Is Machine Learning *Necessary* to Use in Cloud Resource Management?

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About Me

2015

2021

Start: October 2021

Born and raised in Greece.

Undergrad in ECE at NTUA, Athens, Greece.

PhD in CS at Georgia Tech, Atlanta, USA.

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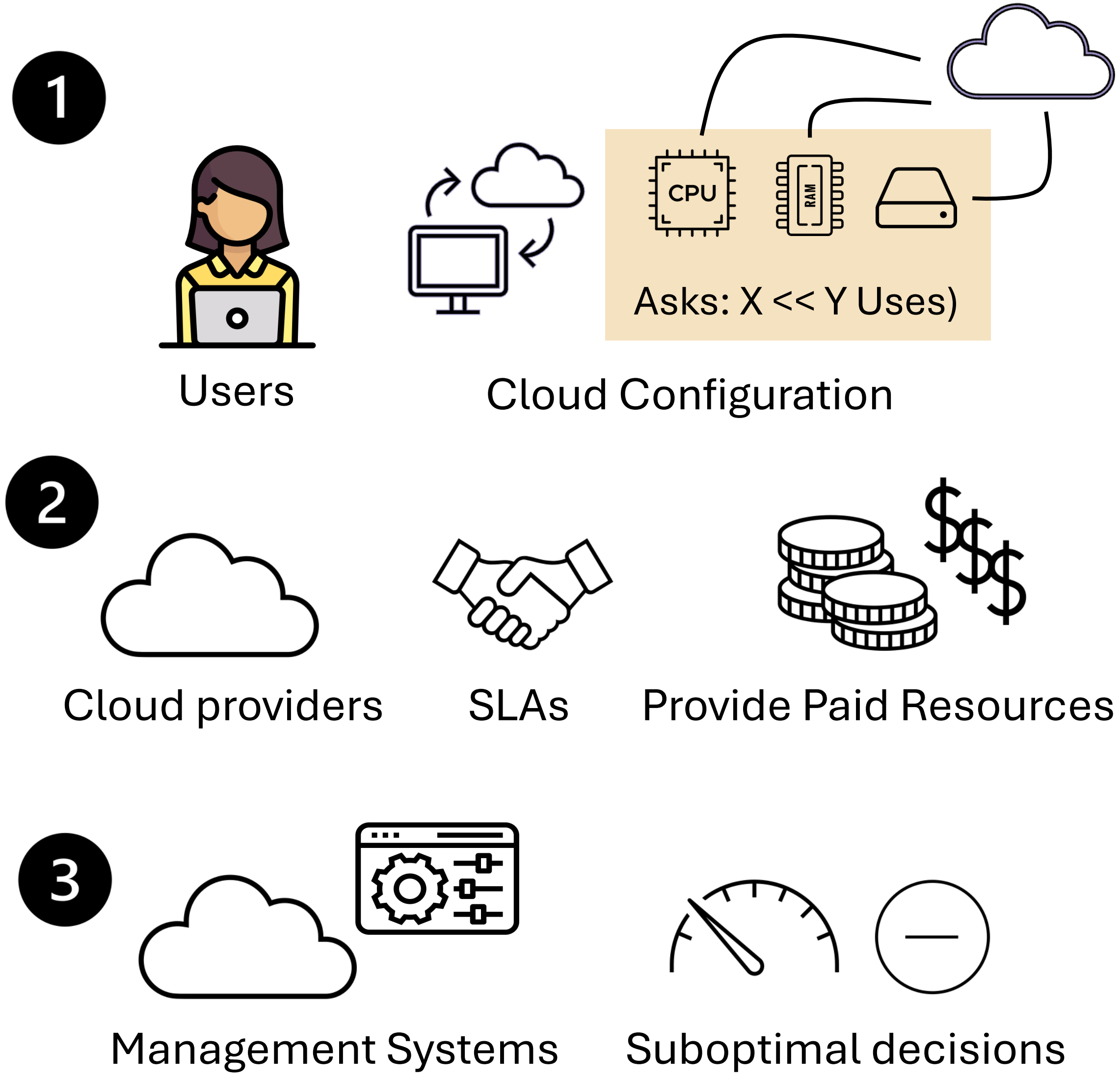
Cloud Resource Efficiency

What causes low resource efficiency?

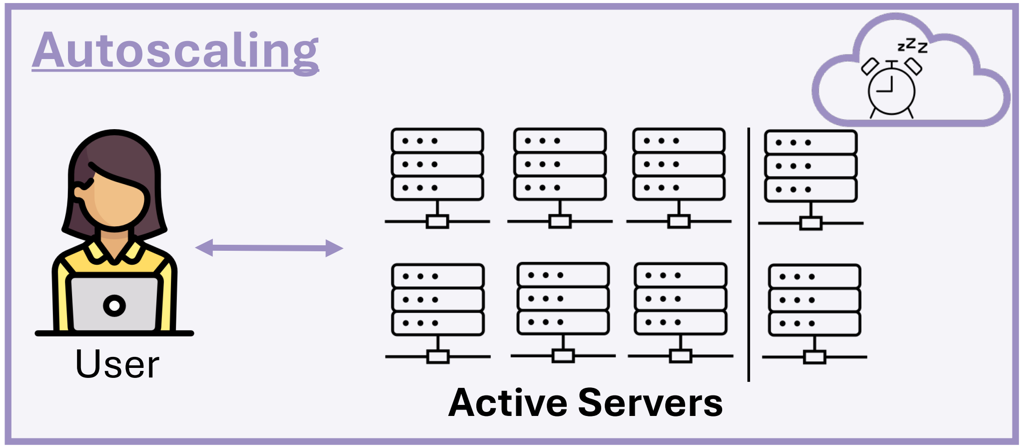


Data center resource utilization ~20%.

