Few labels are all you need: A Weakly Supervised Framework for Appliance Localization in Smart-Meter Series

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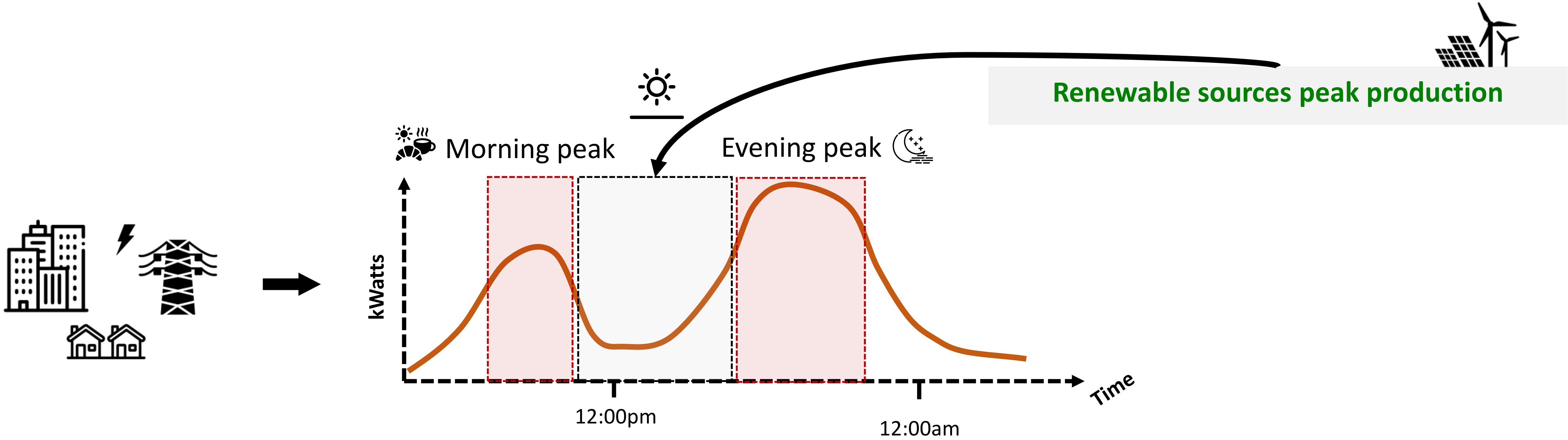
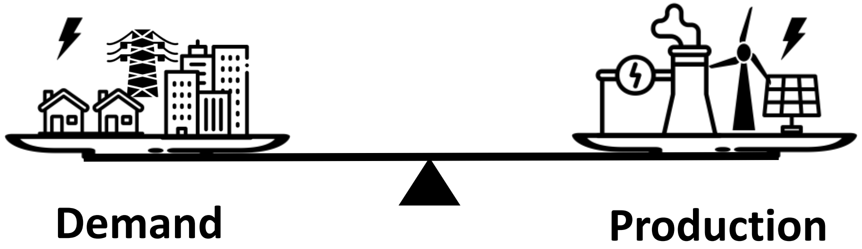
May21st, 2025

Context: From Renewable Surge to the Flexibility Challenge

Typical **daily** electricity **grid domestic demand**

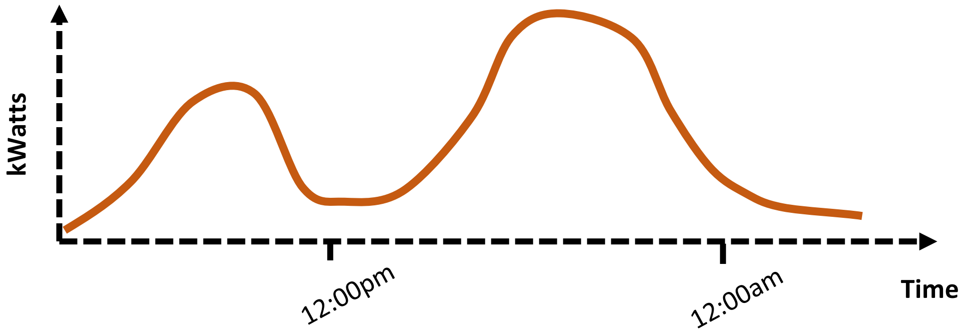


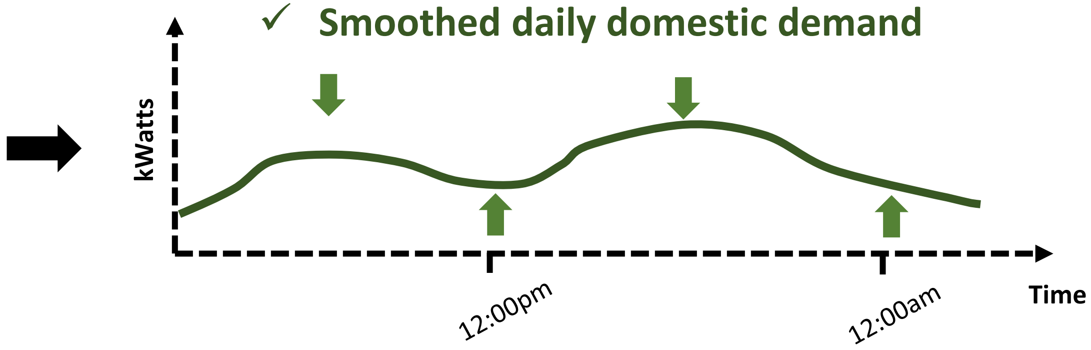
The Flexibility Challenge = real-time ability to match variable supply & demand



RTE technical reports, 2023.

Reducing peak demand: shifting parts of the consumption to off-peak hours

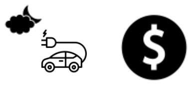




Electricity suppliers (as EDF) need to play an **active role in this process**

*How **convince** clients to **change** their consumption **behaviors**?*

1. Personalized contracts



Lower off-peak pricing, for **charging** your **Electric Vehicle** at night

2. Dynamic pricing

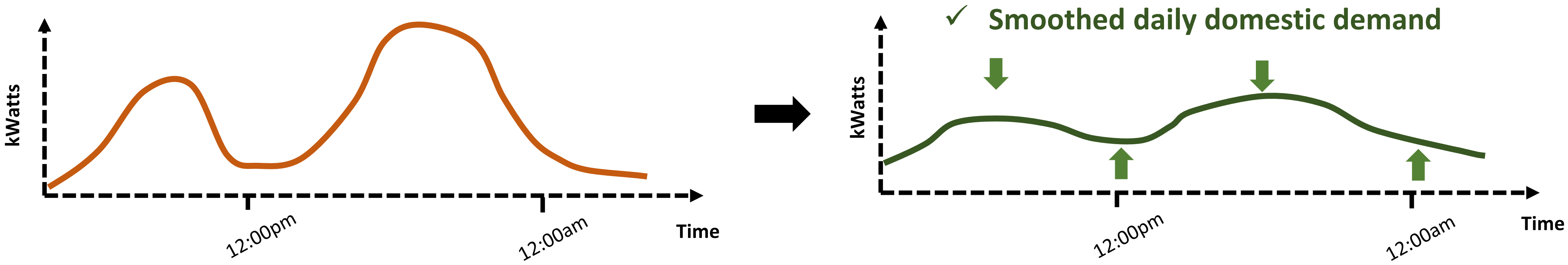
Criticial Peak Pricing
Peak Time Rebeat

3. Appliance-level feedback

How much does your heater **cost you per month**?

Context: The Flexibility Challenge

Reducing peak demand: shifting parts of the consumption to off-peak hours



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2. Dynamic pricing

Critical Peak Pricing

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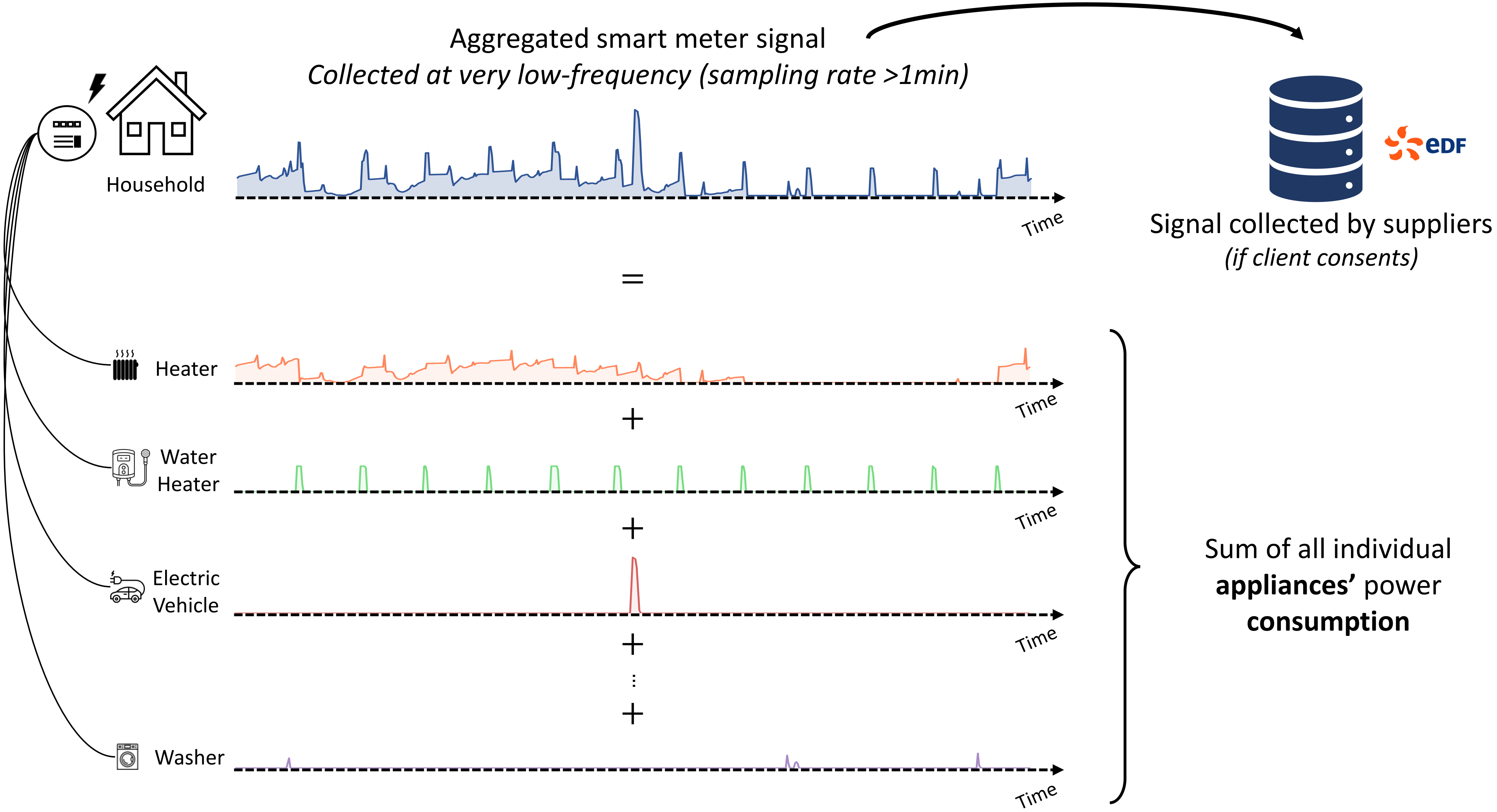
3. Appliance-level feedback

How much does your heater **cost you per month**?

