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Taming the Inconsistency of Wi-Fi Fingerprints for Device-Free Passive Indoor Localization

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The Background

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Why Device-Free & Passive?

- People are not always **carrying devices**.

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Why Device-Free & Passive?

- Disadvantages of **dedicated infrastructure**
  - Installation cost
  - Scalability issue
  - Line-of-sight limitation
  - Range limitation

Motion Sensors

Cameras

RFID
Tag & Reader

BLE Proximity Beacons
(e.g., Estimote)

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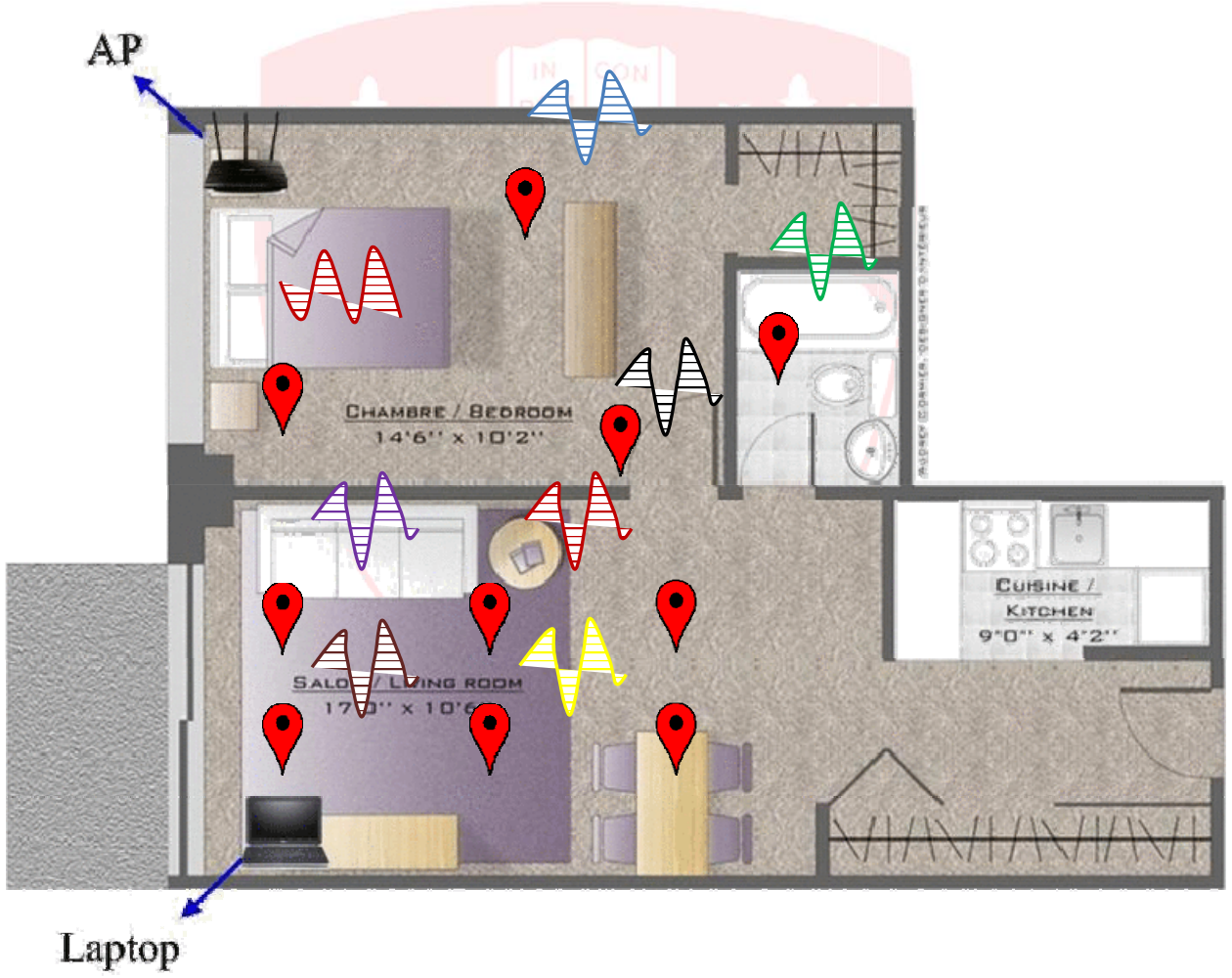
Wi-Fi Based DfP Localization

- **Fingerprinting**: Associate signal features such as Channel State Information (CSI) with users' locations.



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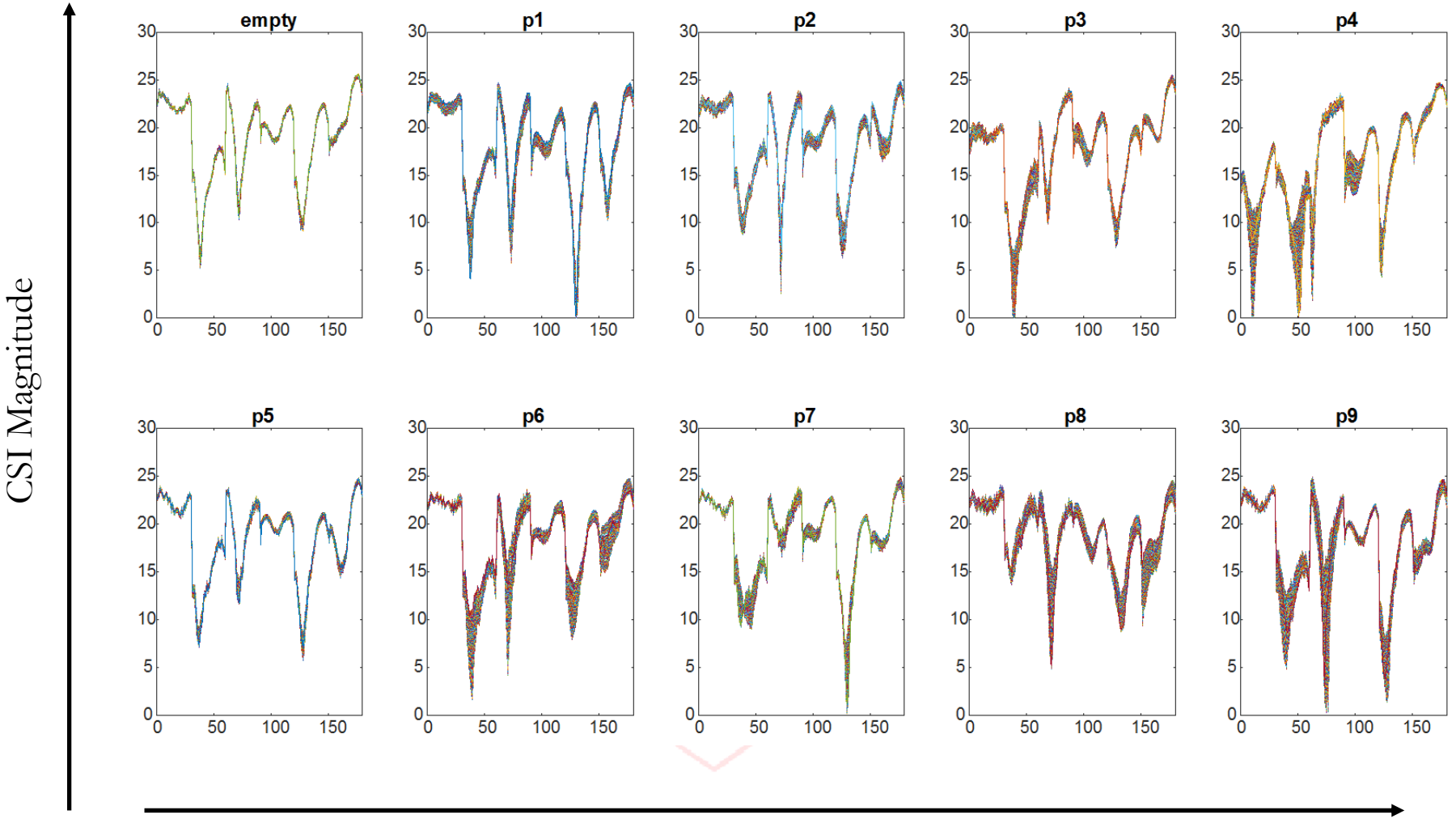
Example CSI Fingerprints



