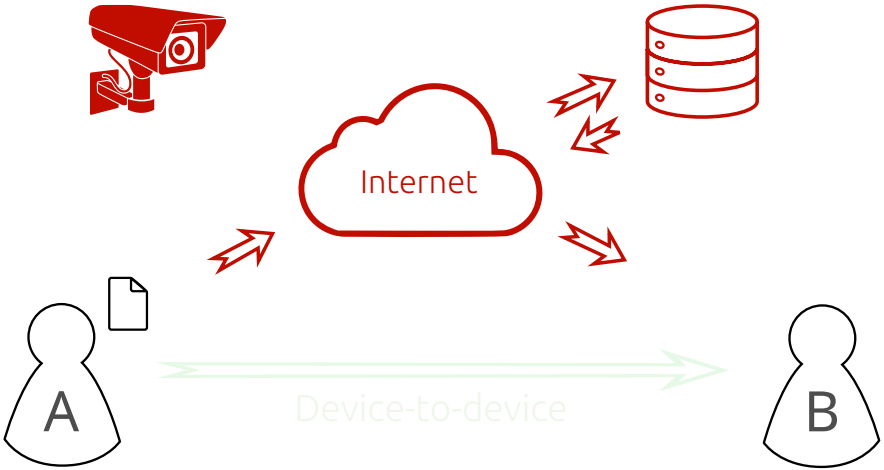

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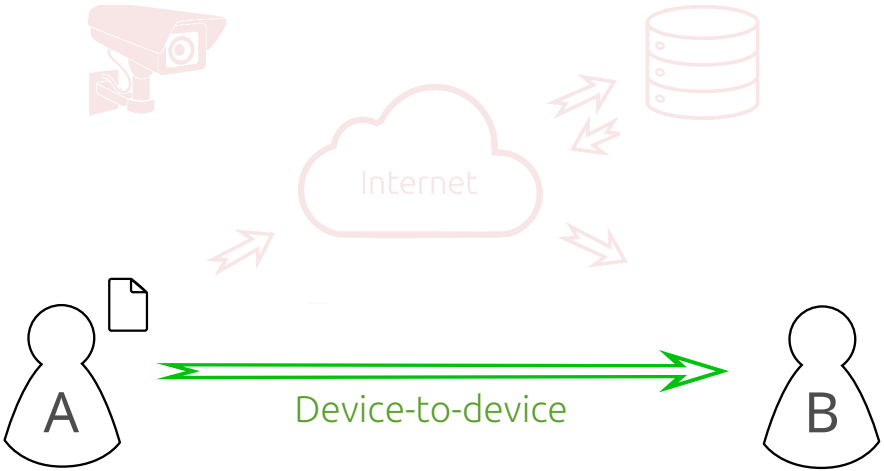

- Many technologies
- Widely deployed
- Proprietary frameworks
  - AirDrop
  - Quick Share

Name	Specification date	Maximum distance	Maximum data rate
Optical			
Infrared (IrDA)	1994	Several meters	16 Mb/s
QR code-flashing	—	Around a meter	23.6 kb/picture
Wi-Fi			
802.11 (legacy)	1997	100 m	1-2 Mb/s
802.11ax (Wi-Fi 6E)	2021	100 m	1.2 Gb/s
802.11ay	2021	10 m	100 Gb/s
Bluetooth			
Bluetooth Core v1	1999	100 m	1 Mb/s
Bluetooth Core v5	2016	100 m	1-3 Mb/s
RFID			
NFC	2004	20 cm	106-424 kb/s
Ultra-WideBand			
UWB	2007	200 m	27 Mb/s

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We realized a survey asking end users about their usage of communication technologies; it collected 364 answers.

Figure: Word cloud of received answers in the free-text feedback field.

Lauric Desauw, Adrien Luxey-Bitri, Rémy Raes, Romain Rouvoy, Olivier Ruas, et al. A critical review of mobile device-to-device communication. *DAIS 2025 - 25th International Conference on Distributed Applications and Interoperable Systems, Jun 2025, Lille, France.* **(hal-04198528v2)**

D2D survey: results

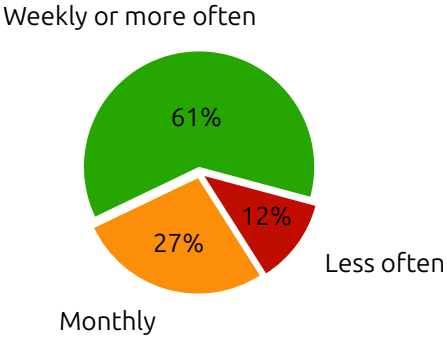


Figure: Distribution of the frequency of the need for D2D communication.

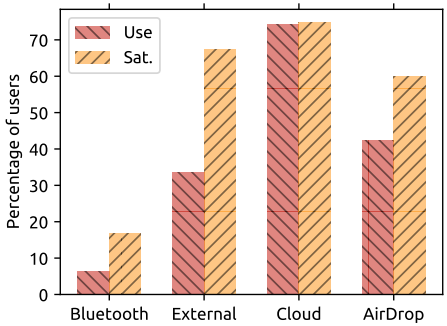
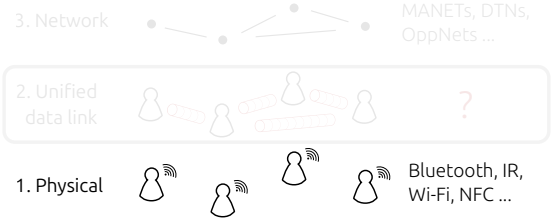


Figure: Use and satisfaction of the different available technologies.

A missing communication layer

- Multiple technologies available
- Many use-cases
- Missing link in-between



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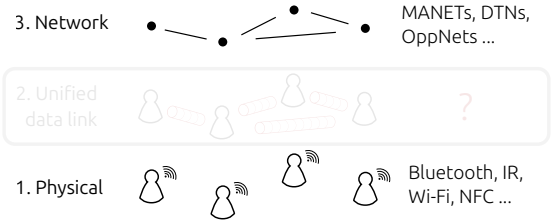

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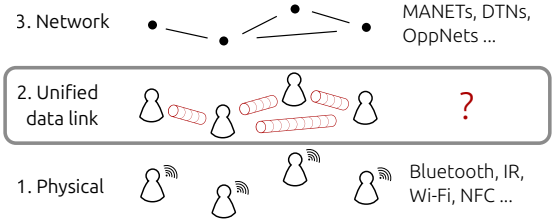

- Multi-platform support (Android, iOS, Linux)
- Set of abstractions to support any tech implementation

Rémy Raes, Adrien Luxey-Bitri, Romain Rouvoy, Davide Frey, François Taïani. Venice: eschewing the cloud by leveraging local communication channels. *ICT4S 2024 - International Conference on Information and Communications Technology for Sustainability, Jun 2024, Stockholm, Sweden.* **(hal-04576743)**

A framework proposal: Venice

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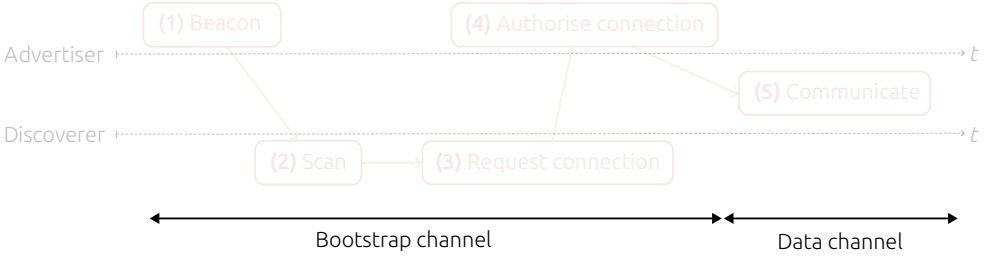

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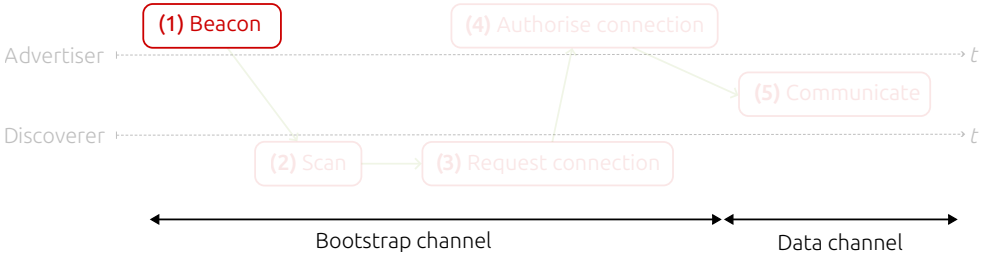

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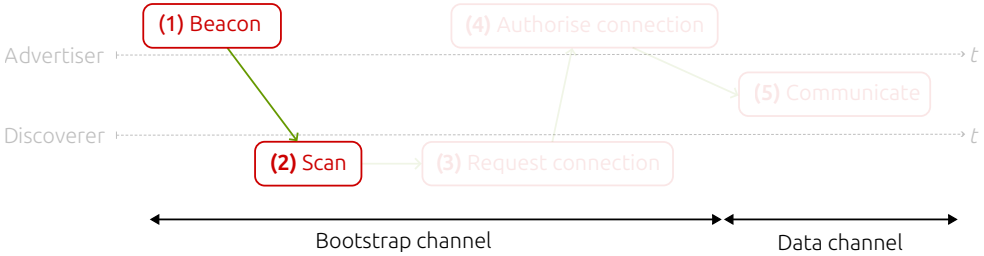

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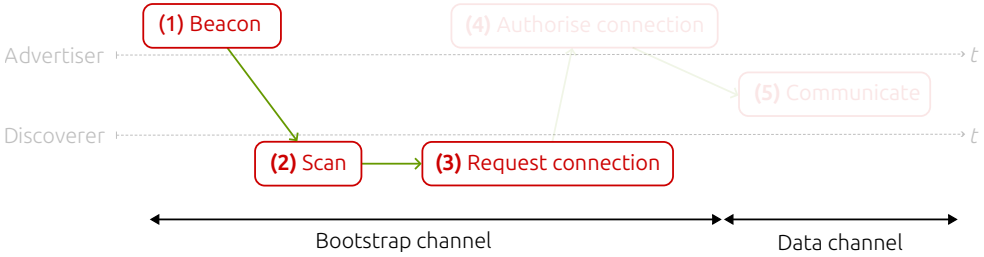