Solutions based on customers' consumption characteristics!

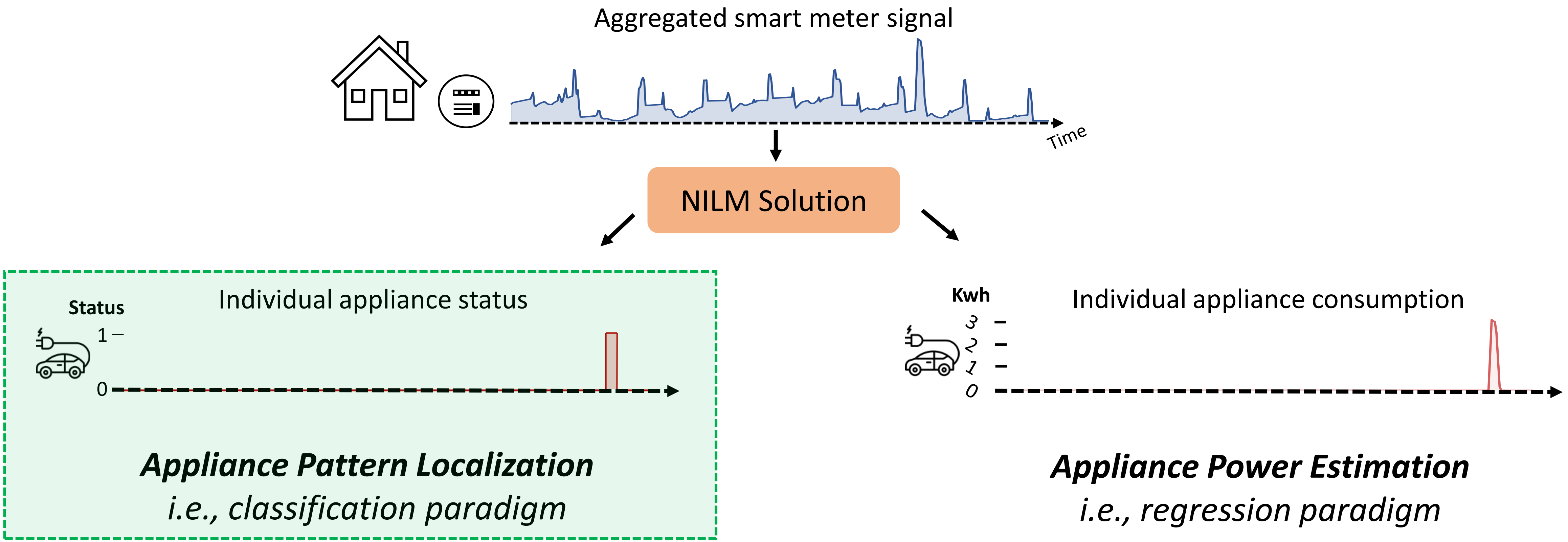
Context: Smart Meter Deployement

Millions of Smart Meters deployed in **individual households**



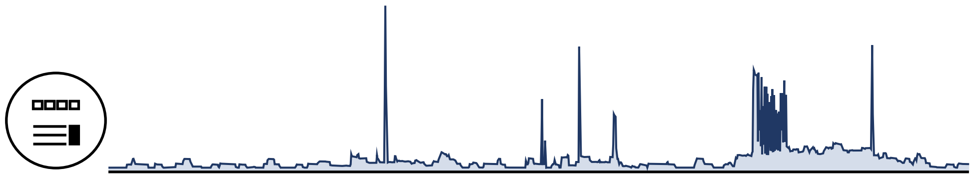
Background: Smart Meter Data Analytics

Non-**I**ntrusive **L**oad **M**onitoring (NILM): estimates **power consumption**, operational **patterns**, or **on/off state** of individual appliances using **only the total aggregated signal**



Appliance Pattern Localization = *when the appliance is used?*

SotA solutions *require* ***large number*** *of* ***strong labels***



Aggregated Consumption Series

+

Ground Truth Appliance **Status**

(one label for each timestep)

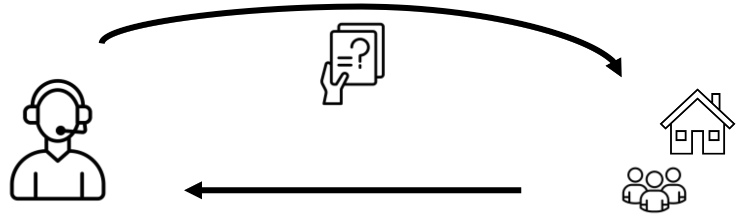
Ground true appliance signals are **extremely expensive** to **collect**

1000$ *to* ***instrument*** *an* ***household with dedicated sensors!***

We already have **weak labels**

Can we use **weak labels** for **accurate appliance localization?**

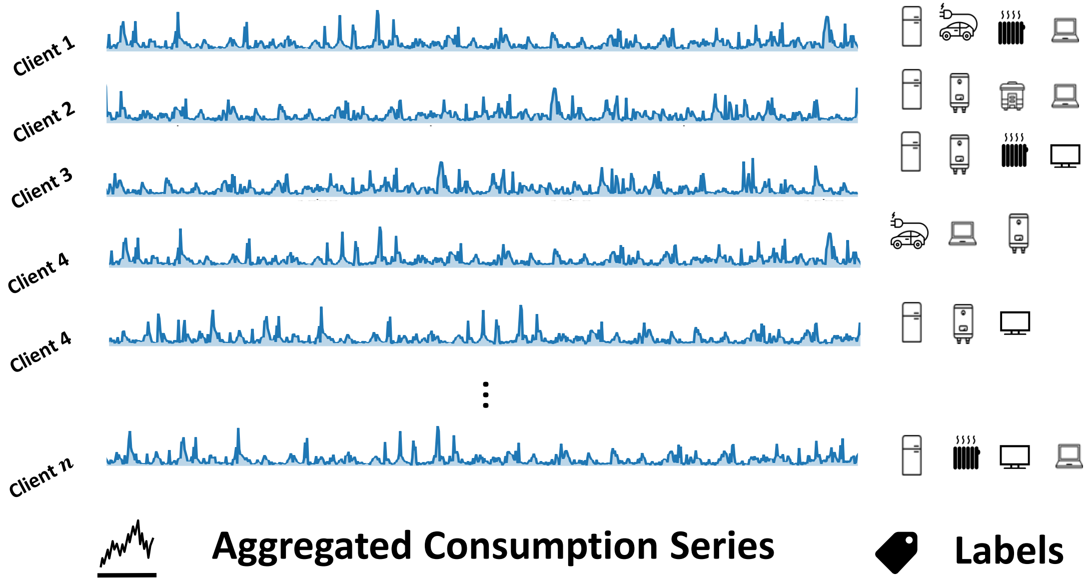
*"Is the appliance **X** present in your household?"*



Customers fill out a **questionnaire** in exchange for a small reward

Max 50$/house

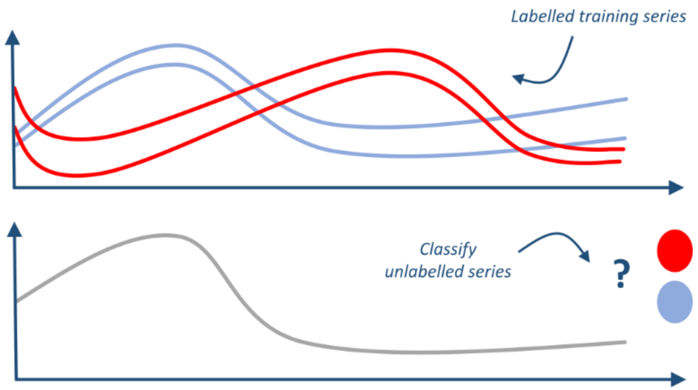
Survey dataset



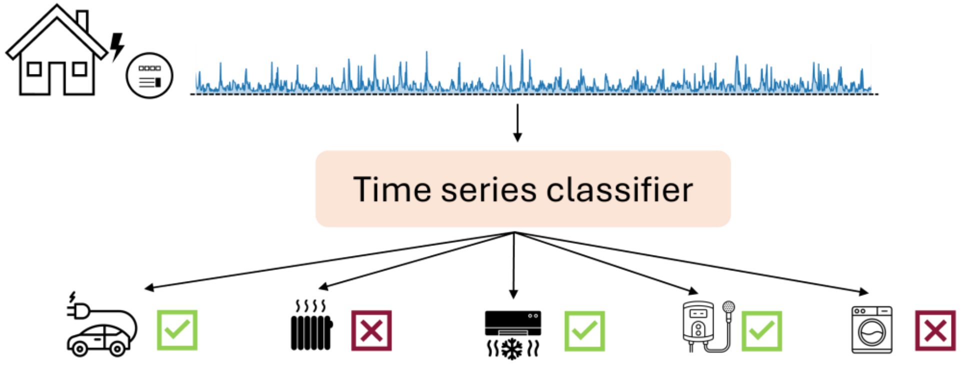
Weak labels :
*No guarantee about **when** (or even if) the **appliance is actually in use***

Lever: Appliance Detection in Consumers Household

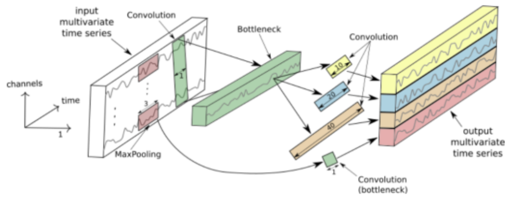
Detecting appliances in consumers households can be cast as a **Time Series Classification Problem**[1].



Time Series Classification



Recent studies demonstrate that **deep learning** (including CNNs) are the most **accurate** solutions for **tackling this task**[1,2].



InceptionTime

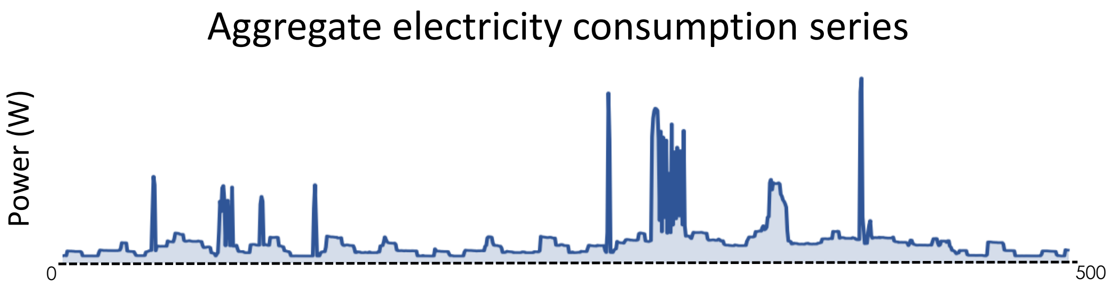
[1] A. Petralia et al., Appliance Detection Using Very Low-Frequency Smart Meter Time Series, ACM e-Energy 2023

[2] A. Petralia et al., ADF & TransApp: A Transformer-Based Framework for Appliance Detection Using Smart Meter Consumption Series, PVLDB, 2024.