A Major Challenge

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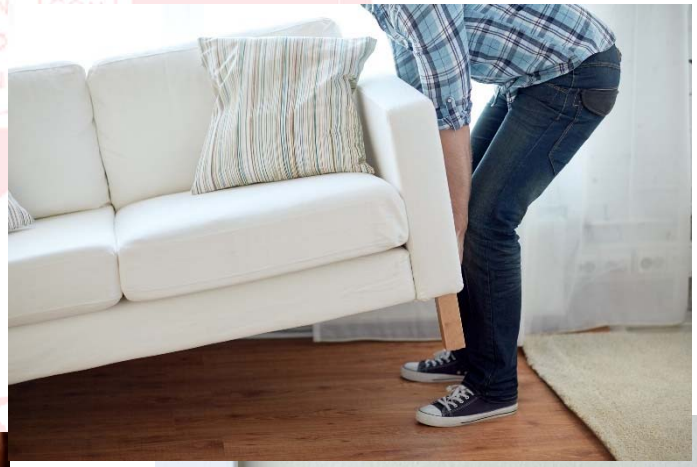
A Major Challenge

- The changes in the indoor environment make the fingerprint **inconsistent** with the current situation.



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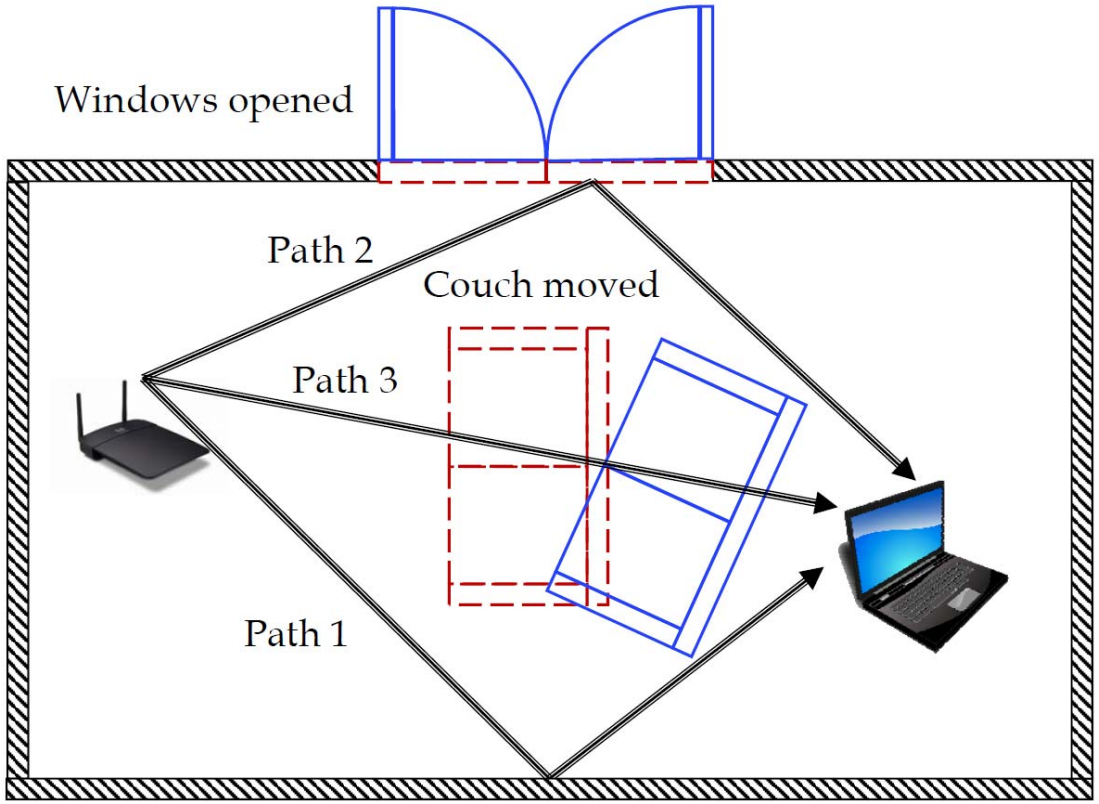
A Major Challenge

- The CSI will be "**contaminated**" by environment changes.
  - The recorded fingerprints no longer represent the **changed** environment.



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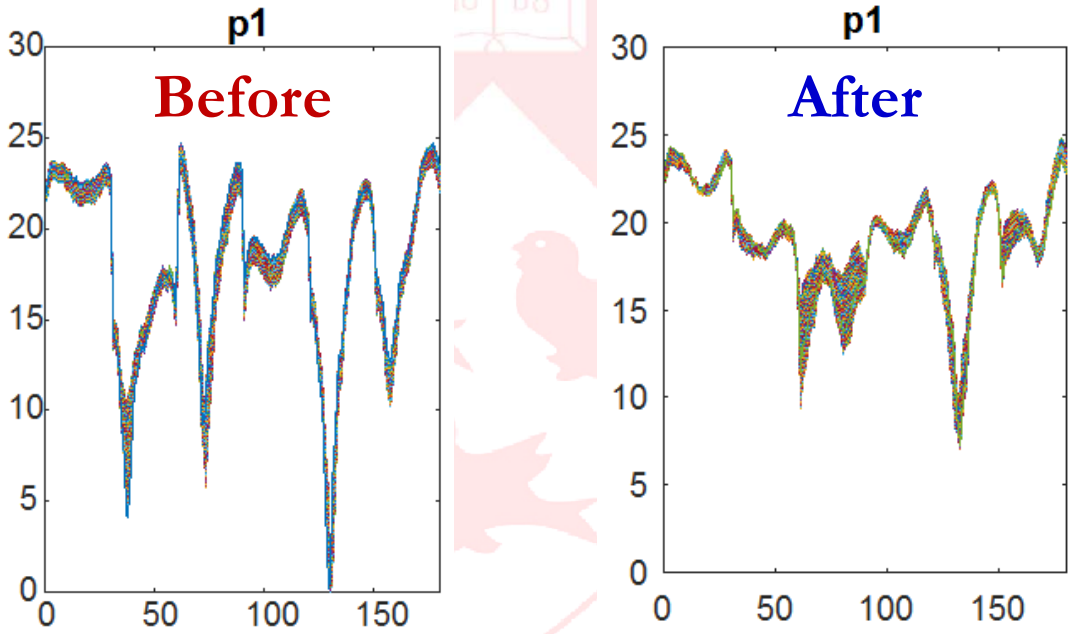

Record the fingerprints again?