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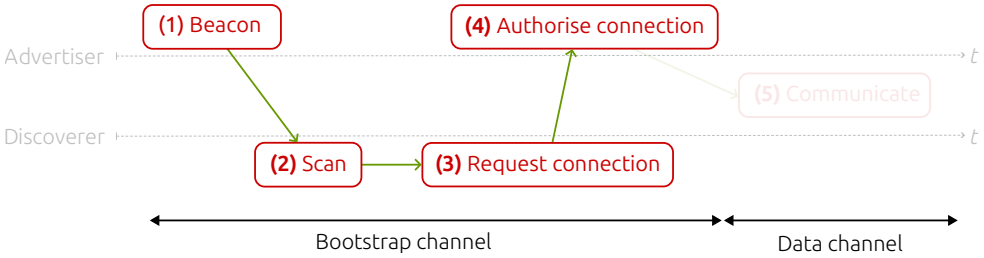

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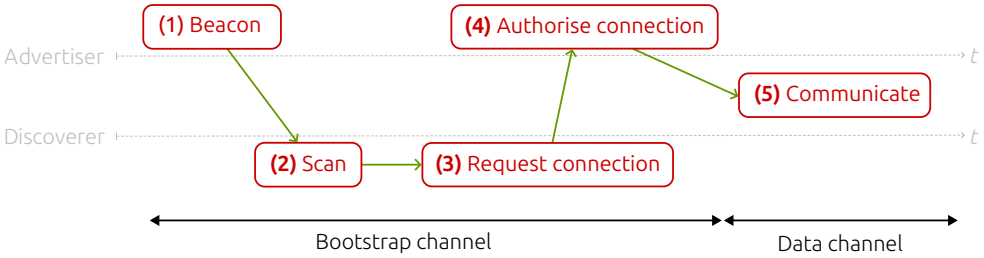

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- Manual choice of channels
- Several use-cases:
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  - File exchange
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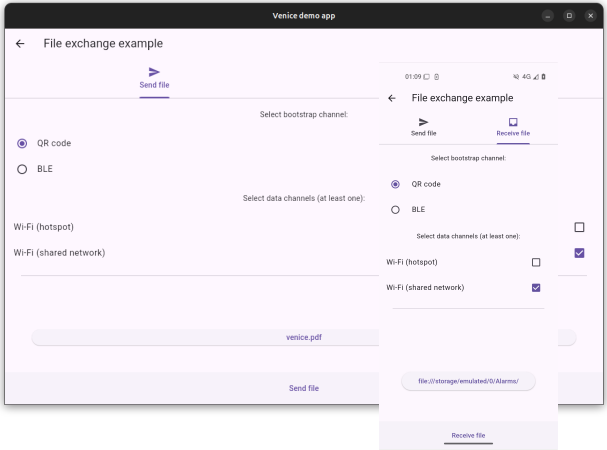

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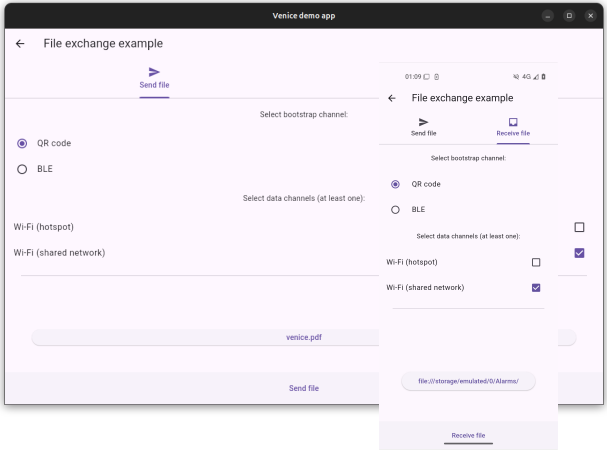

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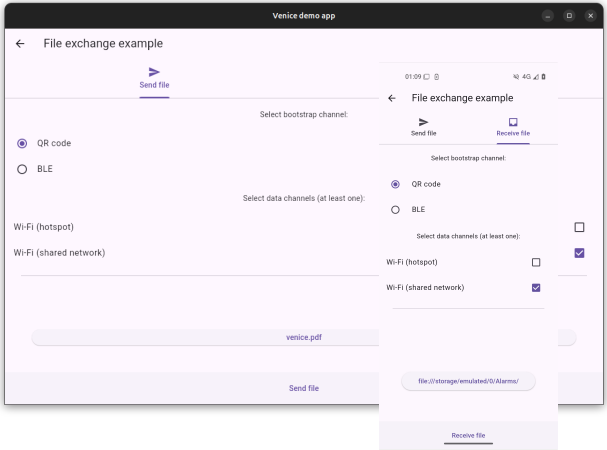

- Uneven system API support
- Tedious integration process
- Creating a multi-platform framework requires multi-platform knowledge
- Missing high-level API

PeripheralManager

API	Android	iOS	macOS	Windows	Linux
state	✅	✅	✅	✅	
stateChanged	✅	✅	✅	✅	
authorize	✅				
showAppSettings	✅	✅			
connectionStateChanged	✅				
mtuChanged	✅			✅	

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```
@override
Future<void> initReceiver() async {
    ConnectionData? connectionData;
    await centralManager.setUp();

    // Wait for Bluetooth to be ready
    while (await centralManager.getState() != BluetoothLowEnergyState.poweredOn) {
      debugPrint("Waiting for Bluetooth to be ready...");
      await Future.delayed(const Duration(milliseconds: 500));
    }

    // Start listening to devices
    centralManager.discovered.listen((event) async {
        String? advName = event.advertisement.name;
        if (advName != "venice") {
          return;
        }

        // Explore device only if it's Venice compatible
        await centralManager.stopDiscovery();
        await centralManager.connect(event.peripheral);

        // Retrieve data channel data from the correct service/characteristic
        List<GattService> services = await centralManager.discoverGATT(event.peripheral);
        List<GattService> matchingServices =
            services.where((element) => element.uuid == veniceUuid).toList();

        GattCharacteristic distantChannelCharacteristic =
                matchingServices.first.characteristics
                    .firstWhere((element) => element.uuid == veniceChannelCharacteristicUuid,
                    orElse: () => throw RangeError("Channel characteristic not found."));

        Uint8List cValue = channelNullValue;
        do {
          cValue = await centralManager.readCharacteristic(distantChannelCharacteristic);
          await Future.delayed(const Duration(seconds: 1));
        } while (cValue.toString() == channelNullValue.toString() || cValue.isEmpty);