Problem

Can we tackle the ***Appliance Pattern Localization*** *problem using* ***minimal supervision****?*

Challenges

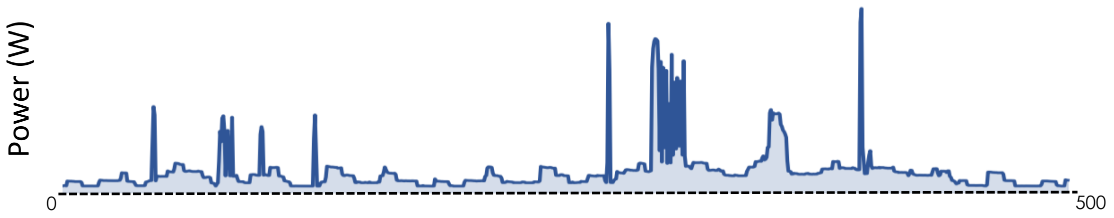


Problem

*Can we tackle the **Appliance Pattern Localization** problem using **minimal supervision**?*

Challenges

Aggregate electricity consumption series



One label per time series and per appliance

(Problem 1)
Appliance Detection

Washer:	Yes
Microwave:	No
Dishwasher:	No
Kettle:	Yes

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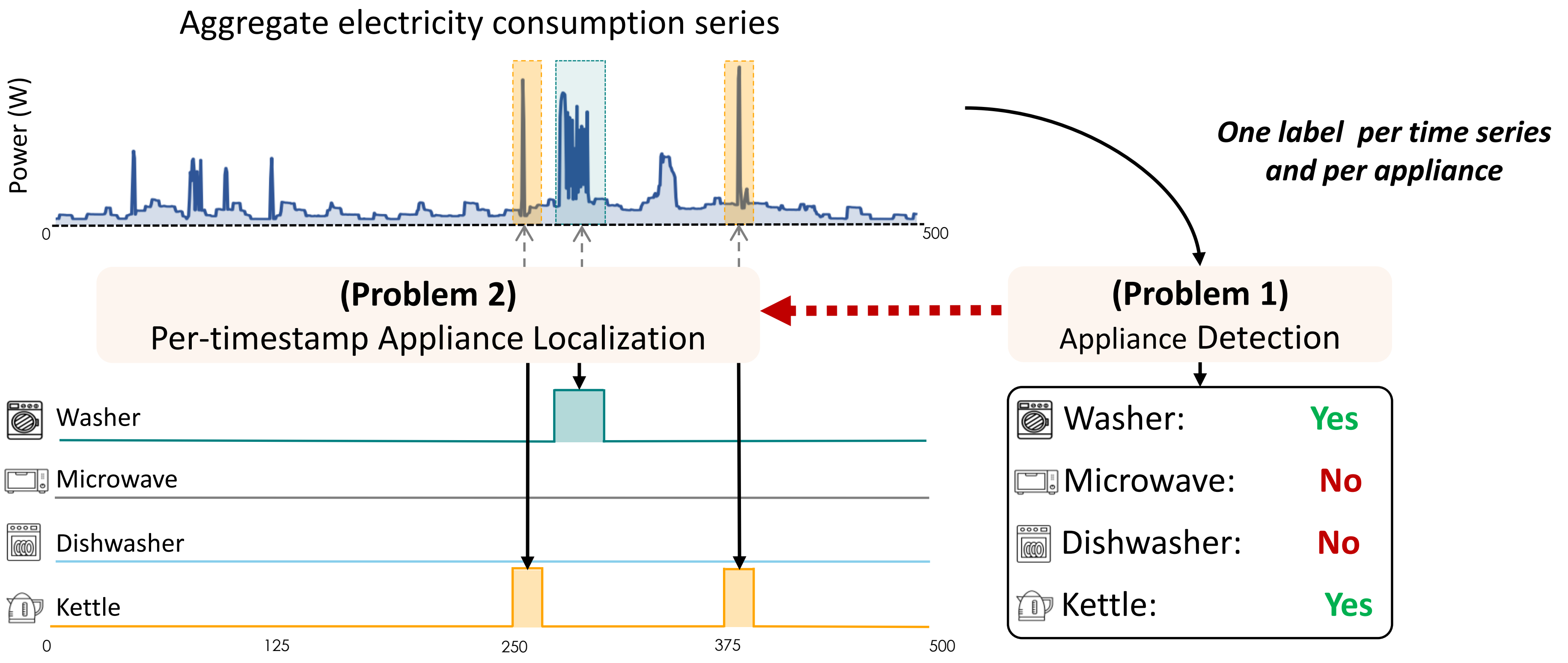
Challenges

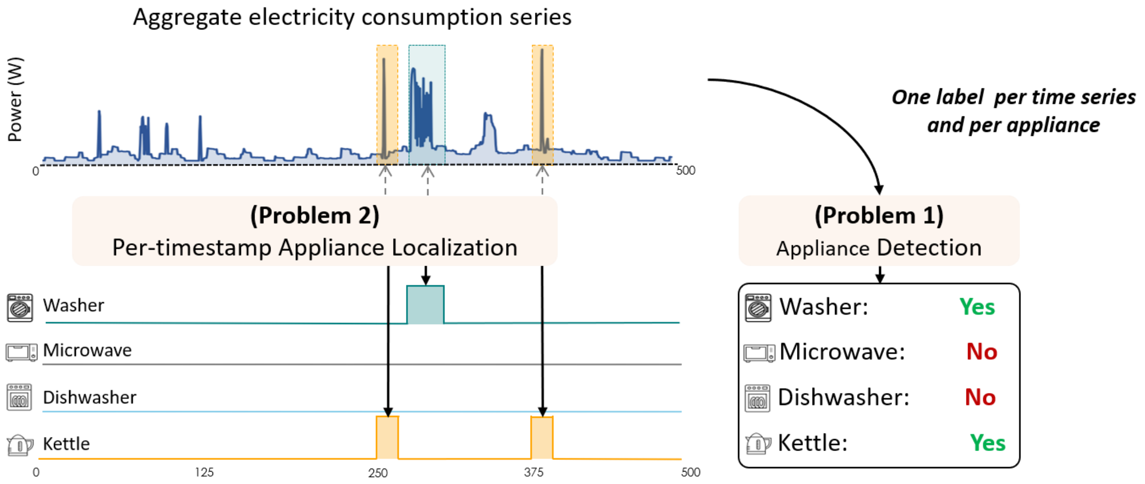


Solving Problem 2 from Problem 1

Problem

*Can we tackle the **Appliance Pattern Localization** problem using **minimal supervision**?*

Challenge



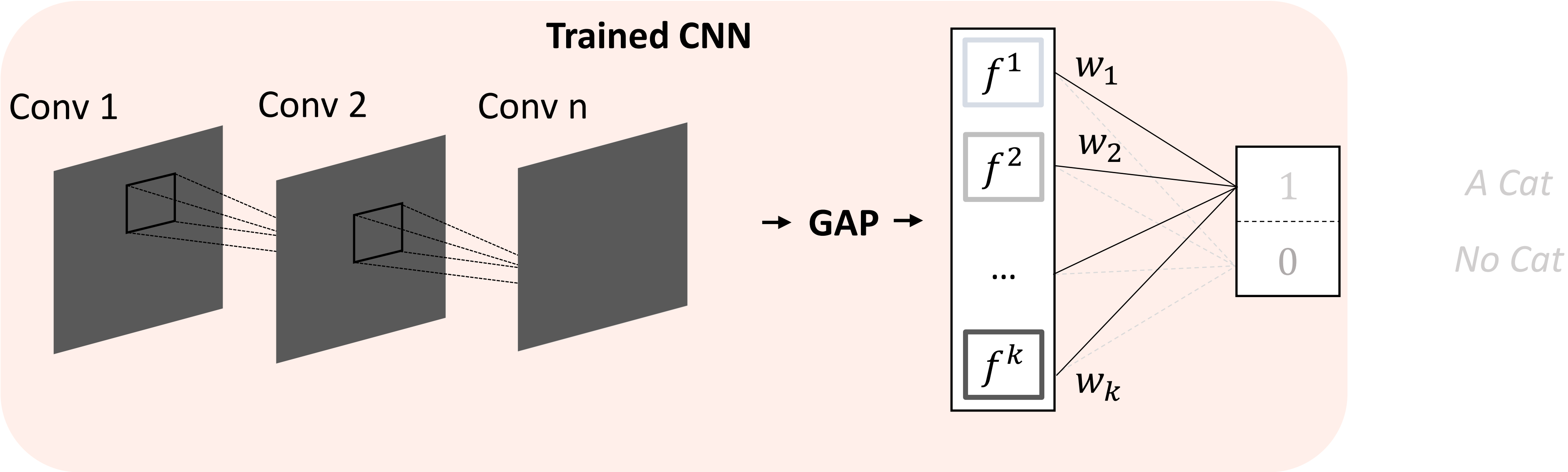
Solution

✓ **CamAL**

Class **A**ctivation **M**ap based **A**ppliance **L**ocalization

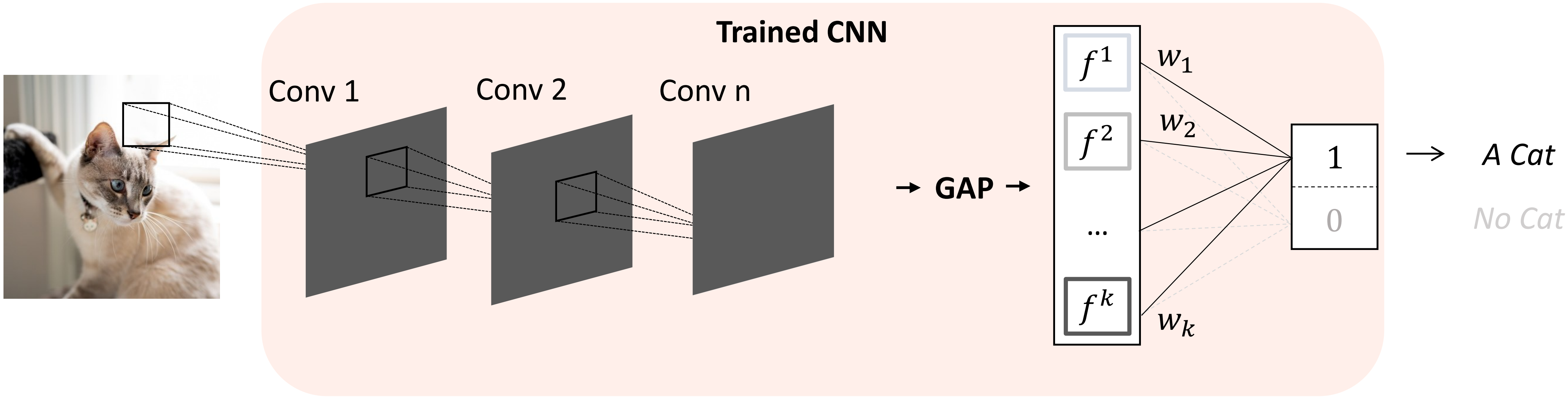
Background: Weakly Supervised Localization

Explainable AI - **C**lass **A**ctivation **M**ap (CAM)



B. Zhou et al., *Learning Deep Features for Discriminative Localization*, CVPR, 2016.

Explainable AI - Class **A**ctivation **M**ap (CAM)