Our Solution to Recycle

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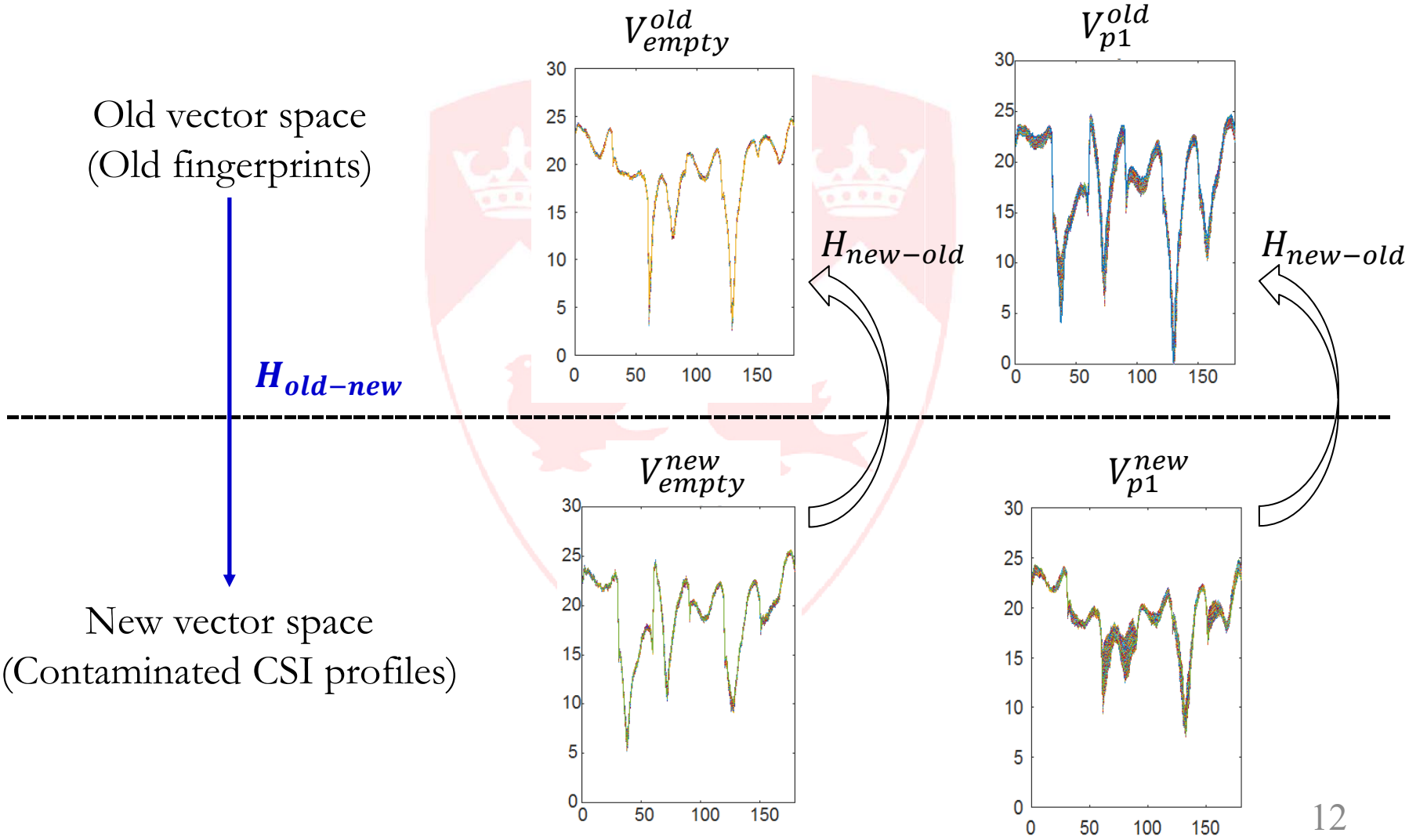
Reuse the Fingerprints

- **Reconstruct** old fingerprint space from the changed one.



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The Mapping Functions

- Map CSI from one space to another

$$
\begin{aligned}
V_{p1}^{old} &= H_{p1} \times V_{p1}^{new} + n_{p1}, \\
V_{p2}^{old} &= H_{p2} \times V_{p2}^{new} + n_{p2}, \\
&\vdots \\
V_{pN}^{old} &= H_{pN} \times V_{pN}^{new} + n_{p3}.
\end{aligned}
$$

Fingerprints
(associated with locations)

Contaminated CSI profiles
(locations unknown)

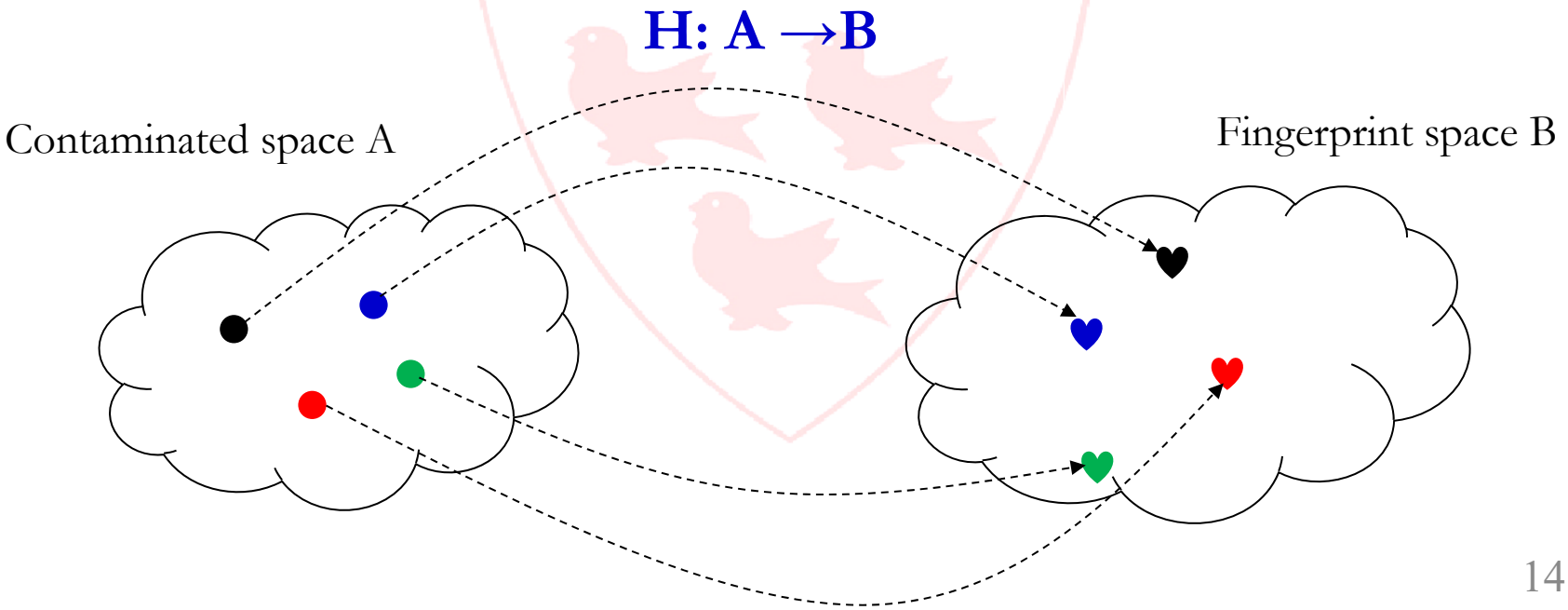
Unknown mapping
How to determine?