        ChannelMetadata channelMetadata = ChannelMetadata( utf8.decode(cValue).split(";") );
        // Data channel can now be opened...
    }
}
```

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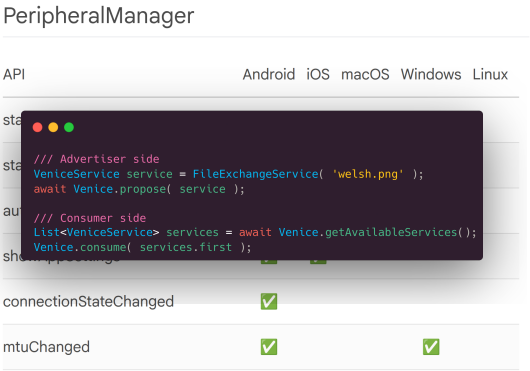
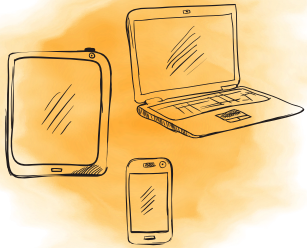


Storage
1. FLI
2. FLInD



Terminals

Computing
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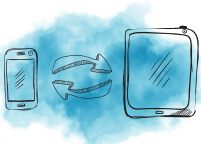

Communication
4. Survey
5. Venice

Energy
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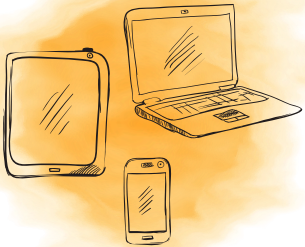

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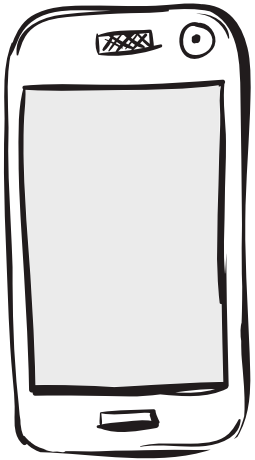
- Many TPLs for the same feature...
- ...and biased ways to pick one



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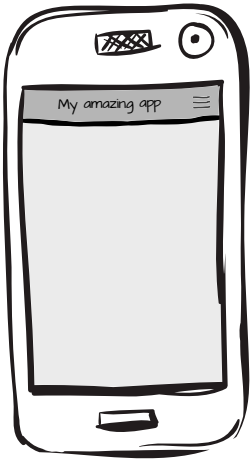

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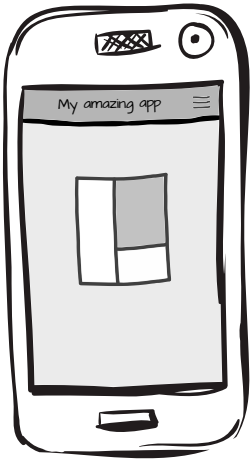

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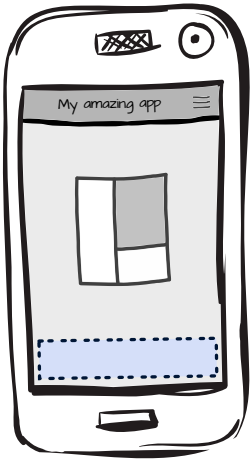

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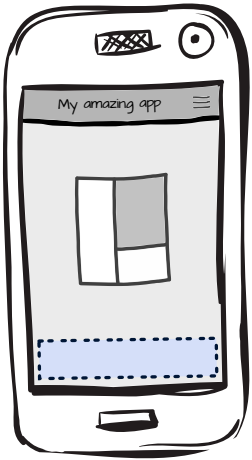

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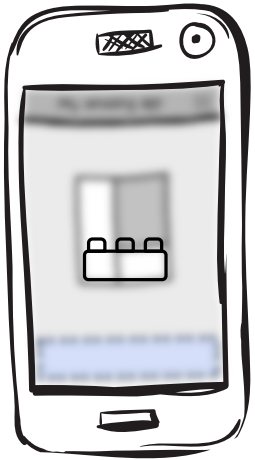

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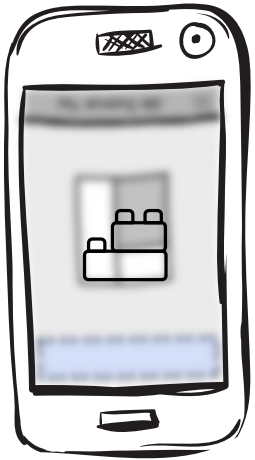

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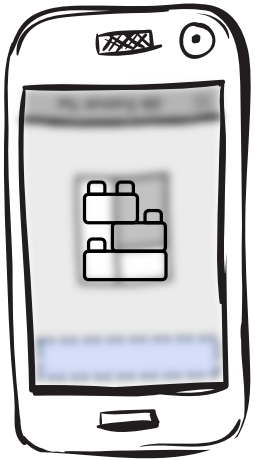

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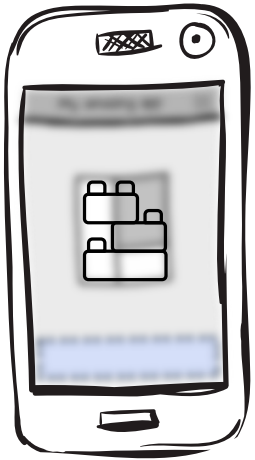

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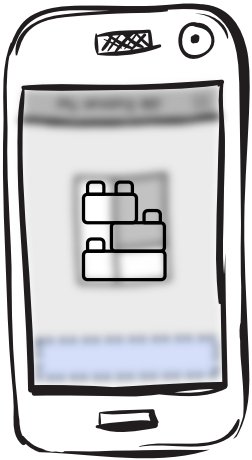


Android Ad Network statistics and market share

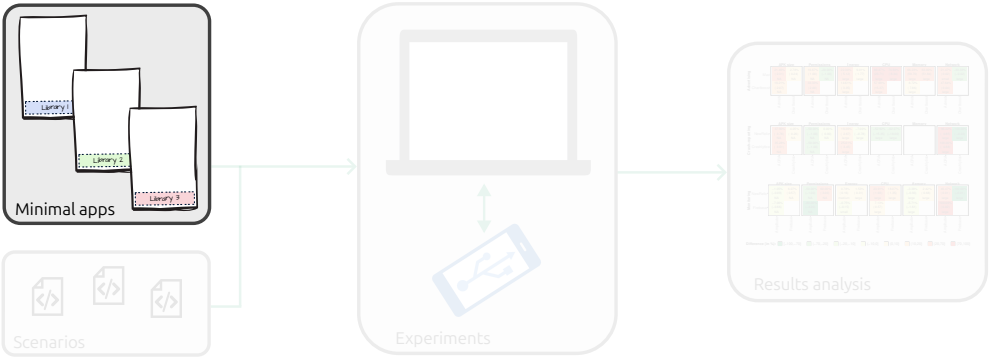
Use the market share of Android Ad networks below to find the best and most popular Ad networks.
More information about these statistics

Ad networks | Social libraries | Development tools

Sort by: Installs, Apps Market share in: Overall, New, Top 500

AdMob	AdMob	AdMob is one of the world's largest mobile advertising networks, offering solutions for discovery, ...	40.97% of apps 33.55% of installs
iab. TECH LAB	Open Measurement	The IAB Open Measurement SDK (OM SDK) offers common code and libraries for facilitating third-party...	9.55% of apps 18.56% of installs
facebook	Facebook Audience Network	Facebook Audience Network allows you to monetize your Android apps with Facebook ads.	12.38% of apps 16.86% of installs

Rubén Saborido, Rémy Raes, Rodrigo Morales, Romain Rouvoy, Foutse Khomh & Yann-Gaël Guéhéneuc. Simply the best – A systematic evaluation approach for third-party libraries based on mobile app quality attributes. *Empirical Software Engineering 31, 137 (2026).* **(10.1007/s10664-026-10872-w)**



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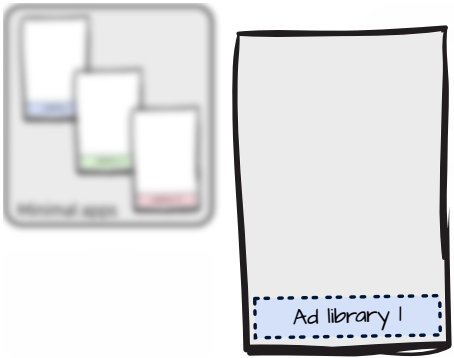

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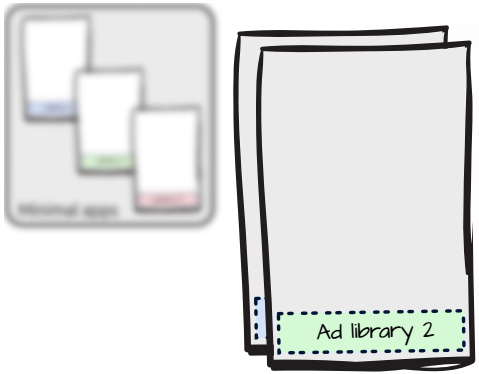

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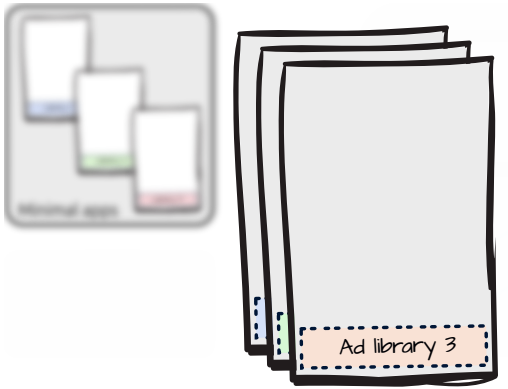