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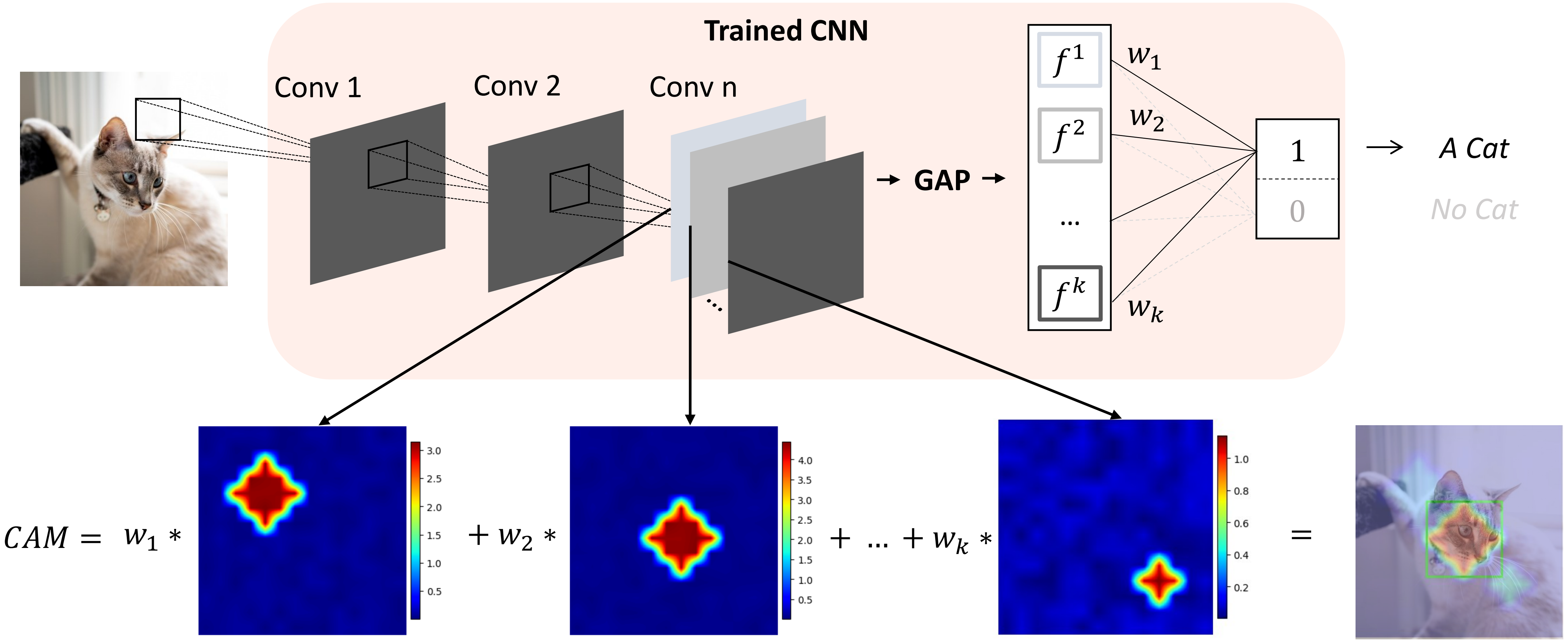

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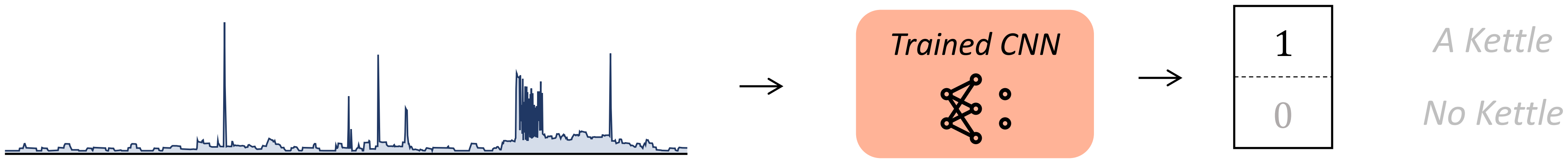
Proposed Approach: CAM for Appliance Pattern Localization?

CNNs (ResNet, Inception) perform well on the Appliance Detection task

Is CAM a « Free Lunch » for **Appliance-Pattern Localization** ?



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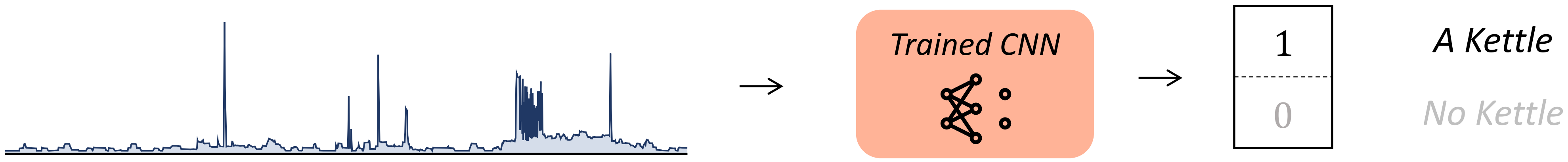

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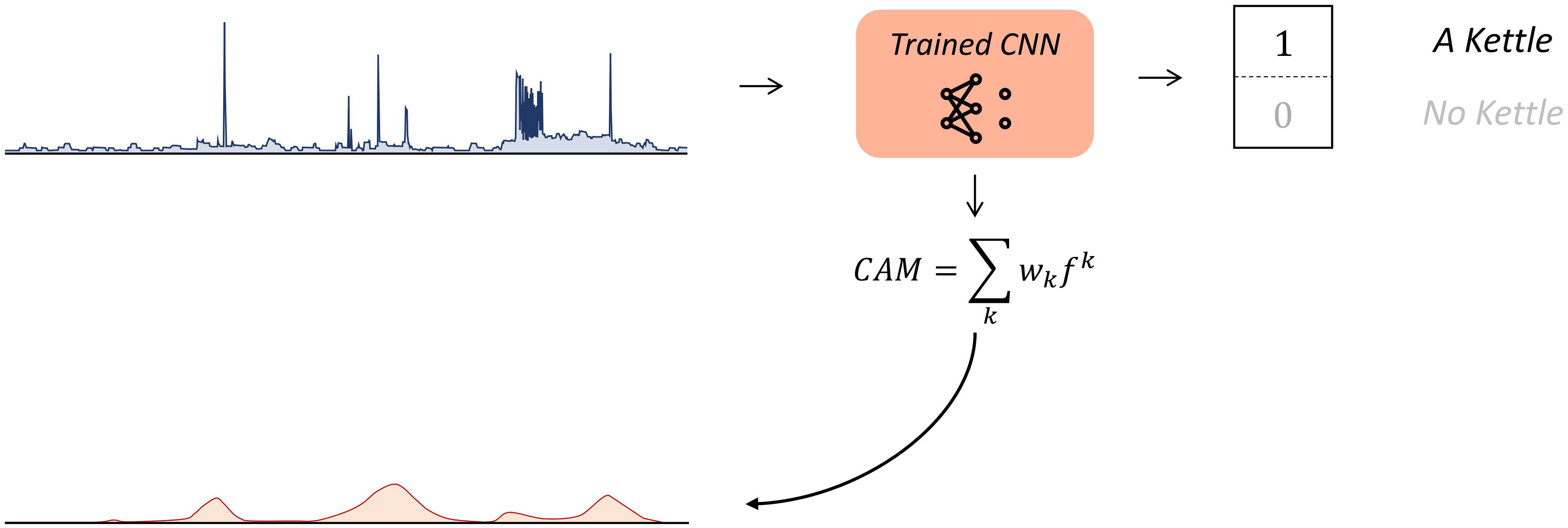

Class Activation Map

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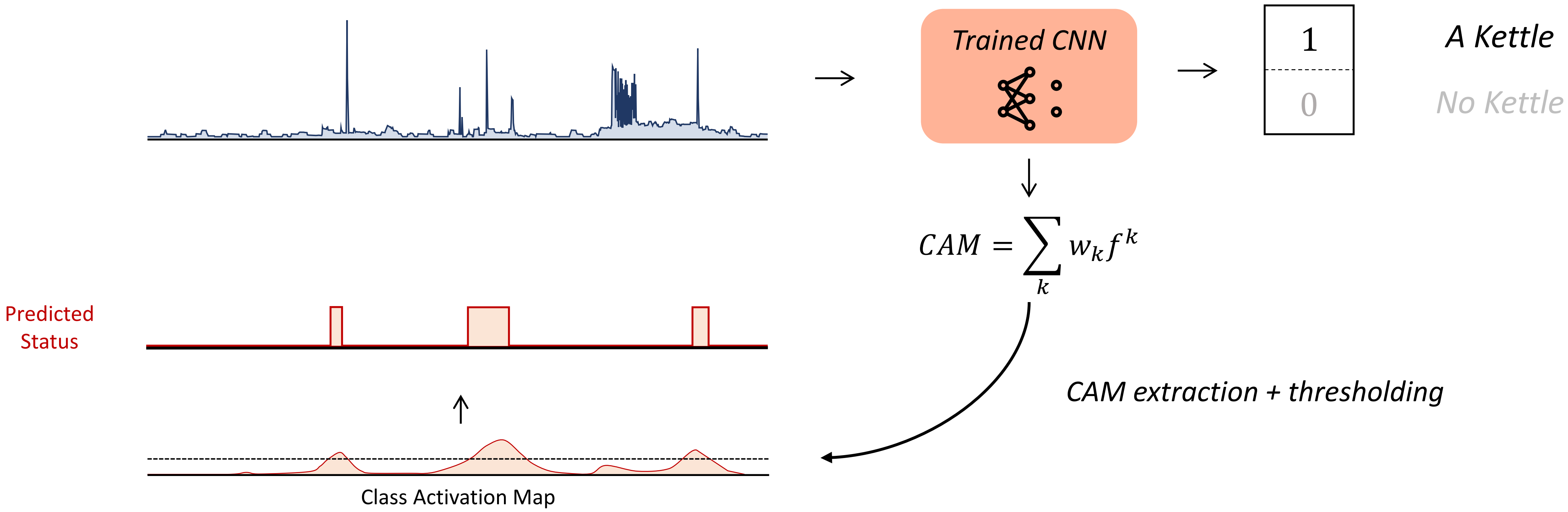

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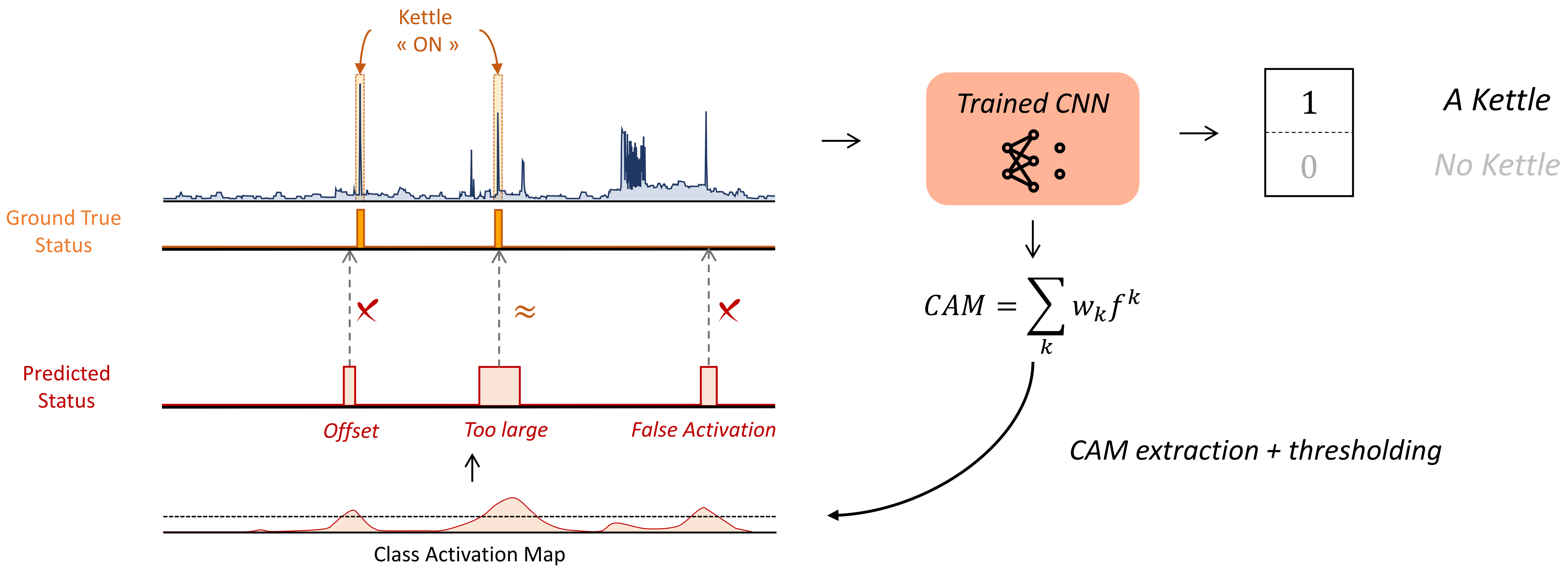