The Mapping Functions

- The mapping functions are identical for different locations.

$$H_{p1} = H_{p2} = \cdots = H_{pN} = H.$$

  - Space-to-space mapping



The Mapping Functions

- An identical H

$$
\begin{aligned}
V_{p1}^{old} &= H \times V_{p1}^{new} + n_{p1}, \\
V_{p2}^{old} &= H \times V_{p2}^{new} + n_{p2}, \\
&\vdots \\
V_{pN}^{old} &= H \times V_{pN}^{new} + n_{p3}.
\end{aligned}
$$

The Mapping Function

- An identical H
  - How to autonomously associate one V^{new} to a location without human effort?

$$V_?^{old} = \underbrace{H \times V_?^{new}}_{\text{Both unknown!}} + n_?.$$

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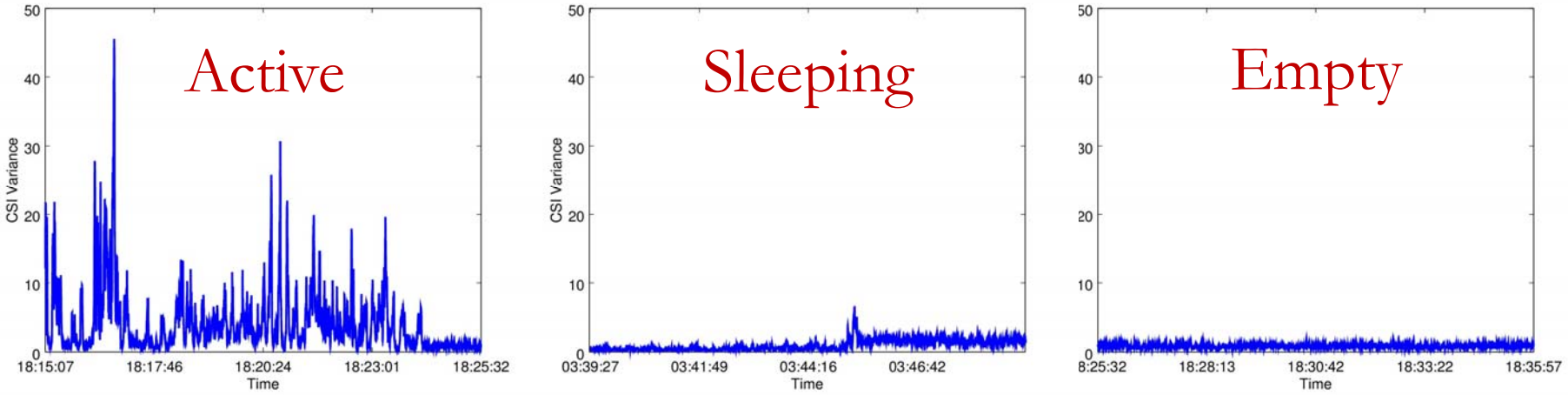
Autonomous Fingerprinting

- The status of an **empty area** can be detected autonomously using variance of CSI magnitude.
  - Detecting Empty ⇔ Associate V^{new} to P_{empty}



$$V_{empty}^{old} = H \times V_{empty}^{new} + n \quad .$$

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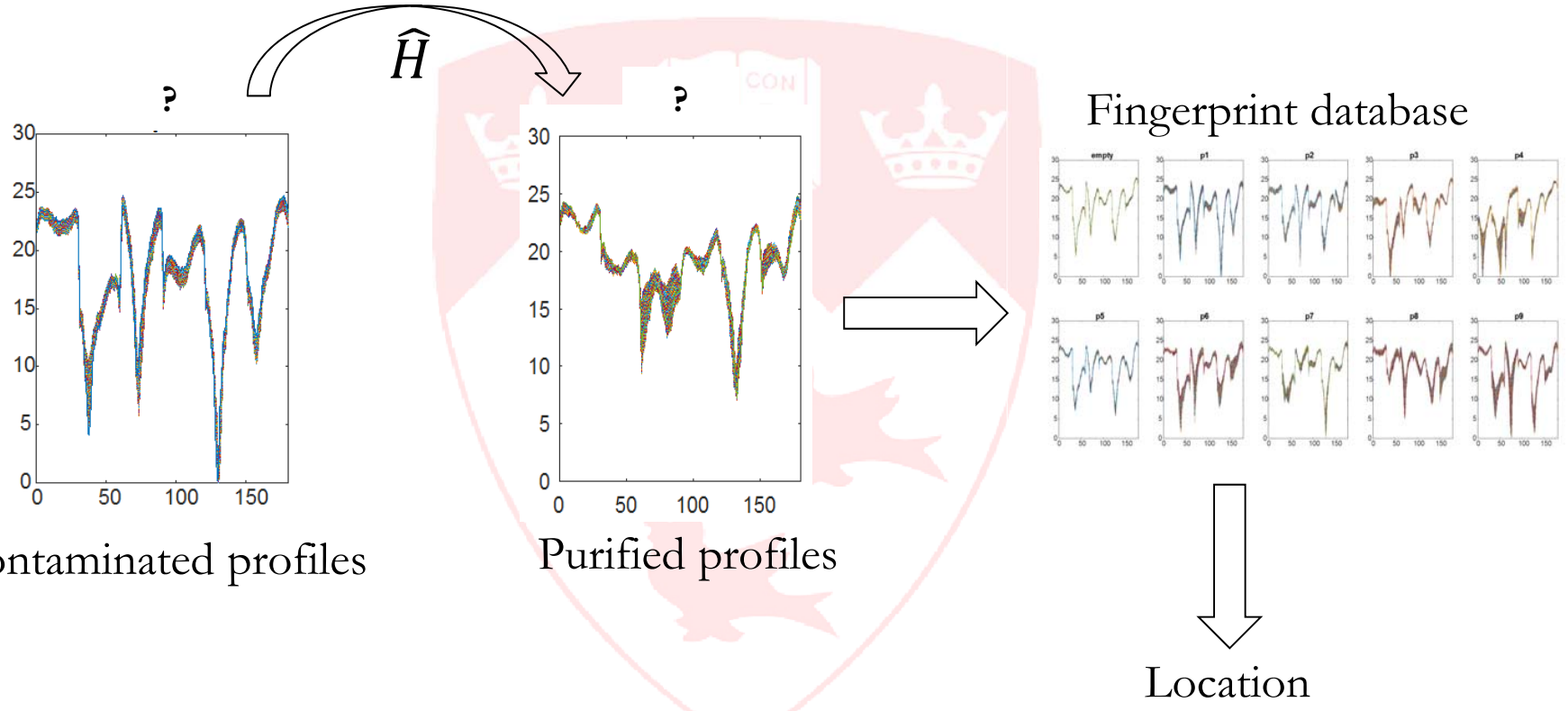
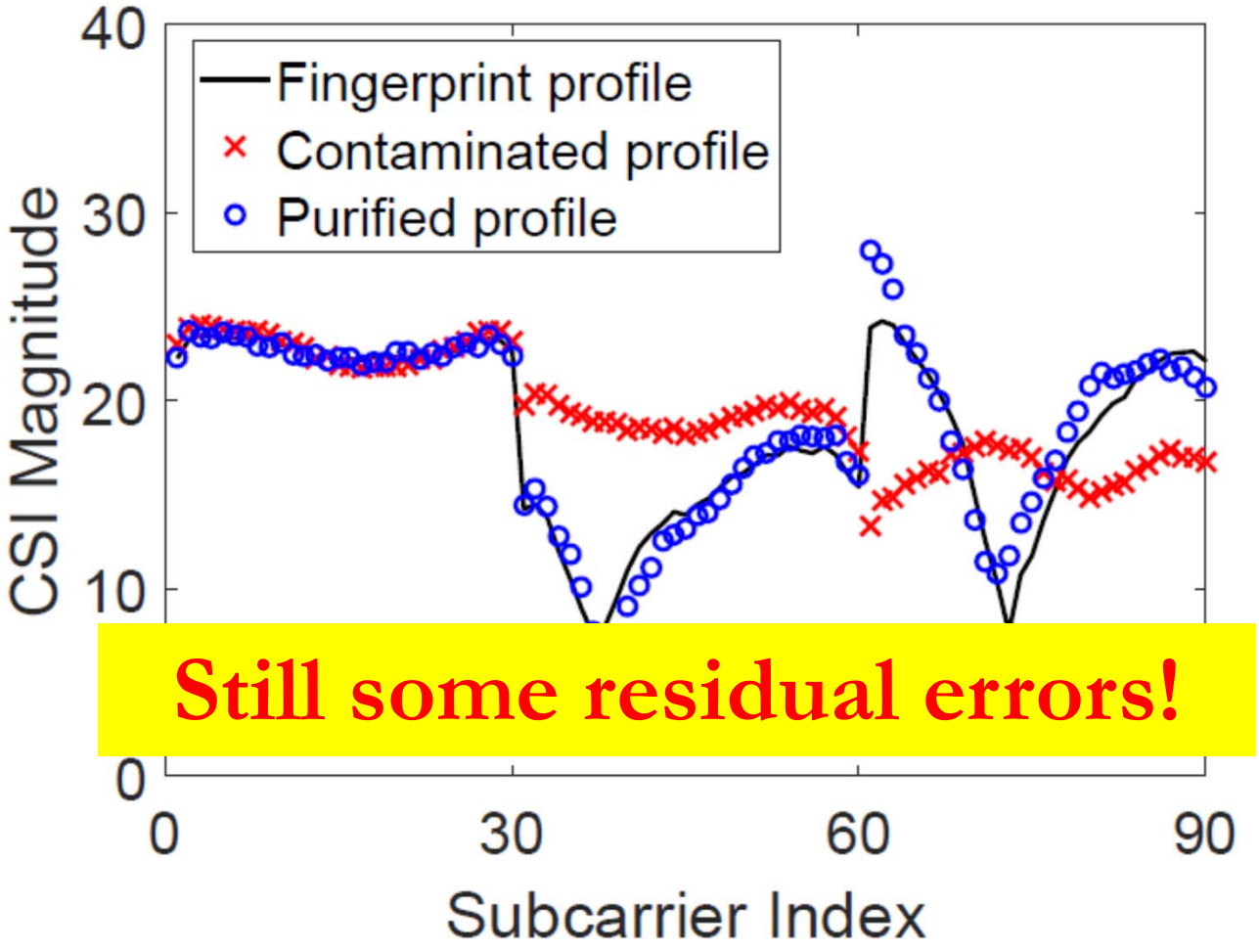
Contaminant Removal