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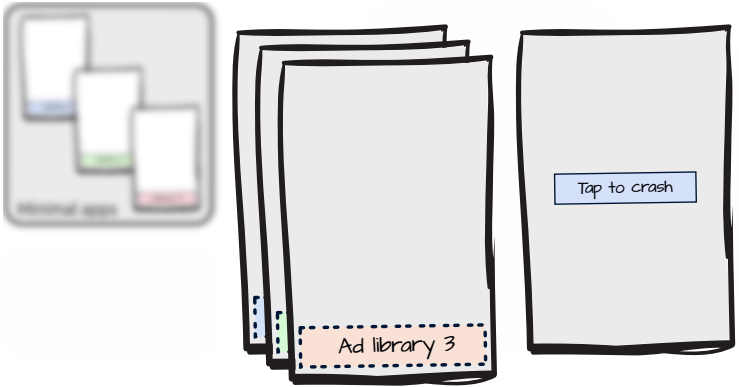

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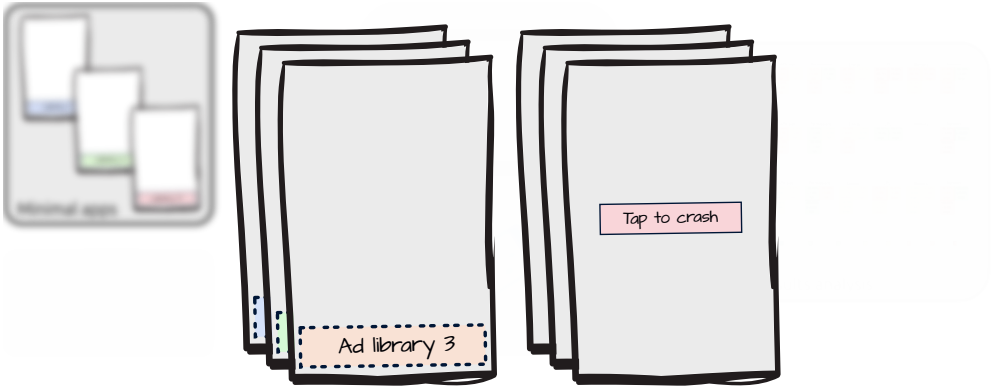

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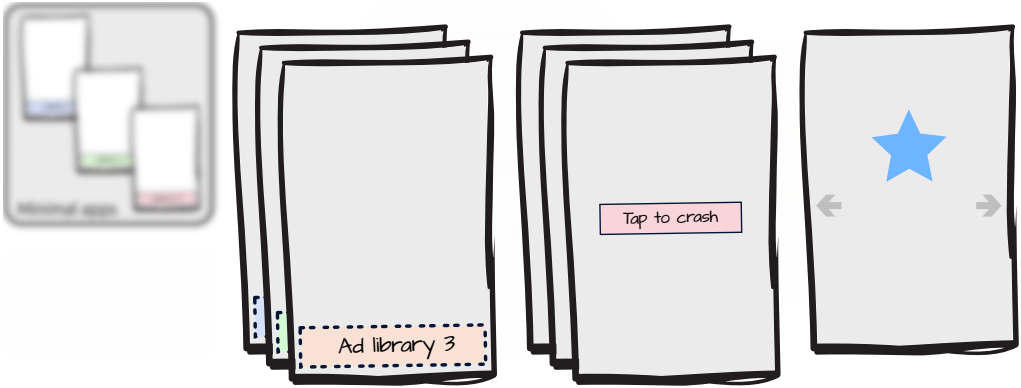

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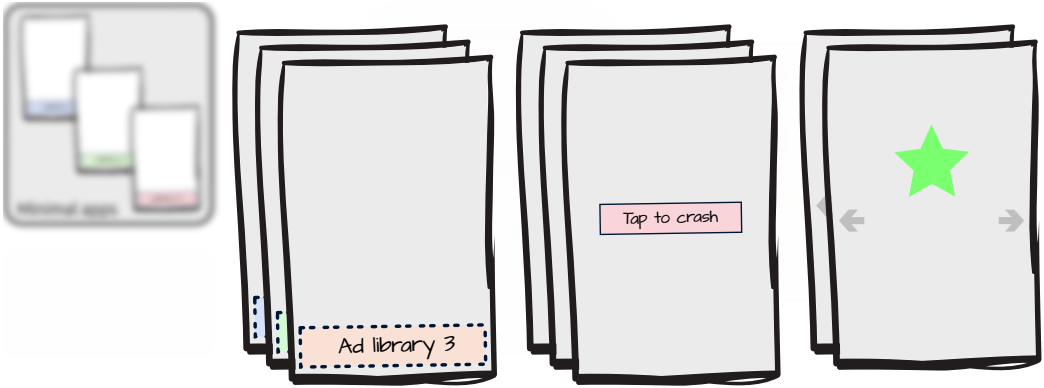

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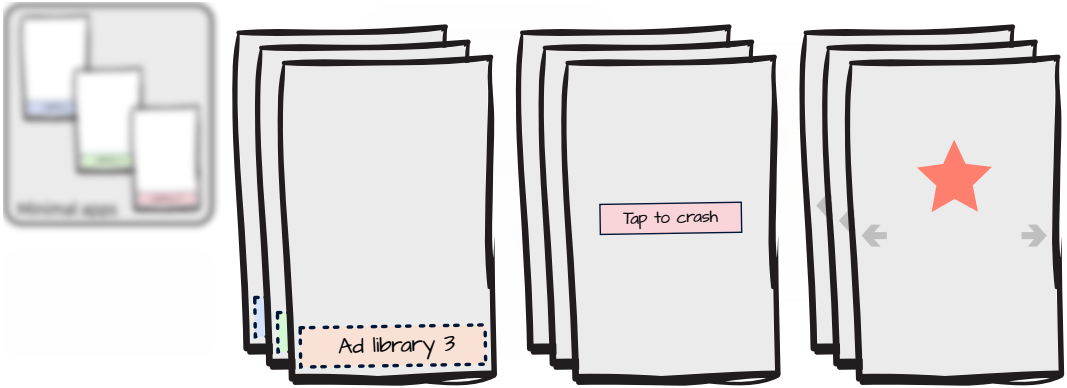

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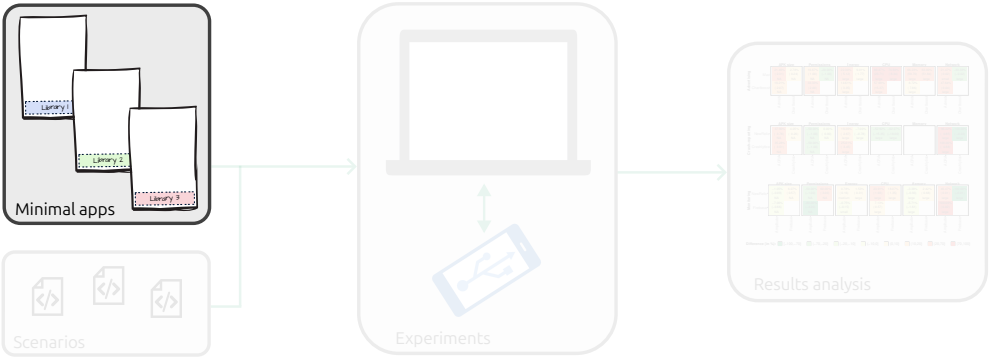

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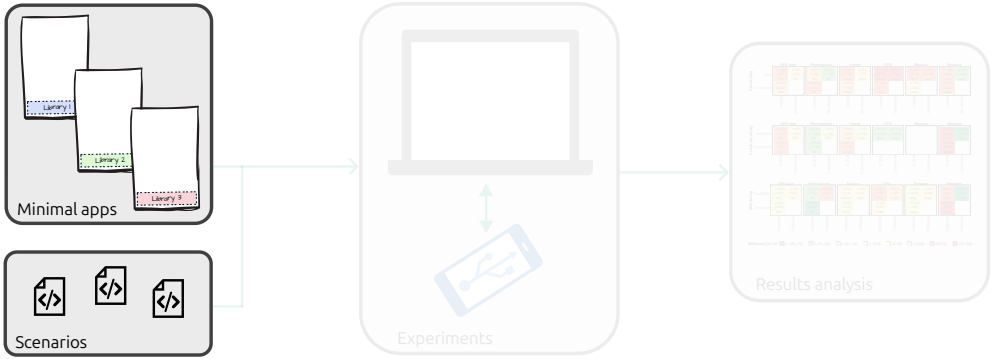

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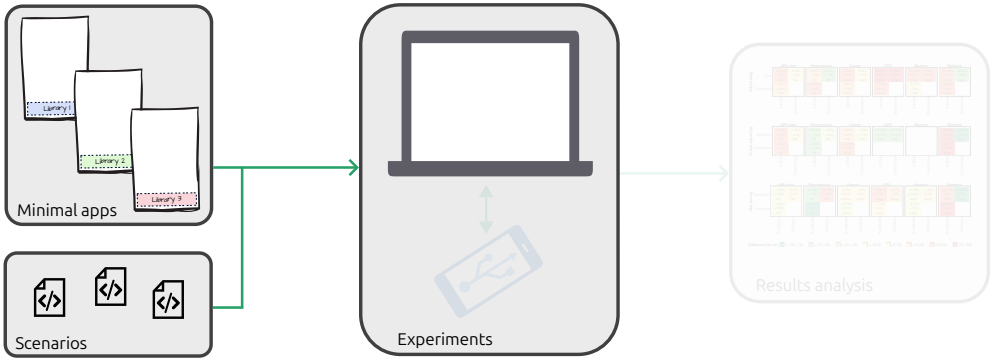

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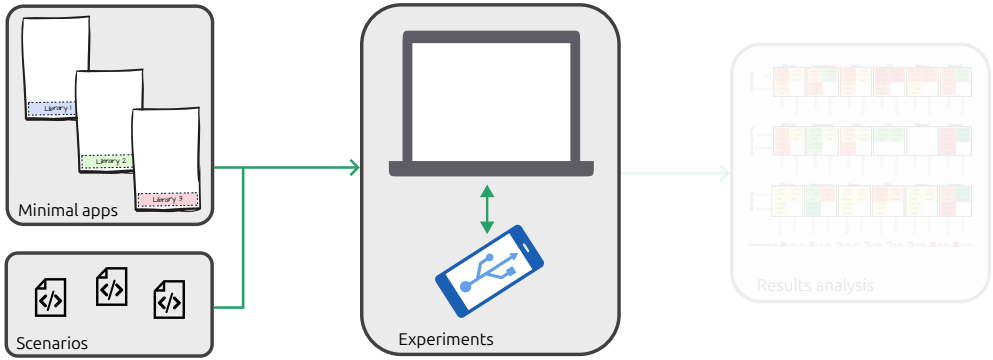

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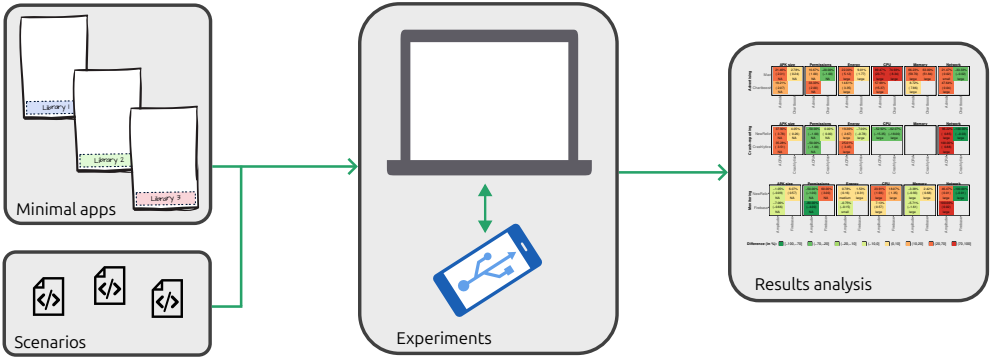

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Table: Popular Android TPLs for popular TPL categories.

Name	Version	Provider	Category
Admob	20.5.0	Google	Advertising
Chartboost	9.1.0	Chartboost	Advertising
Max	11.5.3	AppLovin	Advertising
ACRA	5.9.7	ACRA	Crash-reporting
Crashlytics	29.0.4	Google	Crash-reporting
NewRelic	6.4.1	New Relic	Crash-reporting
Amplitude	2.23.2	Amplitude	Monitoring
Firebase	29.0.4	Google	Monitoring
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- App size
- Energy
- Memory
- Permissions
- CPU
- Network

Figure: Android library energy test bench.

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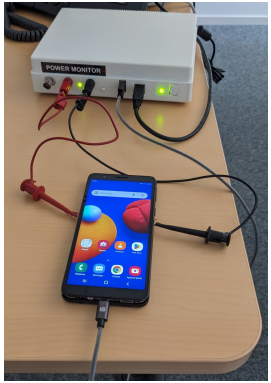
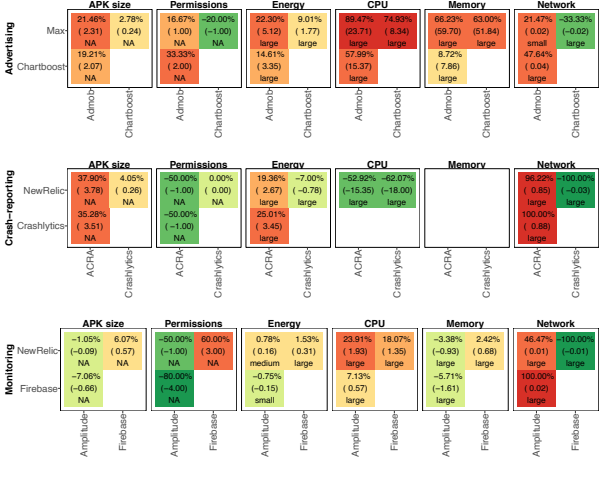


Figure: Android library energy test bench.

- Dashboard as output
- Global overview of libraries



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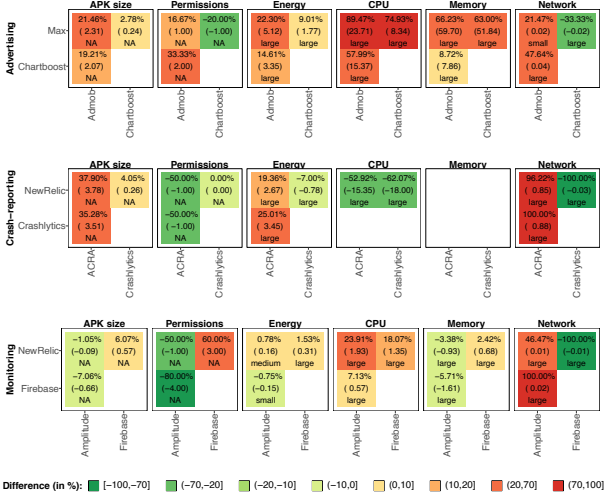
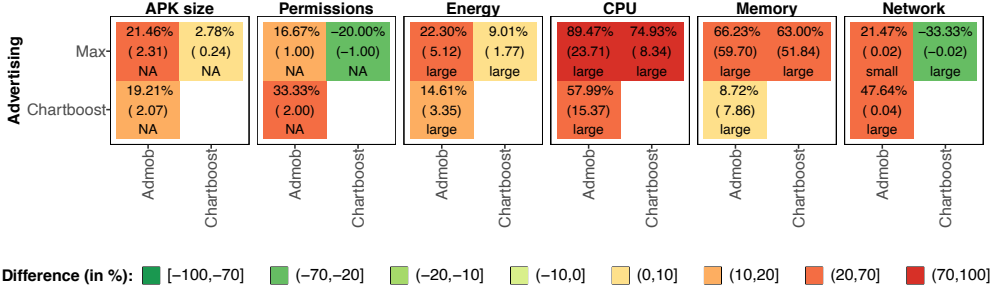
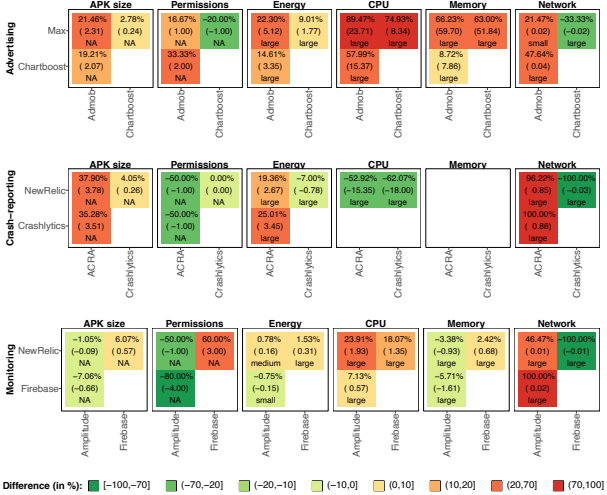



APK size
Permissions
Energy
CPU
Memory
Network
Advertising
Max
Chartboost
21.46% (2.31) NA
2.78% (0.24) NA
19.21% (2.07) NA
16.67% (1.00) NA
−20.00% (−1.00) NA
33.33% (2.00) NA
22.30% (5.12) large
9.01% (1.77) large
14.61% (3.35) large
89.47% (23.71) large
74.93% (8.34) large
57.99% (15.37) large
66.23% (59.70) large
63.00% (51.84) large
8.72% (7.86) large
21.47% (0.02) small
−33.33% (−0.02) large
47.64% (0.04) large
Admob
Chartboost
Difference (in %):
[−100,−70]
(−70,−20]
(−20,−10]
(−10,0]
(0,10]
(10,20]
(20,70]
(70,100]

- No clear winner... as expected!
- Multiple libraries, for multiple use-cases



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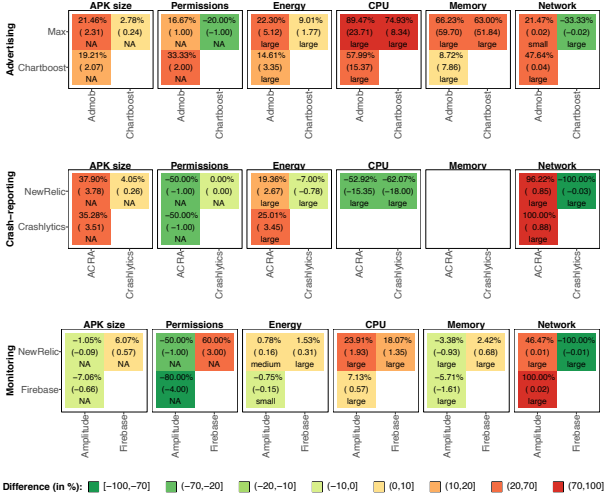
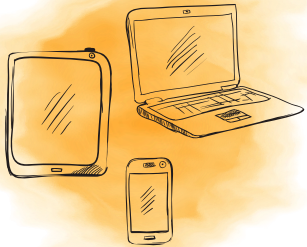


Storage
1. FLI
2. FLInD

Computing
3. INTACT



Terminals

Energy
6. Simply the Best

Communication
4. Survey
5. Venice

Storage

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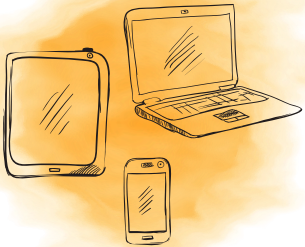
2. FLInD

Computing

3. INTACT



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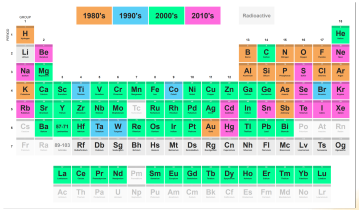