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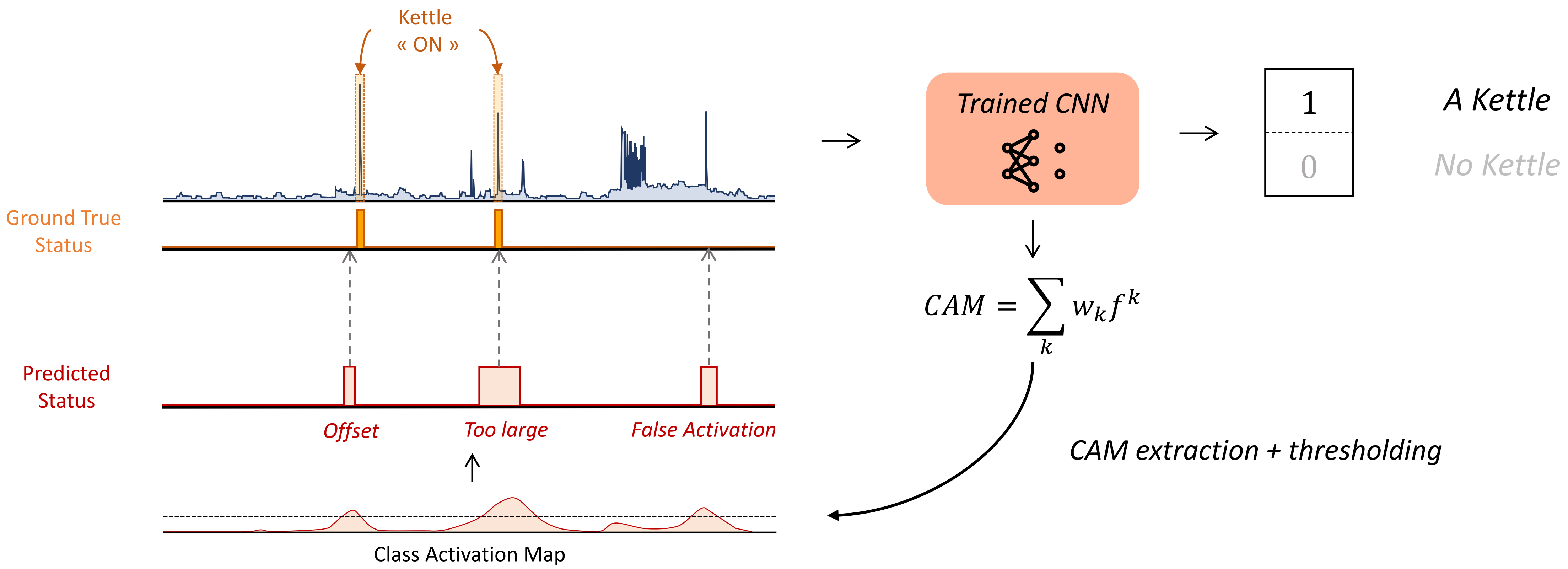
Is CAM a « Free Lunch » for **Appliance-Pattern Localization** ? → ***Not that simple…***



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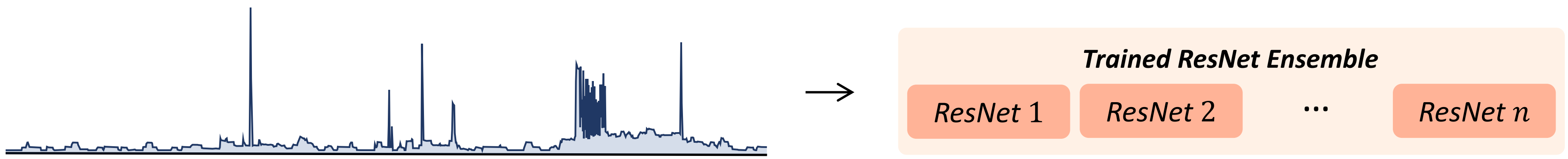
Proposed Approach: CamAL

Improving **CAM** for **A**ppliance **L**ocalization

A **ResNet ensemble** with **varying kernel sizes**



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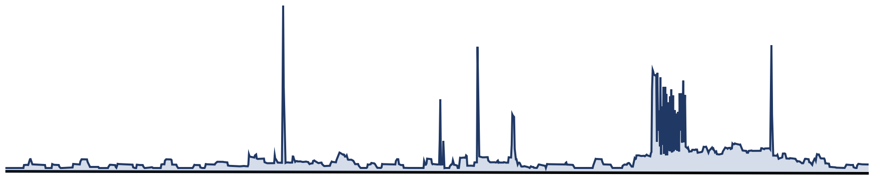

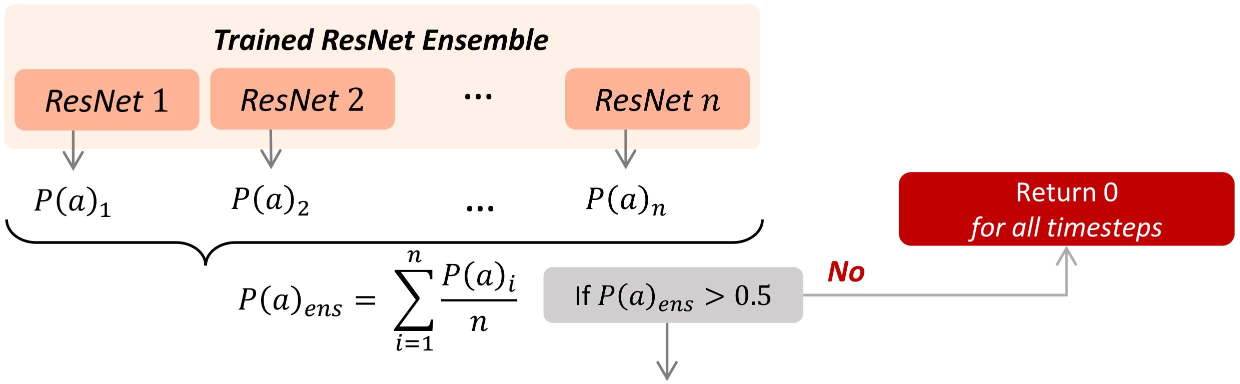

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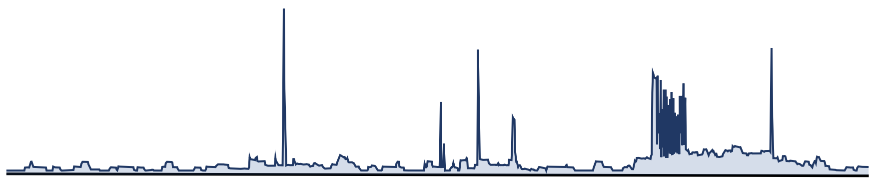