- $\hat{H} = \hat{H}_{Empty}$



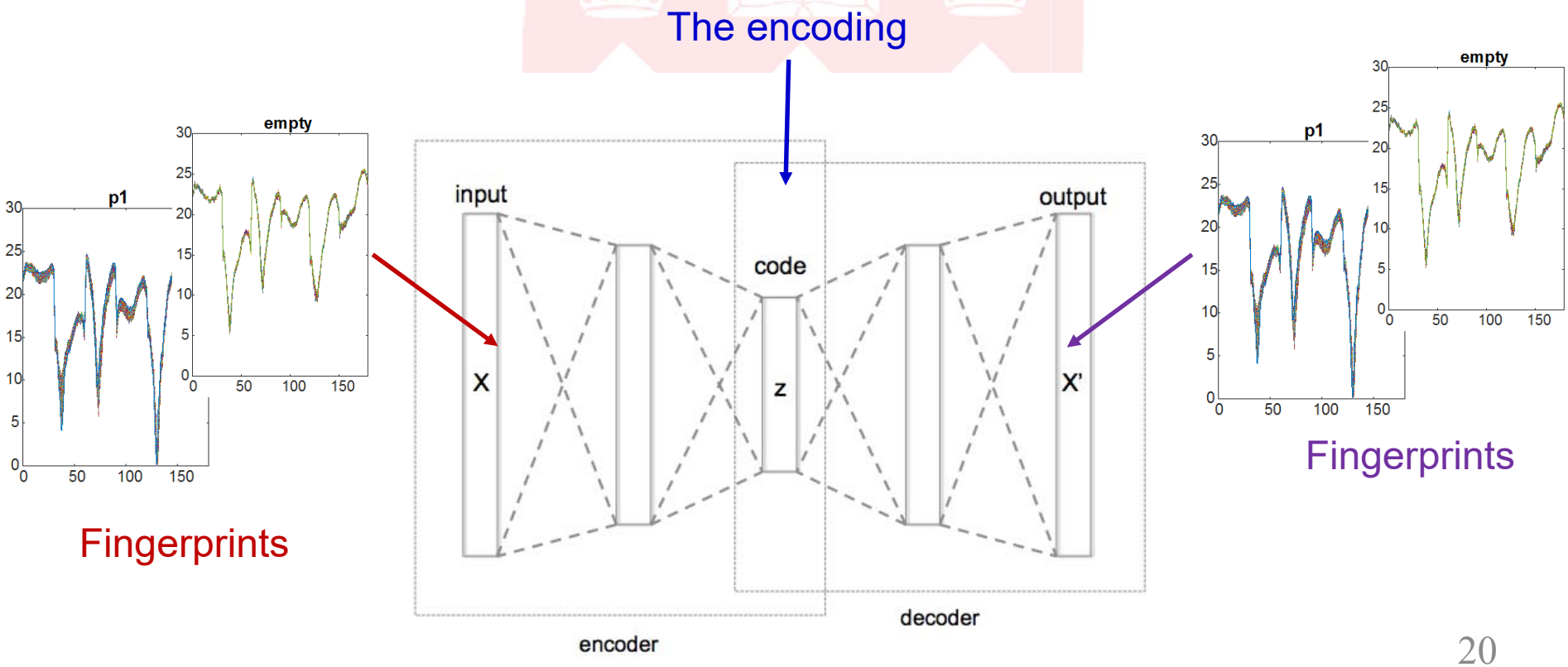
Contaminant Removal Example

- An example of contaminant removal result @ P1



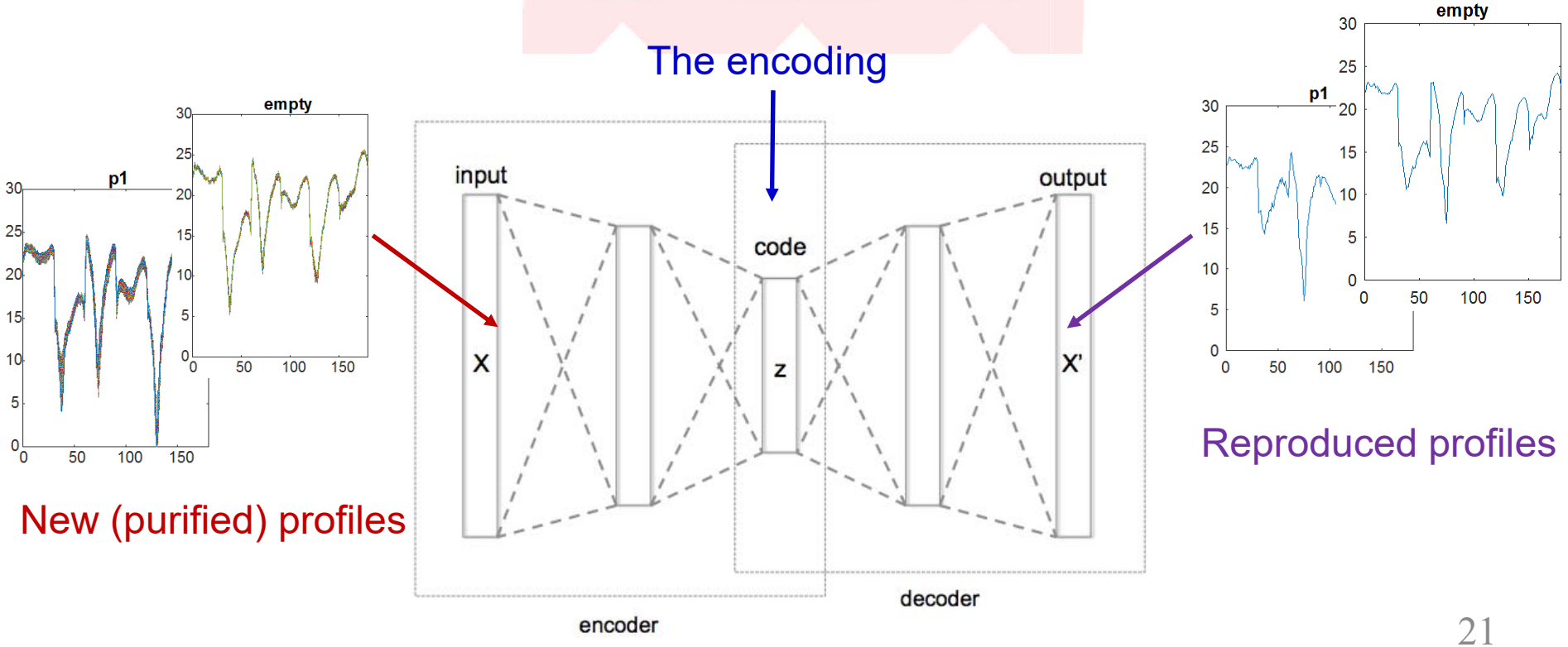
Removing Residual Errors

- An autoencoder learns **an encoding** of the fingerprint space.
  - This encoding contains certain characteristics of the space.



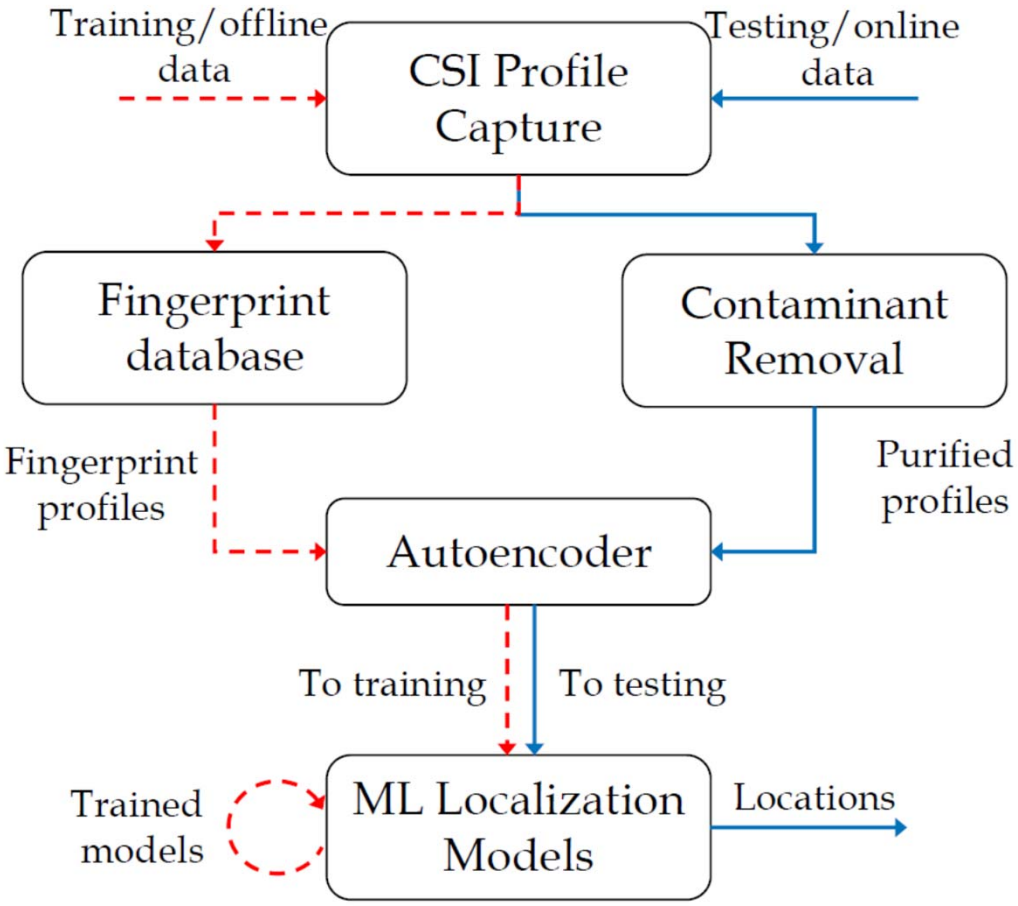
Autoencoders