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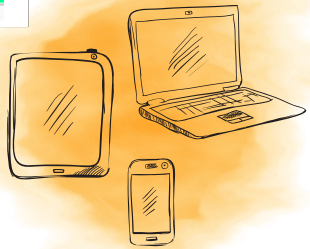

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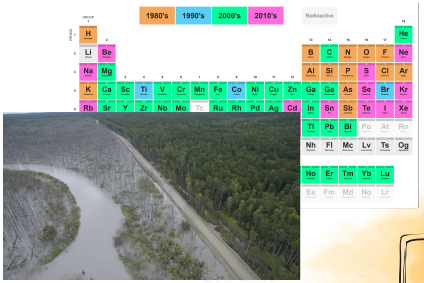

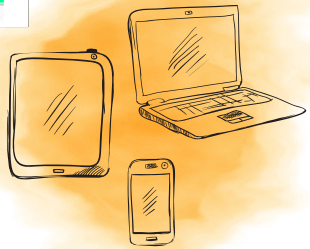

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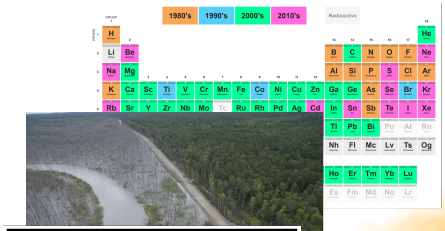

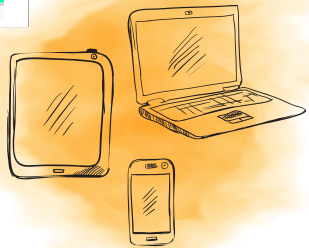

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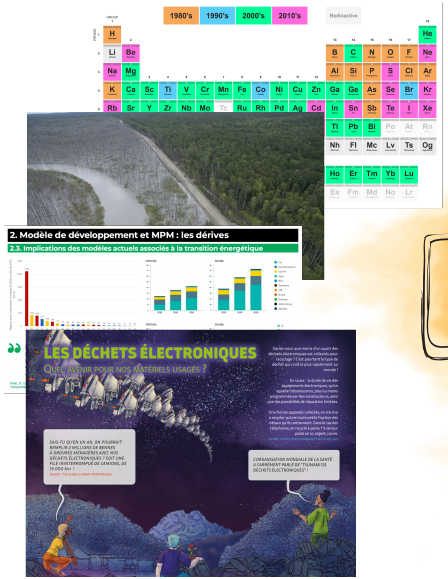

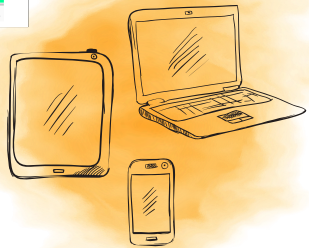

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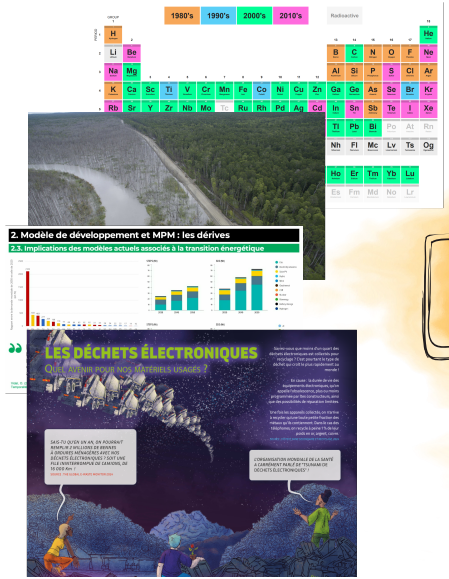

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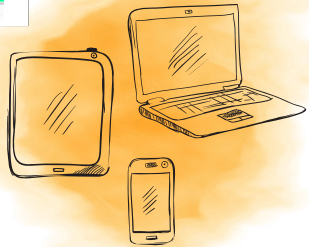

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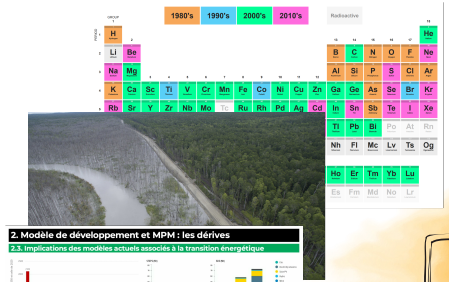

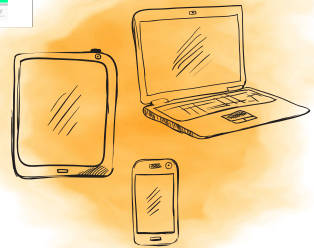

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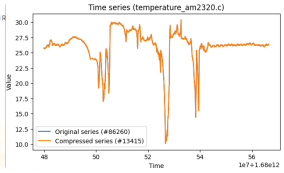

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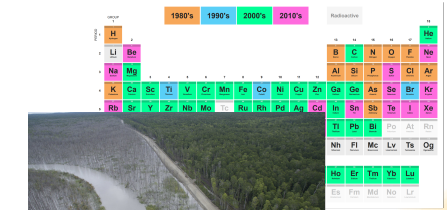

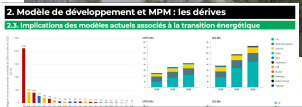

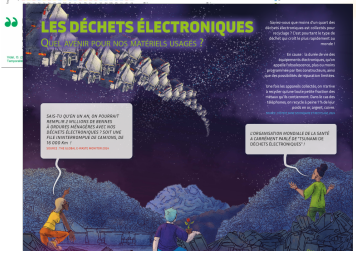

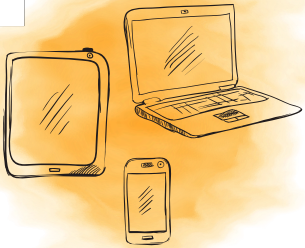

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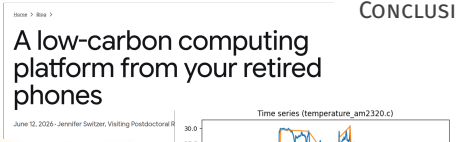

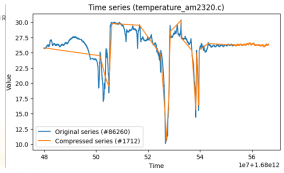

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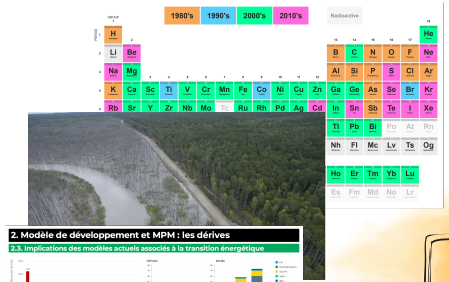

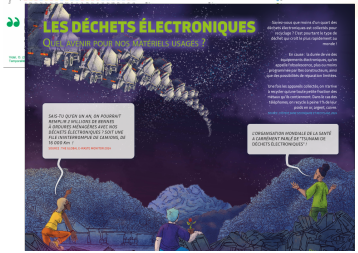

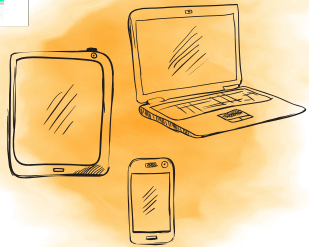

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A low-carbon computing platform from your retired phones

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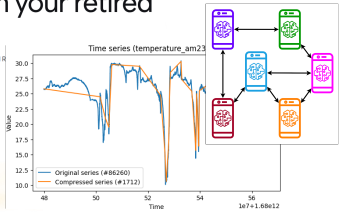

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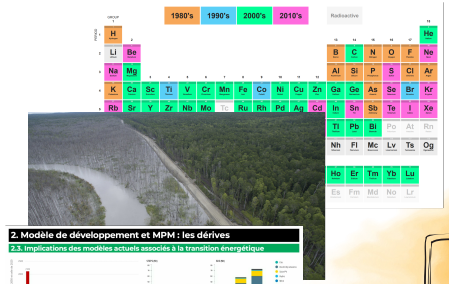

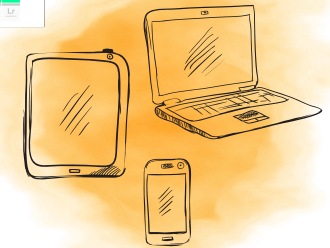

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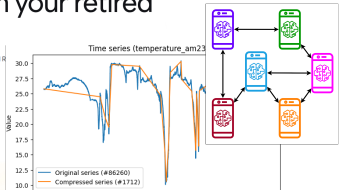

Local-First Software: You Own Your Data, in spite of the Cloud

Martin Kleppmann
Department of Computer Science and Technology
University of Cambridge
Cambridge, United Kingdom
martin.kleppmann@cl.cam.ac.uk

Adam Wiggins
Ink & Switch
Berlin, Germany
adam@inkandswitch.com

Peter van Hardenberg
Ink & Switch
San Francisco, CA, USA
pvh@inkandswitch.com

Mark McGranaghan
Ink & Switch
Seattle, WA, USA
mark@inkandswitch.com

Abstract

Cloud apps like Google Docs and Trello are popular because they enable real-time collaboration with colleagues, and they make it easy for us to access our work from all of our devices. However, by centralizing data storage on servers, cloud apps also take away ownership and agency from users. If a service shuts down, the software stops functioning, and data created with that software is lost.