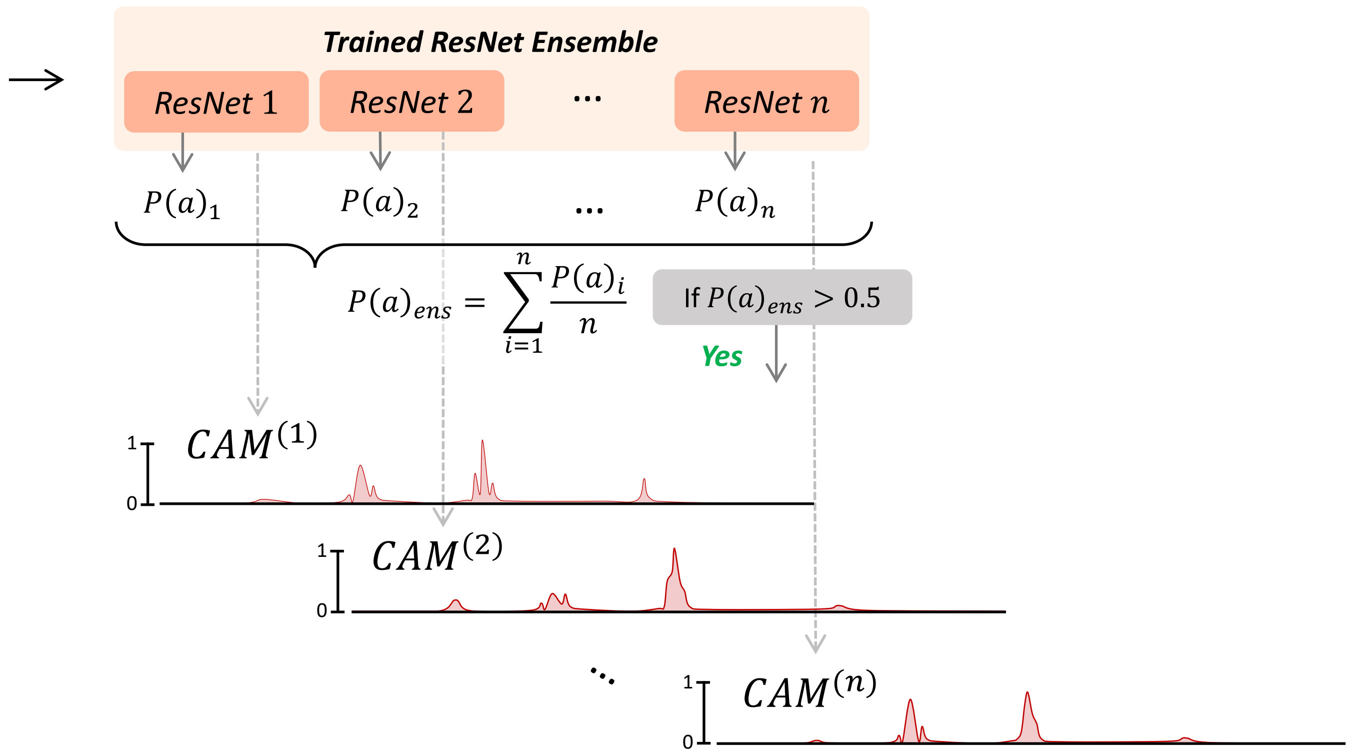

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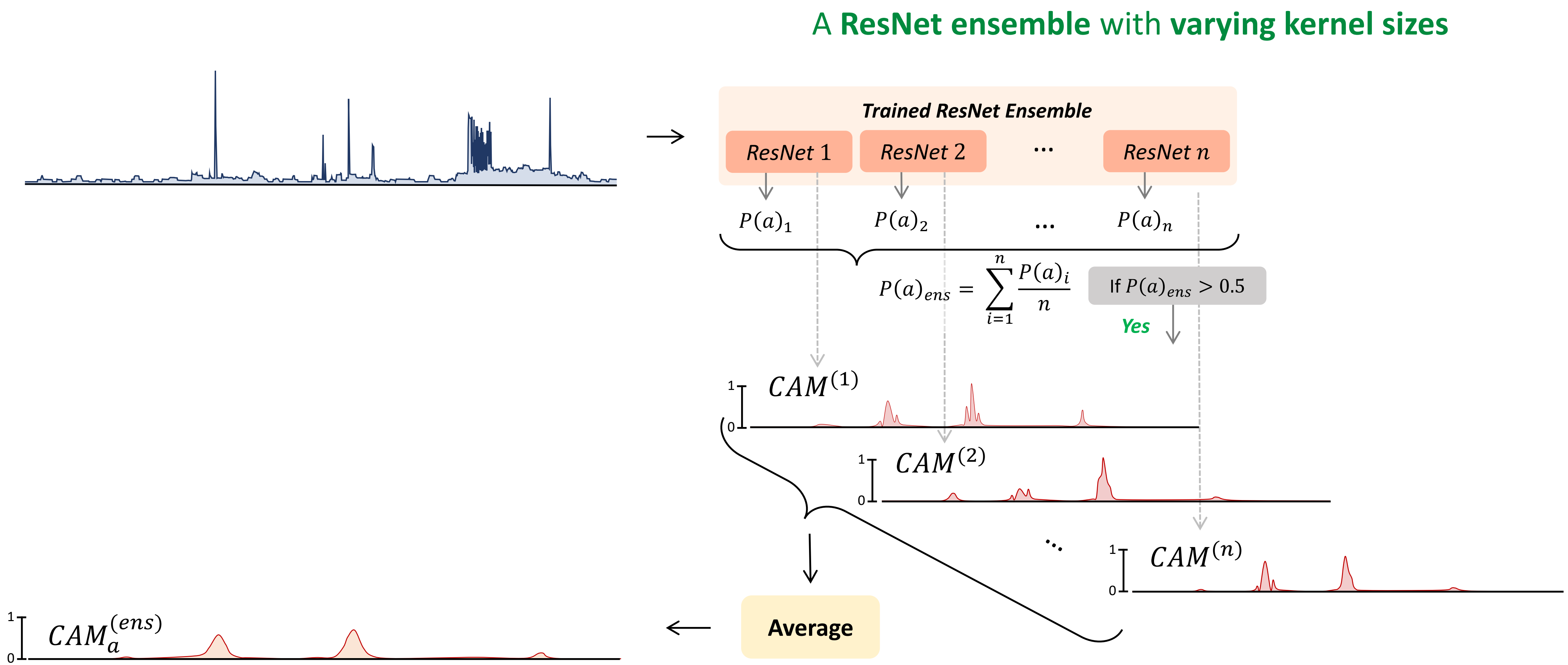

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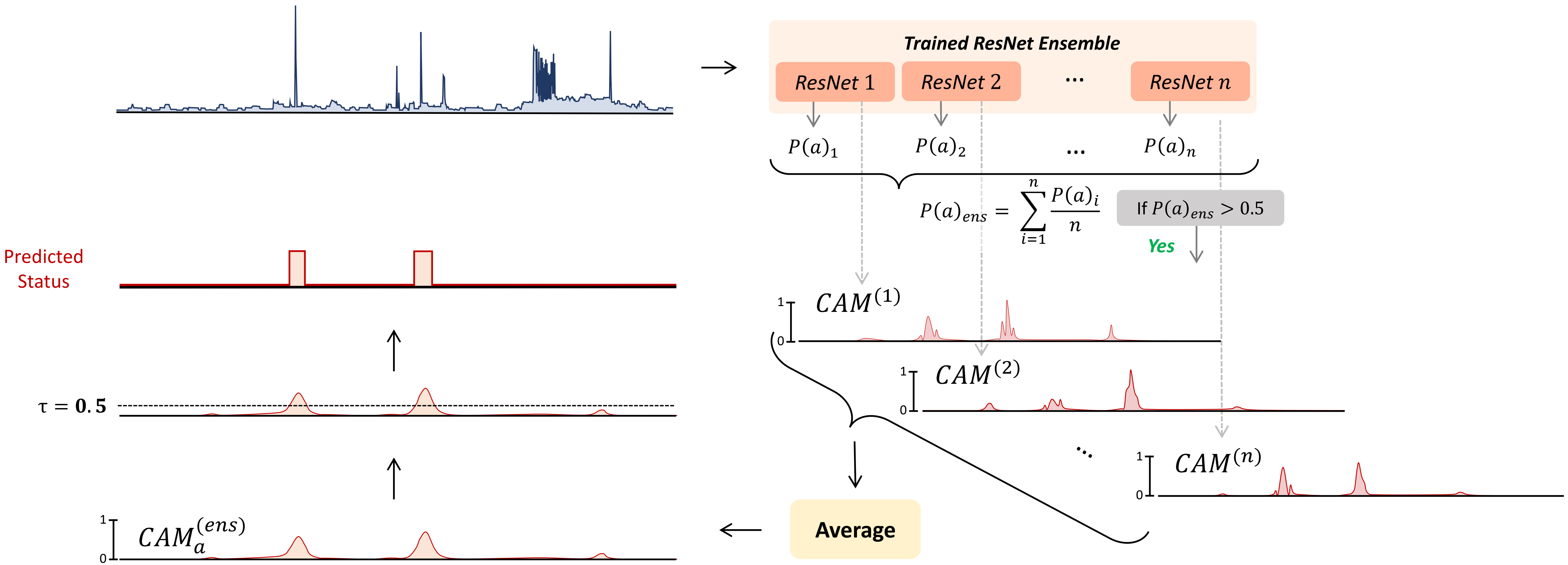

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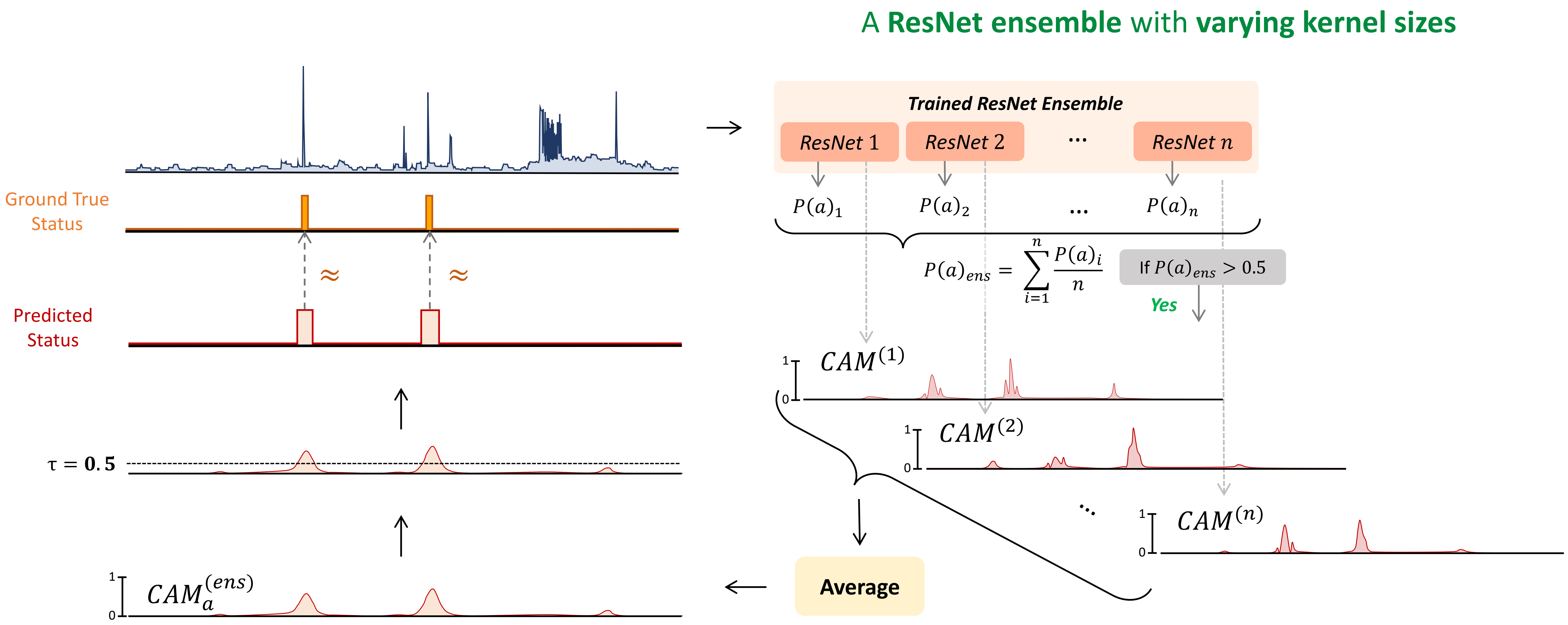
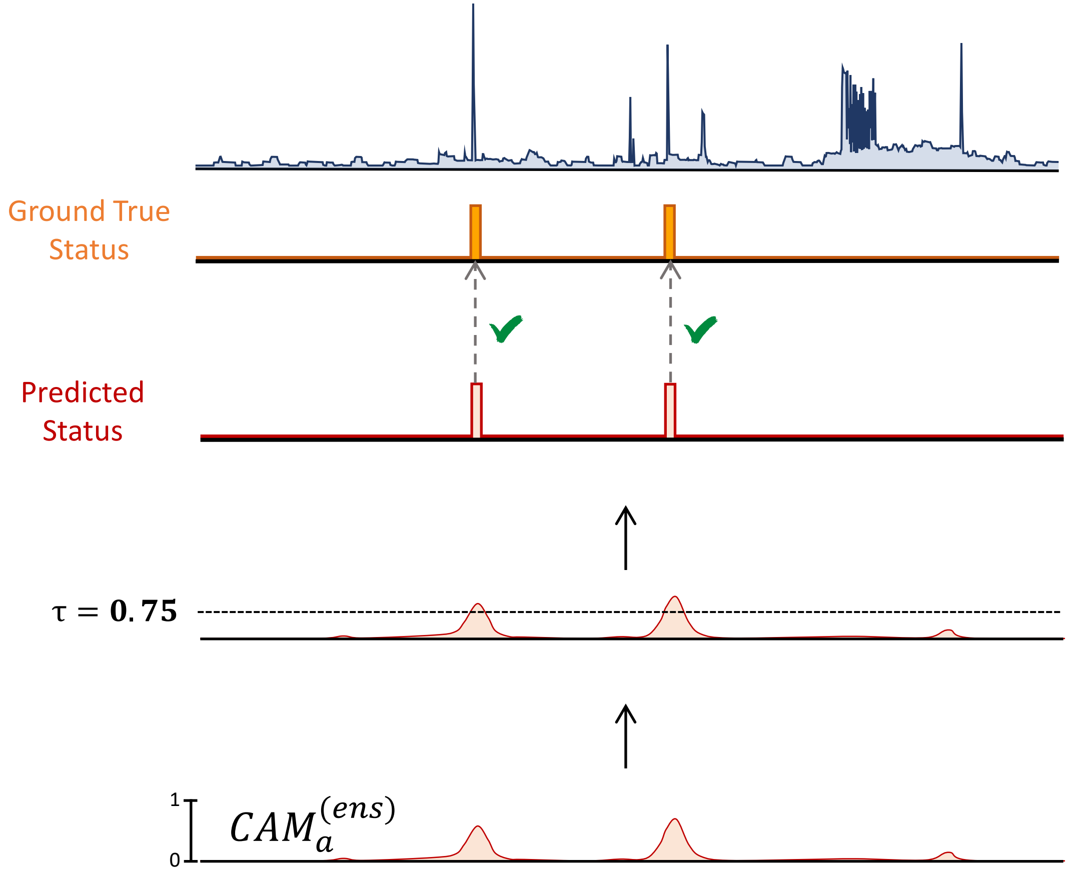