- The autoencoder **maps** new profiles back to the fingerprint space using the recorded encoding.
  - Old space characteristics are encoded back to the contaminated profiles.



AutoFi

- The architecture of AutoFi.



Experiments

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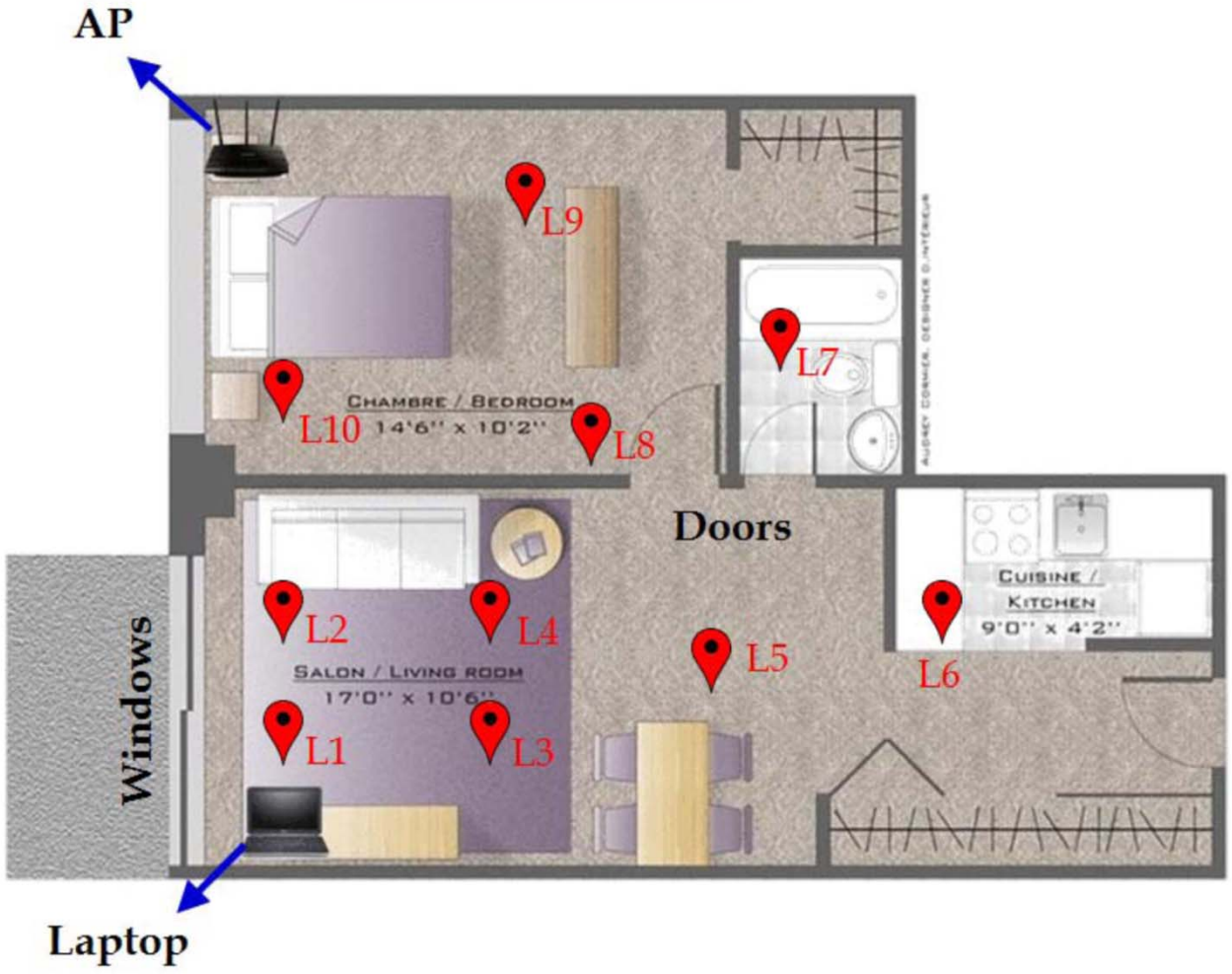
Experiment Setup

- A Linksys WRT160N router, a laptop with Intel 5300 NIC.
  - Wi-Fi traffic: 10 – 20 pings per second.