In this article we propose *local-first software*, a set of principles for software that enables both collaboration and ownership for users. Local-first ideals include the ability to work offline and collaborate across multiple devices, while also improving the security, privacy, long-term preservation, and user control of data. We look at existing approaches to data storage and sharing, assess them against our ideals, and evaluate practical ways forward. We conclude that there is encouraging progress towards local-first software, but many technical challenges remain.

CCS Concepts • **Human-centered computing** → **Collaborative content creation.** *Ubiquitous and mobile computing systems and tools*; • **Computer systems organization** → *Peer-to-peer architectures*; • **Software and its engineering** → *Software collaboration*; *Organizing principles*

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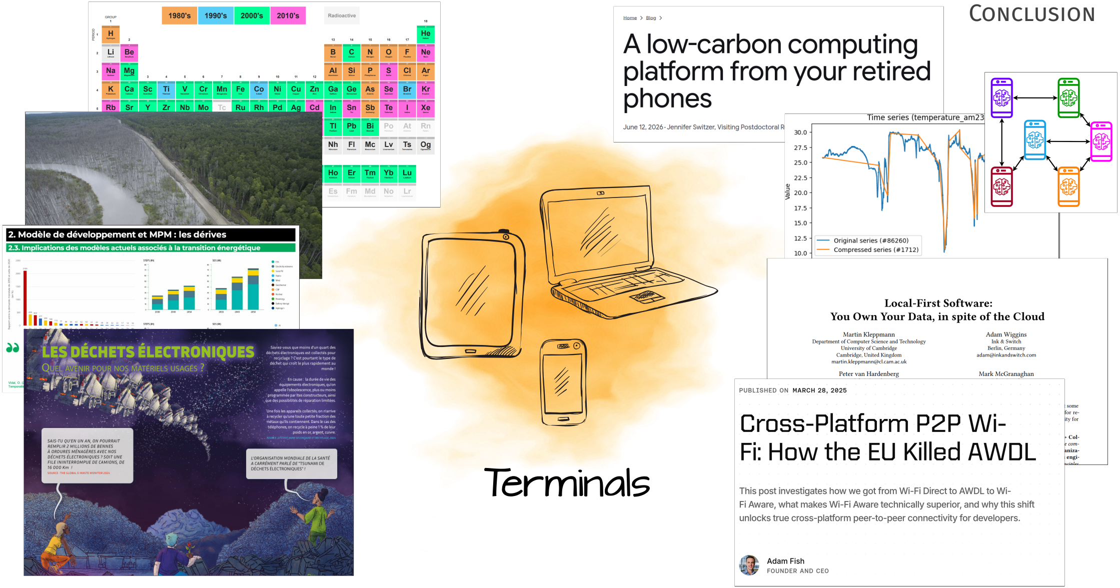
Conclusion



1980's
1990's
2000's
2010's
Radioactive
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2.3. Implications des modèles actuels associés à la transition énergétique
LES DÉCHETS ÉLECTRONIQUES
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A low-carbon computing platform from your retired phones
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Time series (temperature_am23
Original series (#86260)
Compressed series (#1712)
Value
Local-First Software:
You Own Your Data, in spite of the Cloud
Martin Kleppmann
Department of Computer Science and Technology
University of Cambridge
Cambridge, United Kingdom
martin.kleppmann@cl.cam.ac.uk
Adam Wiggins
Ink & Switch
Berlin, Germany
adam@inkandswitch.com
Peter van Hardenberg
Mark McGranaghan
PUBLISHED ON MARCH 28, 2025
Cross-Platform P2P Wi-Fi: How the EU Killed AWDL
This post investigates how we got from Wi-Fi Direct to AWDL to Wi-Fi Aware, what makes Wi-Fi Aware technically superior, and why this shift unlocks true cross-platform peer-to-peer connectivity for developers.
Adam Fish
FOUNDER AND CEO
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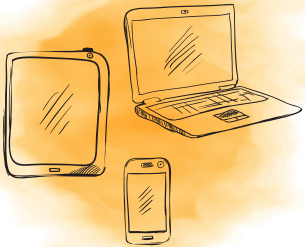
Storage

1. FLI

2. FLInD

Computing

3. INTACT



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Energy

6. Simply the Best

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Thanks for listening!

Appendix table of contents

ABOUT THE *EPSILON* VALUE

- The quality of the models directly depends on the selected ϵ

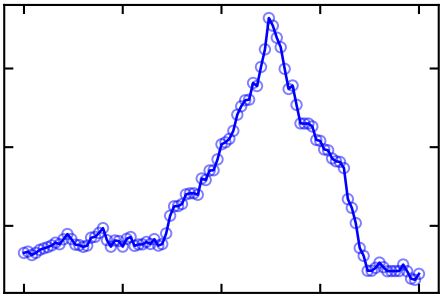


Figure: Overfitting case.

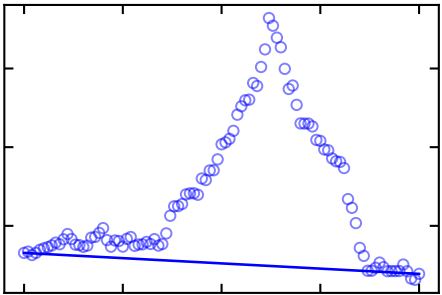
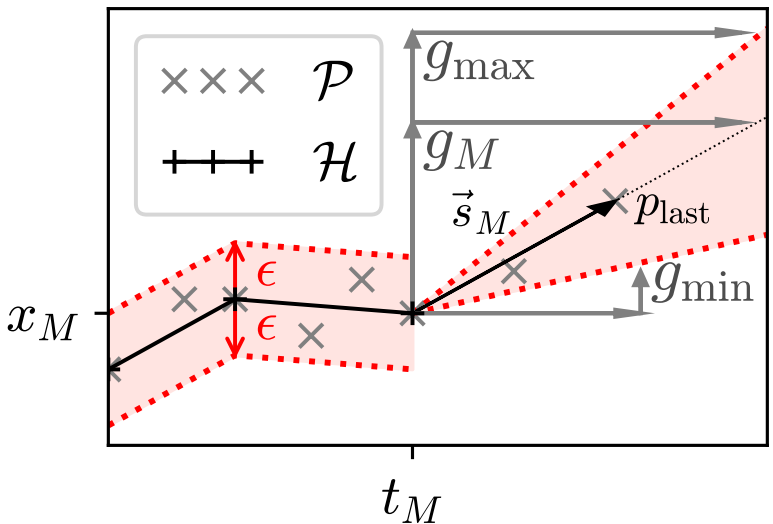


Figure: Underfitting case.


$\mathcal{P}$
$\mathcal{H}$
$g_{\max}$
g_M
$\vec{s}_M$
p_{last}
$g_{\min}$
ϵ
ϵ
x_M
t_M

Memory benchmark: Cabspotting Vs Privamov

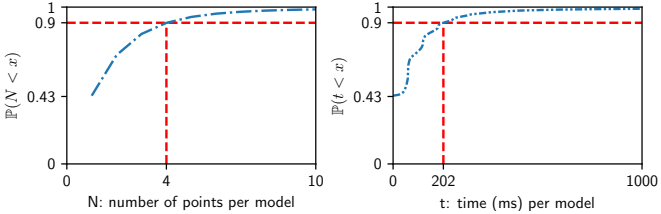


Figure: Cabspotting compression

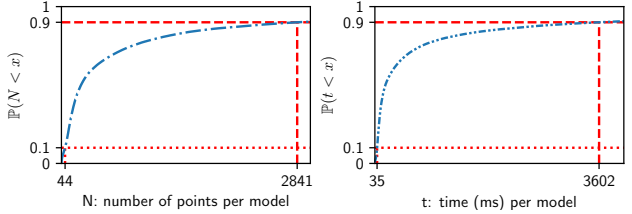


Figure: Privamov compression

Additional results

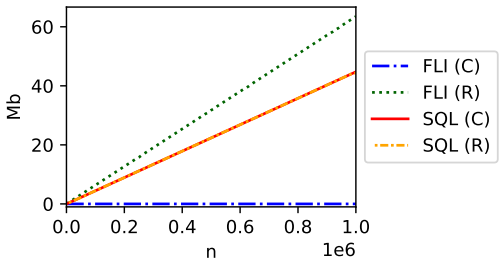


Figure: Inserting 1*M* samples, random (R) or constant (C), in SQLite and FLI.

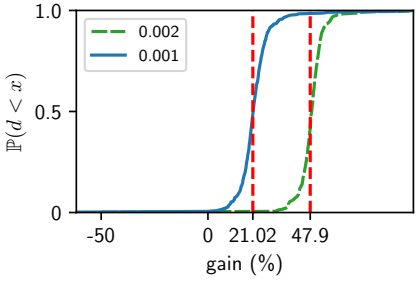


Figure: Memory gain distribution when storing Cabspotting with FLI.

Incomplete comparison?

- **Storing Privamov:**
  - *SQLite:* from 7.2GB to 5 (30.56% gain)