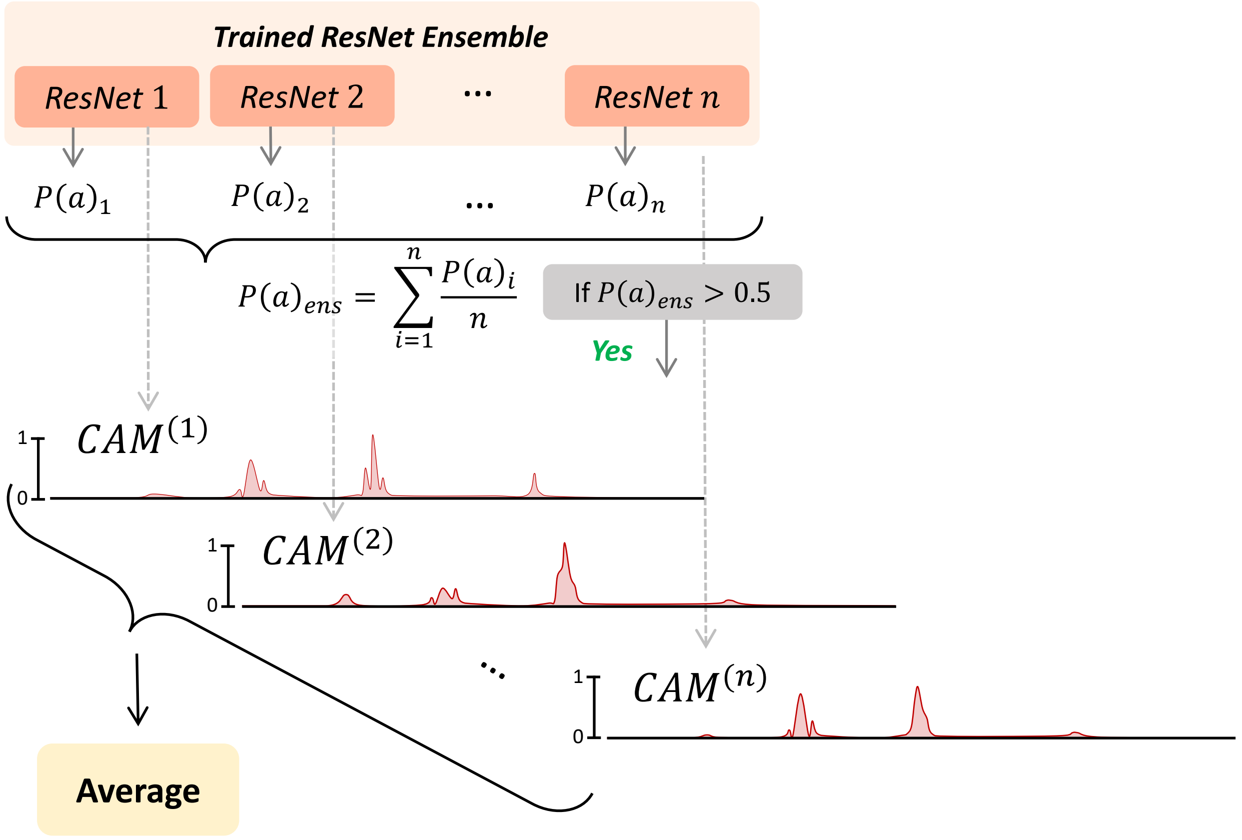
Proposed Approach: CamAL

Improving **CAM** for **A**ppliance **L**ocalization

Continues to depend on a **hyperparameter,** which needs to be **manually tuned** for **each scenario**

A **ResNet ensemble** with **varying kernel sizes**



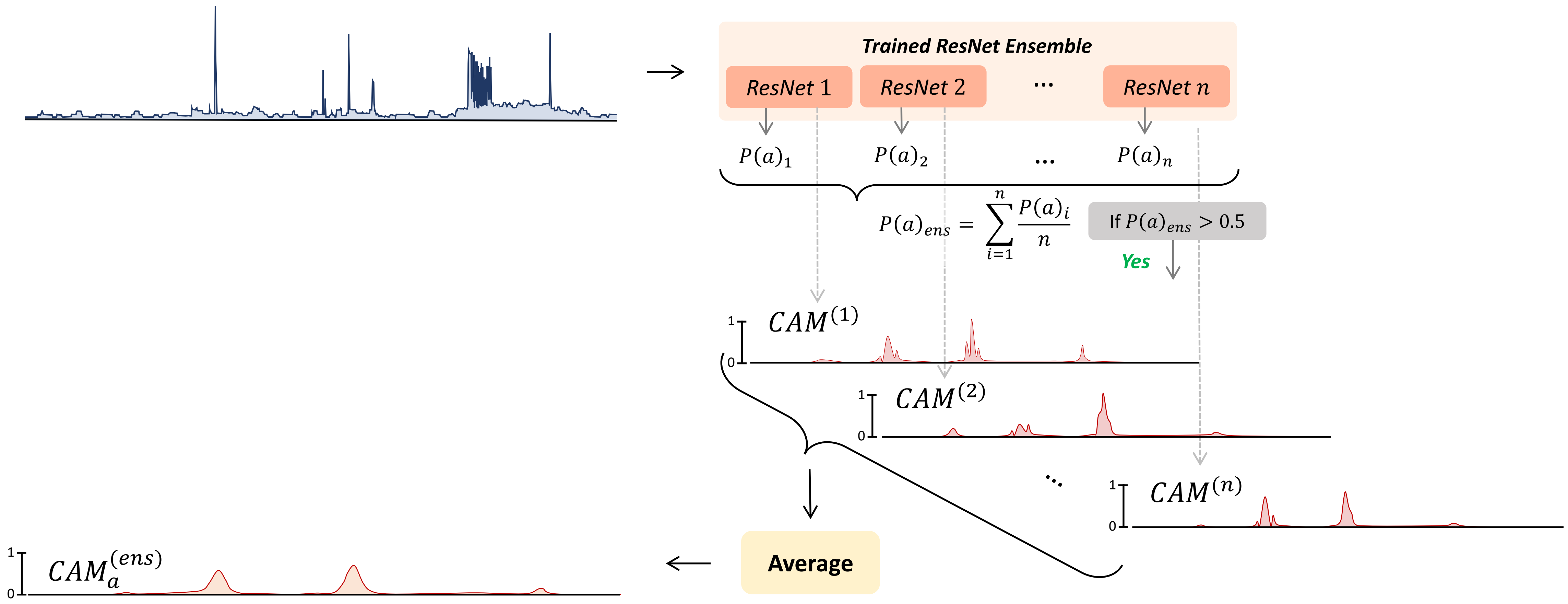


Proposed Approach: CamAL

Improving **CAM** for **A**ppliance **L**ocalization

*Considers the **shape** of the **input aggregated signal!***

A **ResNet ensemble** with **varying kernel sizes**



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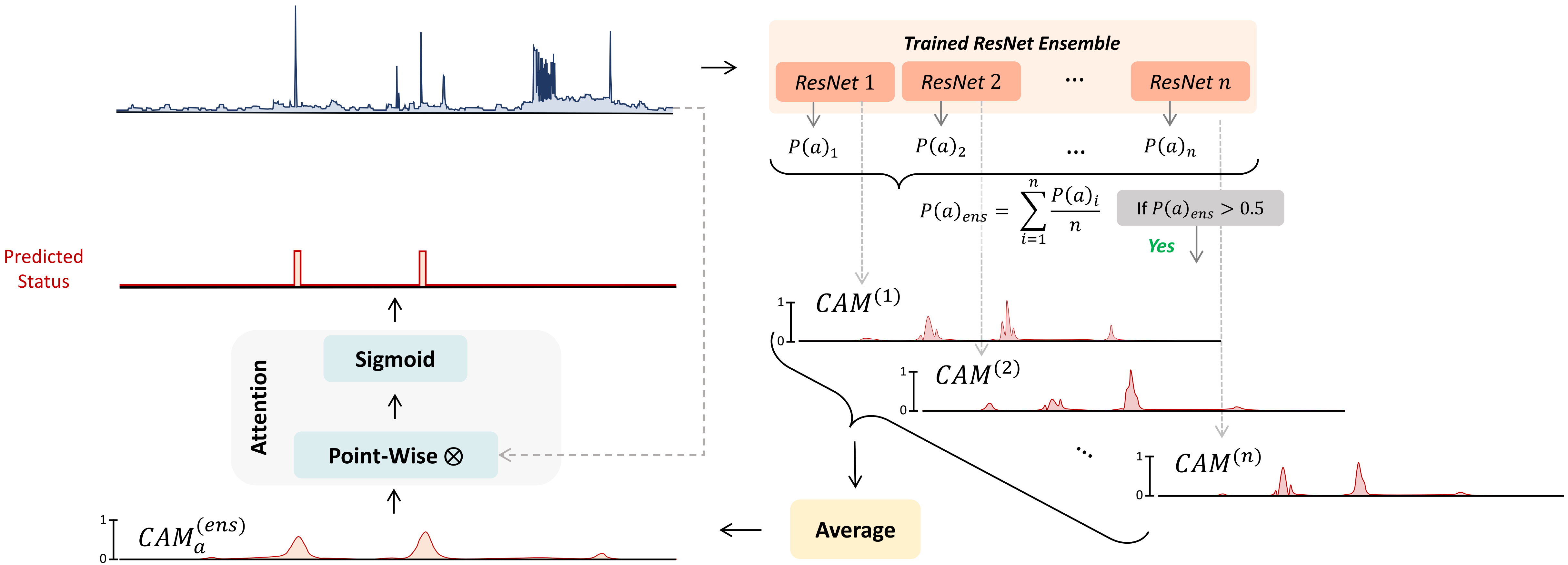