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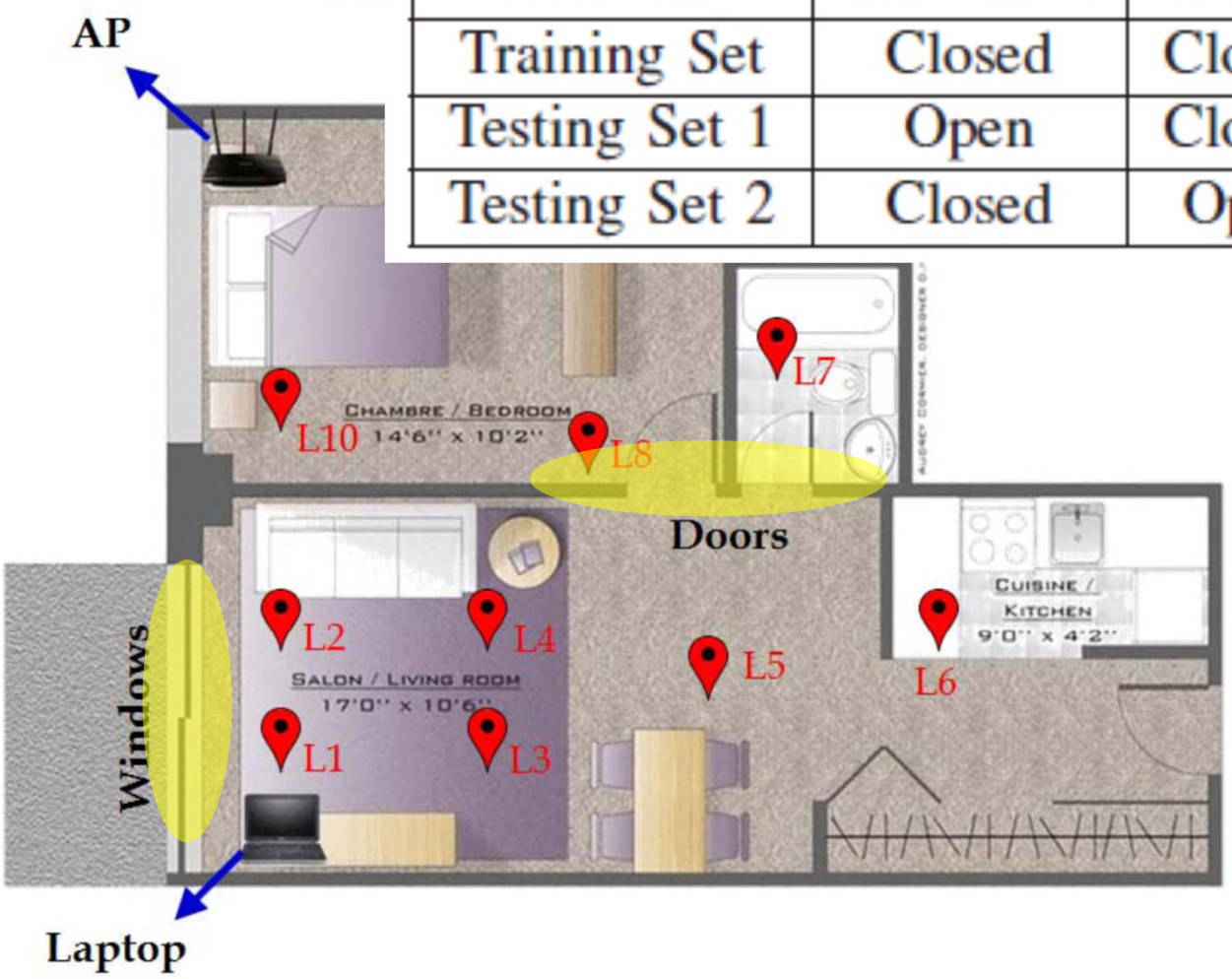
Experiment Setup

- Introducing the "contaminants"

Data Set	Windows	Doors
Training Set	Closed	Closed
Testing Set 1	Open	Closed
Testing Set 2	Closed	Open



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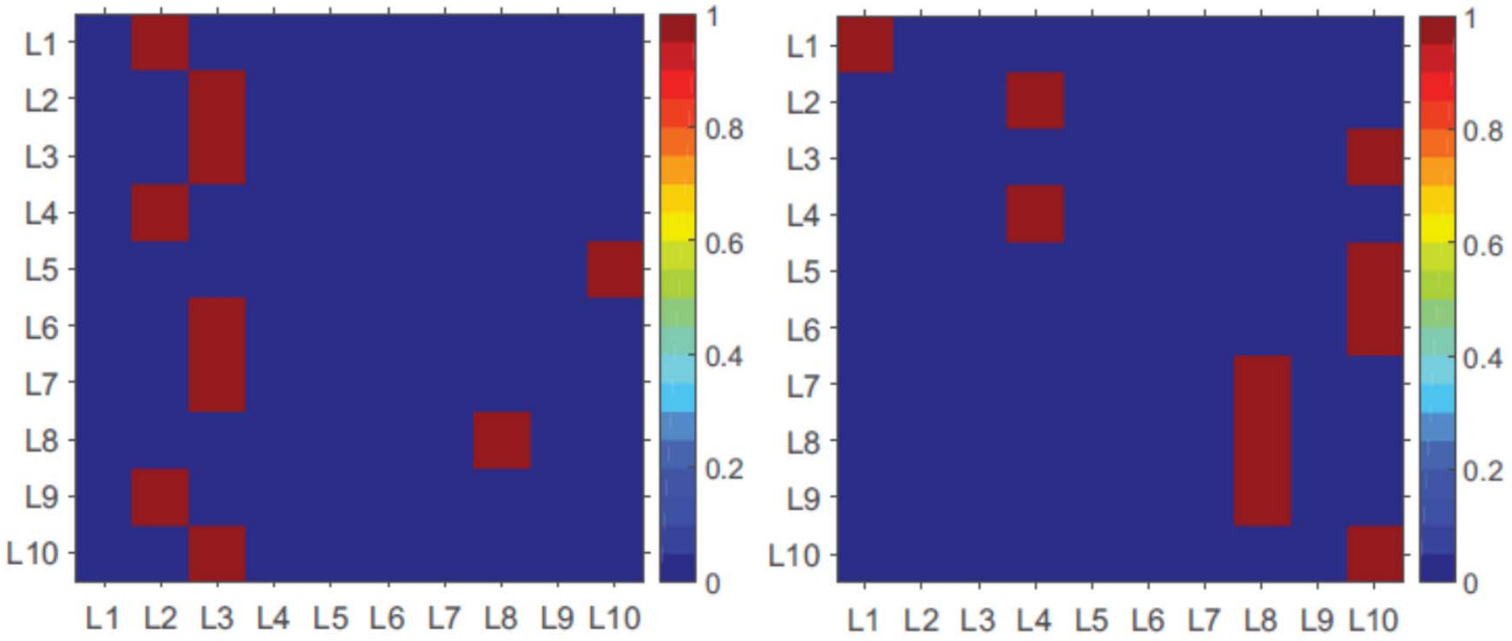
Experiment Results

- Baseline, no mapping was applied, Random Forest (RF).