  - *SWAB:* comparable to FLI
  - *Greycat:* too slow

- **Input speed:**
  - *SWAB* is slower because of the bottom-up segment building
  - *Greycat* even slower, we could only insert 10*k* samples instead of 1*M*
- **Output speed:**
  - FLI is better due to its dichotomy search of the correct linear segment
  - Comparison with Greycat would be unfair (due to the above criterion)

Data utility with location data

Size results

- $\epsilon = 10^{-3}$
- From 7.2 GB to 25 MB

Data utility

- Latitude
  - Tolerated error: 10^{-3} *deg* $\approx 111\,m$
  - Median error: 5.33×10^{-5}
  - RMSE: 3.72×10^{-4}
- Longitude
  - Tolerated error: 10^{-3} *deg* $\approx 88\,m$
  - Median error: 2.81×10^{-5}
  - RMSE: 3.44×10^{-4}

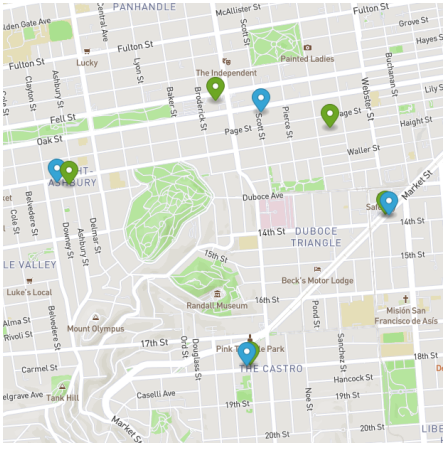


Figure: Points of Interest computed using raw data and FLI-modeled data.

Architectural scheme

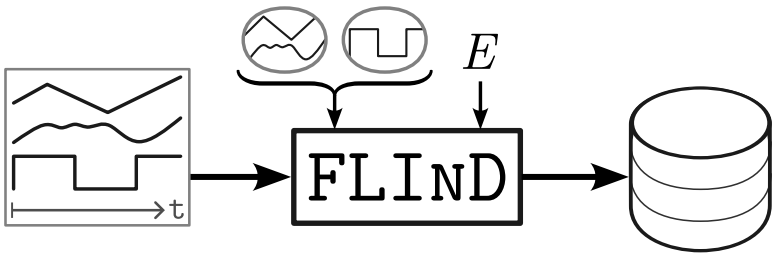
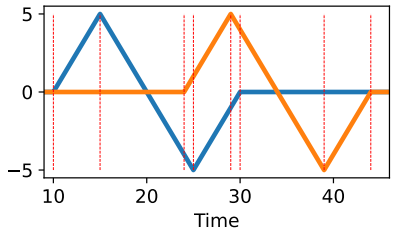
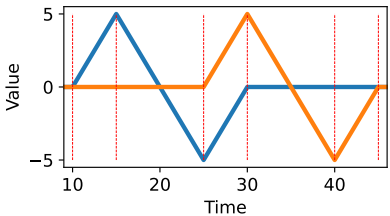


Figure: To compress a multivariate time series, FLInD requires two main parameters: the mapping of the input dimensions into different compression groups *G*, and the array of per-dimension error bound *E*.

Best compression case



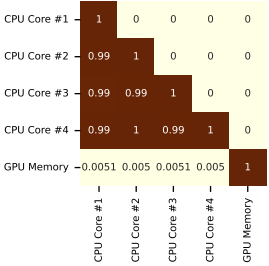
(a) Suboptimal situation for FLInD: the two series change momentum in asynchrony.

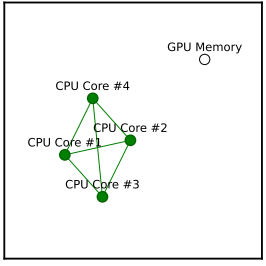


(b) Optimal situation for FLInD: both series change tendencies at the same times.

Figure: Toy example showcasing the influence of a series' alignment on FLInD's compression. Vertical, red-dotted lines mark the breakpoints where an interpolation will be recomputed. FLInDworks best when breakpoints occur at the same time across dimensions.

Clustering series through timestamps





One model for several series	One model per series	Size (floats)
CPU#1, CPU#2, CPU#3, CPU#4	GPU Memory	385,356
CPU#1, CPU#2, CPU#3	CPU#4, GPU Memory	462,164
CPU#1, CPU#2, CPU#4	CPU#3, GPU Memory	462,218
CPU#1, CPU#3, CPU#4	CPU#2, GPU Memory	462,222
CPU#2, CPU#3, CPU#4	CPU#1, GPU Memory	462,306
CPU#1, CPU#2, CPU#3, CPU#4, GPU Memory	∅	462,408
CPU#1, CPU#2	CPU#3, CPU#4, GPU Memory	539,024
CPU#1, CPU#3	CPU#2, CPU#4, GPU Memory	539,030
CPU#1, CPU#4	CPU#2, CPU#3, GPU Memory	539,083
CPU#2, CPU#3	CPU#1, CPU#4, GPU Memory	539,118
CPU#2, CPU#4	CPU#1, CPU#3, GPU Memory	539,168
CPU#3, CPU#4	CPU#1, CPU#2, GPU Memory	539,174
CPU#1, CPU#2, CPU#3, GPU Memory	CPU#4	539,212
CPU#1, CPU#2, CPU#4, GPU Memory	CPU#3	539,270
CPU#1, CPU#3, CPU#4, GPU Memory	CPU#2	539,272
CPU#2, CPU#3, CPU#4, GPU Memory	CPU#1	539,358
CPU#1	CPU#2, CPU#3, CPU#4, GPU Memory	615,796
CPU#2	CPU#1, CPU#3, CPU#4, GPU Memory	615,796
CPU#3	CPU#1, CPU#2, CPU#4, GPU Memory	615,796
GPU Memory	CPU#1, CPU#2, CPU#3, CPU#4	615,796
CPU#4	CPU#1, CPU#2, CPU#3, GPU Memory	615,798
∅	CPU#1, CPU#2, CPU#3, CPU#4, GPU Memory	615,798
CPU#1, CPU#2, GPU Memory	CPU#3, CPU#4	616,070
CPU#1, CPU#3, GPU Memory	CPU#2, CPU#4	616,074
CPU#1, CPU#4, GPU Memory	CPU#2, CPU#3	616,132