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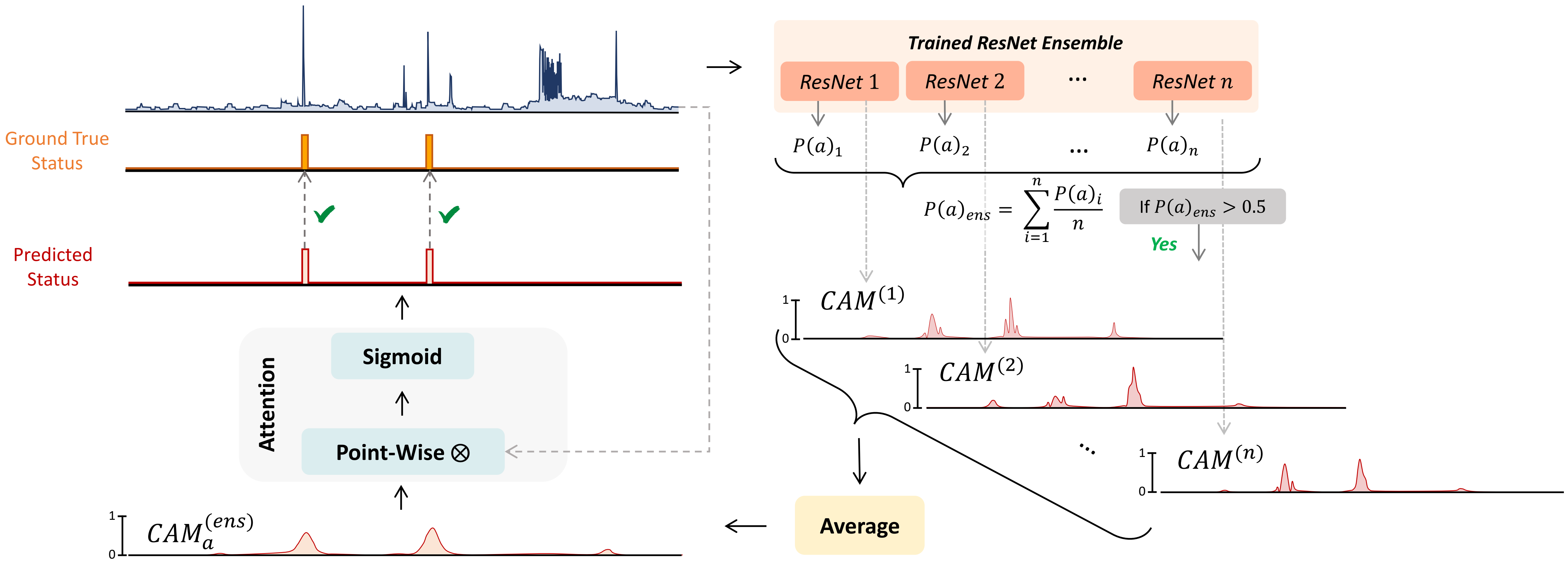
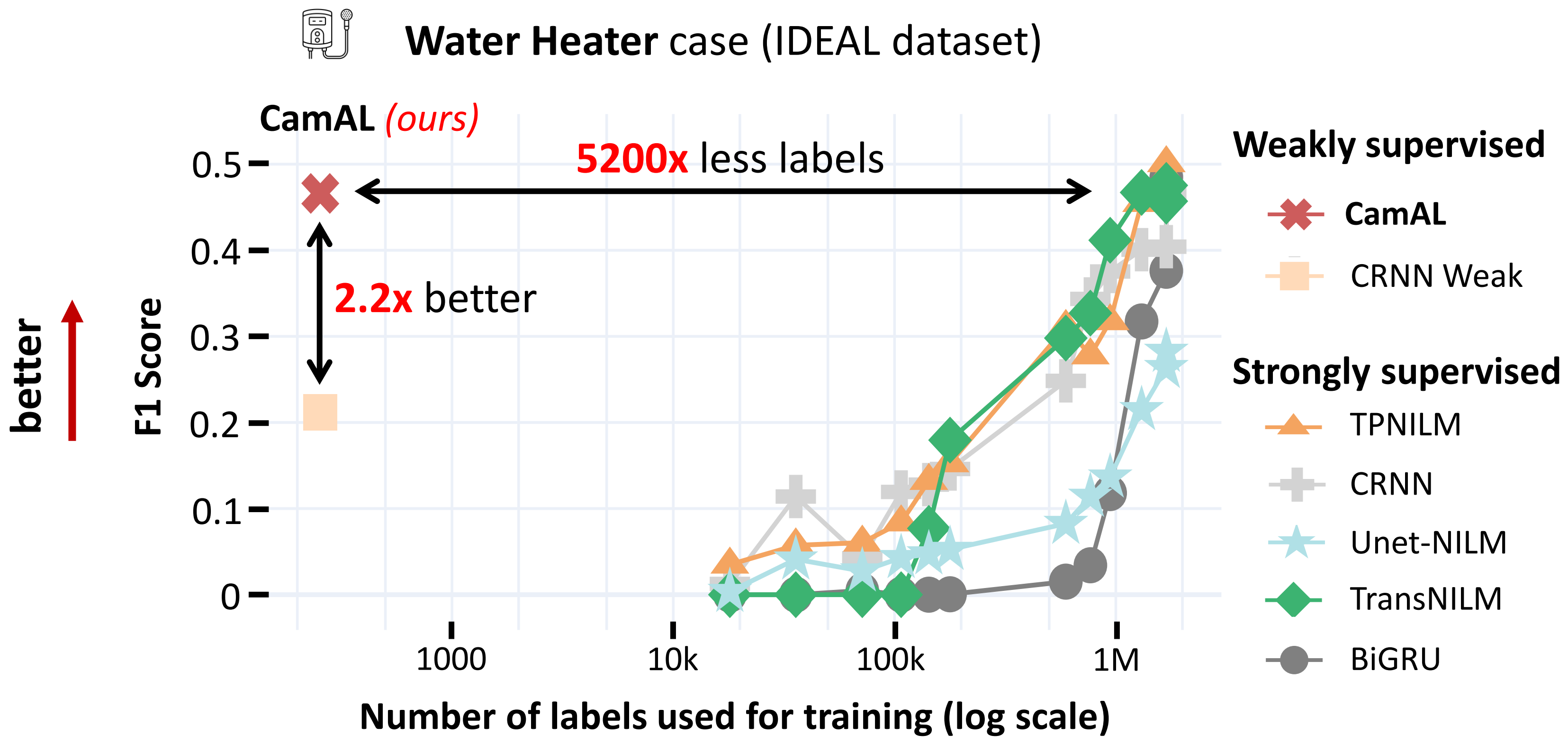
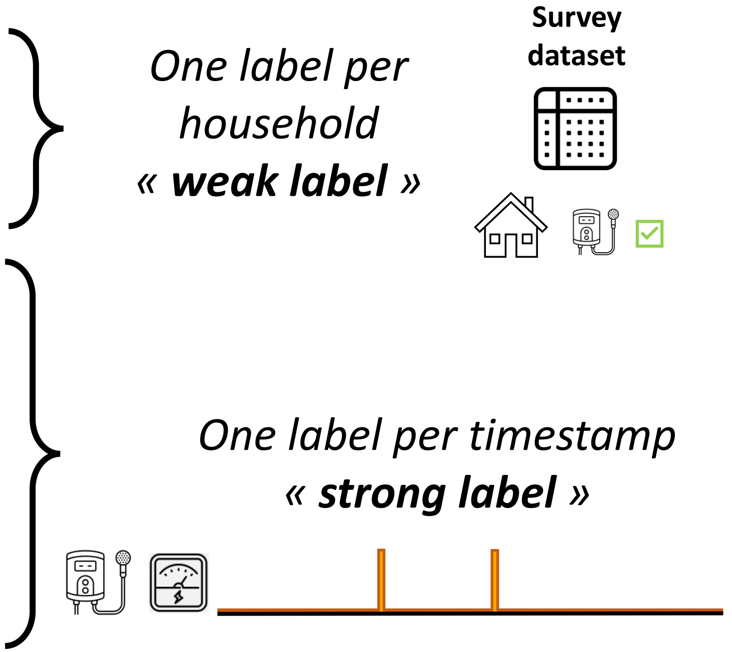


How does **CamAL perform** compared to **strongly-supervised baselines**?



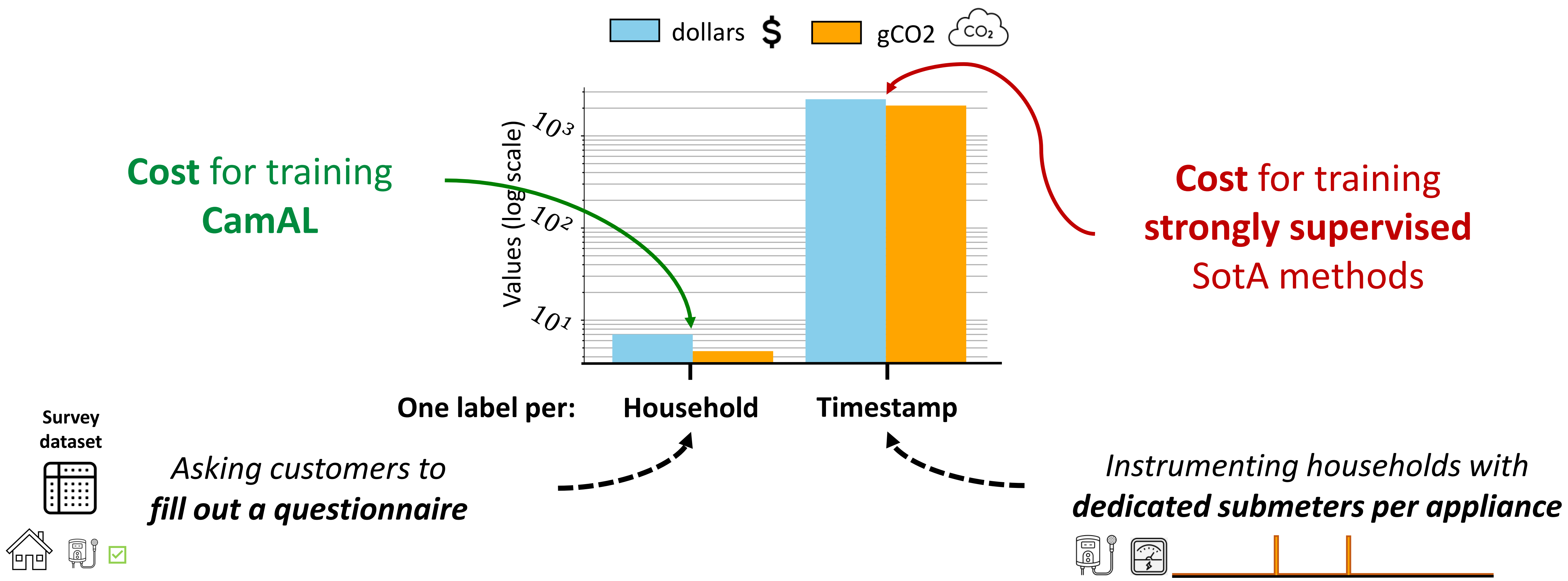


2.2x more accurate *for same number of labels!*

Up to **5200x less labels** *for same accuracy!*

Experimental Evaluation: Results

How do **label-collection costs** vary between **approaches**?



Reduce** collection **cost** (gCO2 and cash) **by up** to **2 magnitude orders!

Conclusion

- **CamAL** (**C**lass **A**ctivation **M**ap based **A**ppliance **L**ocalization)
  - ➢ Leverage **explainable AI** to tackle **appliance-pattern localization** using ***weak labels***
  - ➢ Achieve near–**strongly supervised** method's accuracy while drastically **reducing labeling costs**

- **CamAL** is the first "**frugal**" yet **accurate** method for identifying **appliance-usage patterns** in smart-meter data.

- **Promising open research direction:** generate softly labeled sub-meter activation signals to train sequence-to-sequence approaches.

Thank you!

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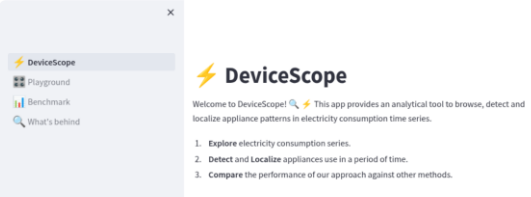

Github repo

Online demo