(a) Opening the windows. (b) Opening the doors.

	Opening windows		Opening doors	
Accuracy	**Mean**	**Min**	**Mean**	**Min**
Baseline	**18.8%**	**0%**	**41.7%**	**0%**

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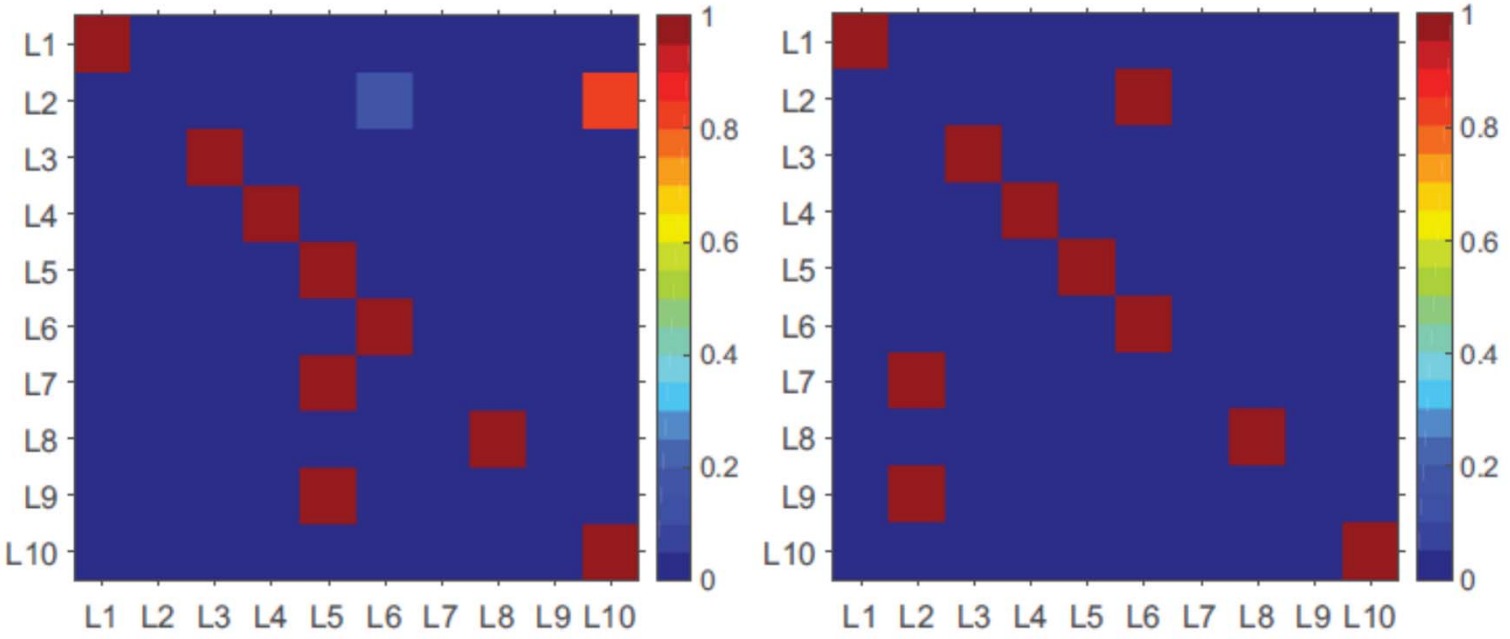
Experiment Results

- Using only contaminant removal technique.



(a) Opening the windows. (b) Opening the doors.

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Accuracy	**Mean**	**Min**	**Mean**	**Min**
Baseline	**18.8%**	**0%**	**41.7%**	**0%**
Con. Rmv.	**69.0%**	**0%**	**70.0%**	**0%**

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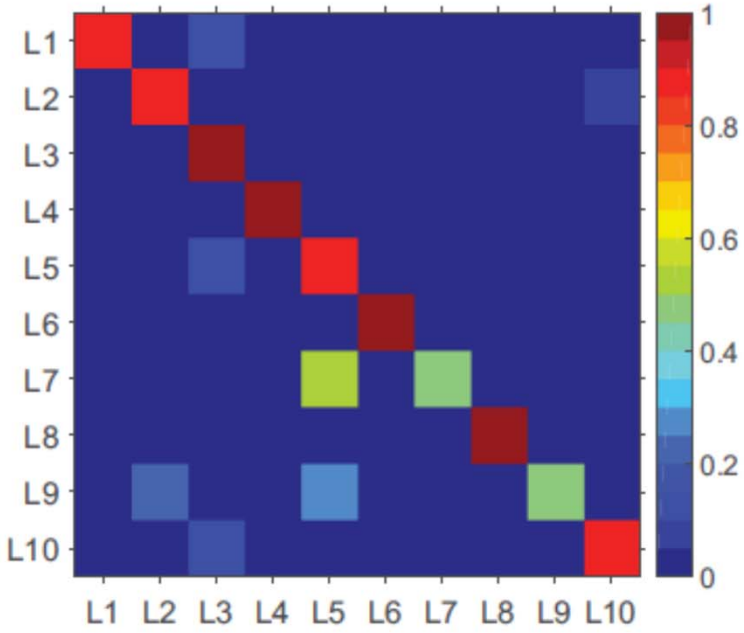
Experiment Results

- AutoFi (both contaminant removal and autoencoder)



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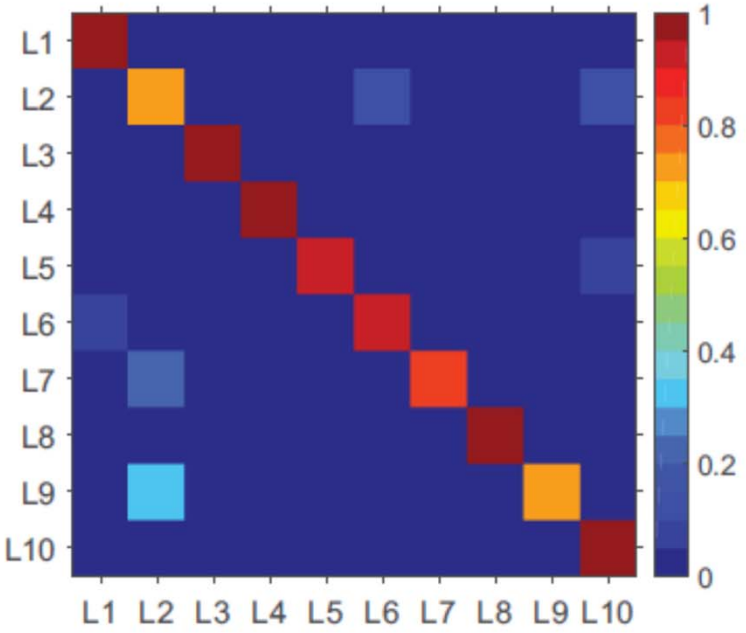

(b) Opening the doors.

	Opening windows		Opening doors	
Accuracy	**Mean**	**Min**	**Mean**	**Min**
Baseline	**18.8%**	**0%**	**41.7%**	**0%**
Con. Rmv.	**69.0%**	**0%**	**70.0%**	**0%**
AutoFi	**84.9%**	**47.6%**	**90.2%**	**71.3%**

Conclusion

Conclusion

- Problem:

  Small variations in the environment may **significantly contaminate** the fingerprints in the localization systems.

- Solution - **AutoFi**
  - Reuse the fingerprints with a **contaminant removal** technique, which **autonomously maps** the contaminated profiles back to the fingerprint space.
  - Utilize an autoencoder to preserve a **characteristic presentation** of the fingerprint space.

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Thank you!

Questions?

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