CPU#2, CPU#3, GPU Memory	CPU#1, CPU#4	616,166
CPU#2, CPU#4, GPU Memory	CPU#1, CPU#3	616,220
CPU#3, CPU#4, GPU Memory	CPU#1, CPU#2	616,224
CPU#4, GPU Memory	CPU#1, CPU#2, CPU#3	692,728
CPU#3, GPU Memory	CPU#1, CPU#2, CPU#4	692,744
CPU#2, GPU Memory	CPU#1, CPU#3, CPU#4	692,750
CPU#1, GPU Memory	CPU#2, CPU#3, CPU#4	692,788

Impact of splitting series between instances

Table: Performances metrics over compressing the Microservices Traces dataset using an increasingly smaller count of dimensions per instance. The lower the dimensions count, the better the error is acknowledged, leading to better total size, but also to increased read/write times due to the dataset being split between many FLInD instances.

Name	Size (MiB) ↓	Reads/sec ↑	Writes/sec ↑	Error P95 ↓
FLInD	143.27	380	257	0.0
100 series per instance	72.63	260	177	0.030
50 series per instance	59.76	181	99	0.038
20 series per instance	44.37	115	48	0.049
10 series per instance	35.05	95	29	0.057
5 series per instance	27.77	59	17	0.066
2 series per instance	21.27	29	7	0.078
1 series per instance (FLI)	18.44	17	4	0.088

Intuition (1/2)

Figure: Data days old

Figure: Data months old

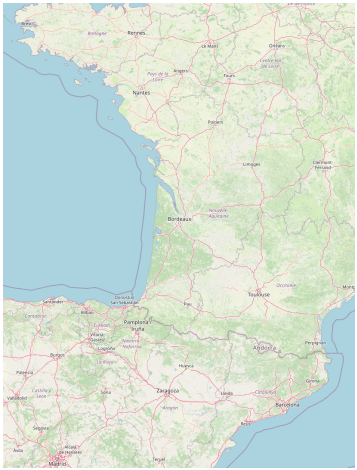
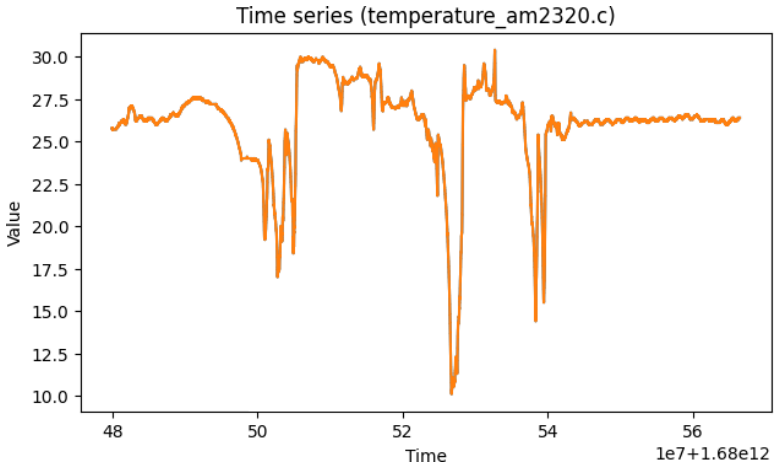
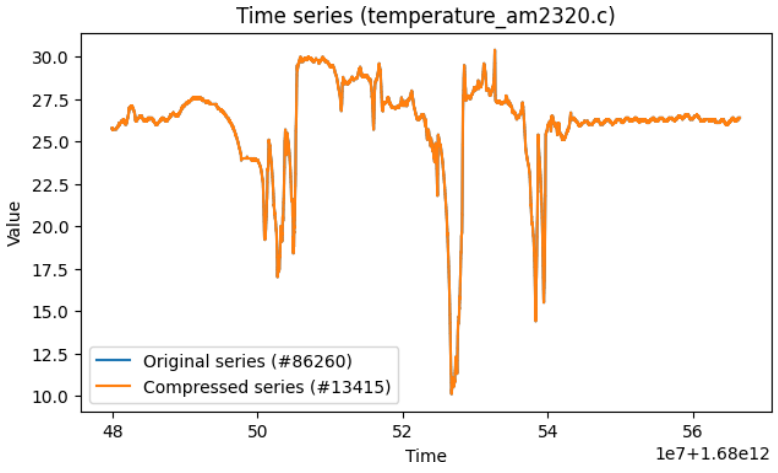


Figure: Data years old

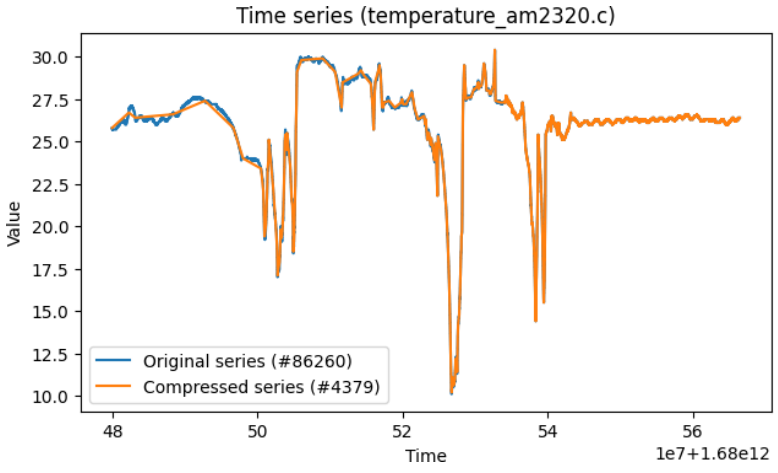
Intuition (2/2)



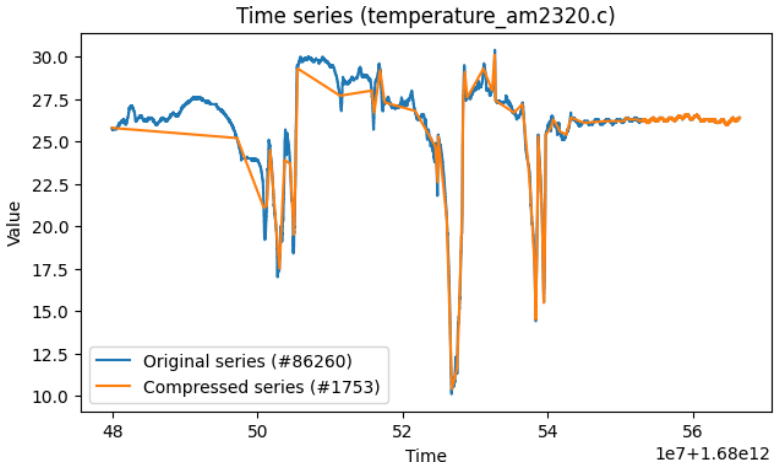
Intuition (2/2)



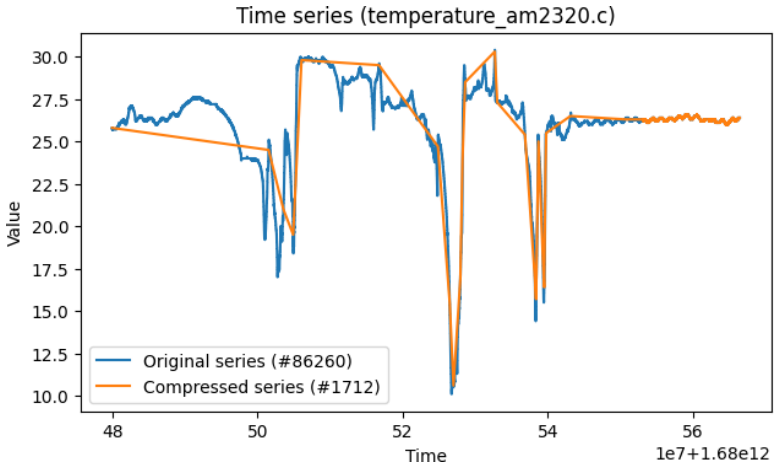
Intuition (2/2)



Intuition (2/2)



Intuition (2/2)



Location datasets

- Cabspotting
  - 536 taxis
  - San Francisco, CA, USA
  - 1 month
  - 11M GPS records
  - 388 MB
- Privamov
  - 100 users
  - Lyon, France
  - 15 months
  - 156M GPS records
  - 7.2 GB

Metrics datasets

Dataset	Hardware performance profile	Electricity load	Solar power data	Microservices traces
Series count	66	370	405	13, 058
Samples count	77, 000	140, 257	105, 120	1, 440
Frequency	1 sec	15 min	5 min	30 sec
Initial size	39.40 MiB	397.00 MiB	325.61 MiB	143.47 MiB

Execution time results

Table: Execution time for PrivaMov `user 1` on different mobile platforms. Previous deployments of these algorithms were made on desktop computers. FLI now enables their instantiation on ubiquitous devices, with reasonable processing times.

Task	Moto Z	Fair Phone 3	Google Pixel 7 Pro	iPhone 12	iPhone 14+
Promesse	1.5s	1.3s	0.4s	0.2s	0.2s
POI-Attack	114.4s	109.2s	30s	18.8s	19.4s

Table: Impact of FLI and D&S on the number of inferred POIs from `user 0` trace in Cabspotting. Thanks to FLI and D&S, Promesse succeeds to protect user privacy at the edge.

	without Promesse		with Promesse	
Algorithm	**Raw POIs**	**FLI**	**Raw POIs**	**FLI**
POI-attack	30	31	0	0
D&S	30	30	0	0
POI-attack ∩ D&S	21	20	-	-

Distributed Machine Learning in Ubiquitous Environments using Location-dependent Models

- How to store unbounded data streams on constrained mobile devices?
- How to exchange relevant model samples among nearby devices?
- How to program DML algorithms for the masses?