Cloud Resource Management Techniques

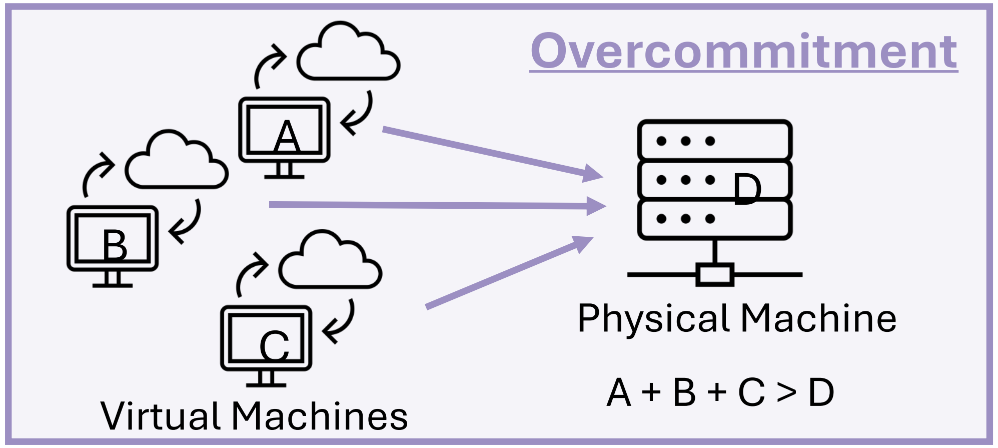
The following techniques help increase resource utilization and efficiency.

Basic idea: don't give to the user what they ask for, only what they actually use.



Dynamically **scale up or down** the number of computational resources e.g., active servers, number of CPUs.

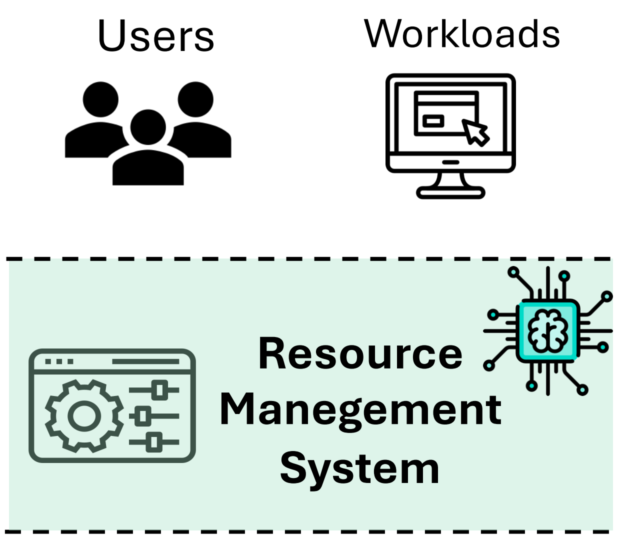
Delayed adjustment.
Performance reduction.



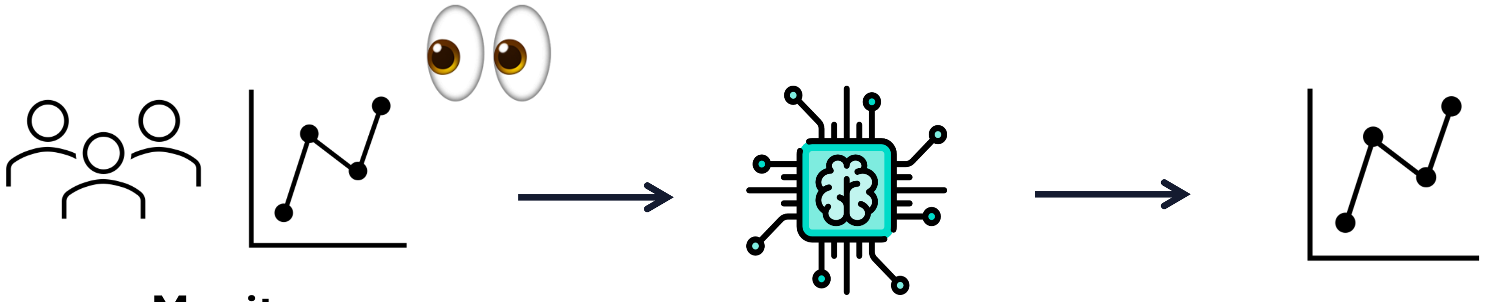
Allocate **more virtualized** resources than the ones physically available.
Assumes users *underutilize* resources.

Resource contention.
Performance reduction.

The Key: Resource Usage Forecasting



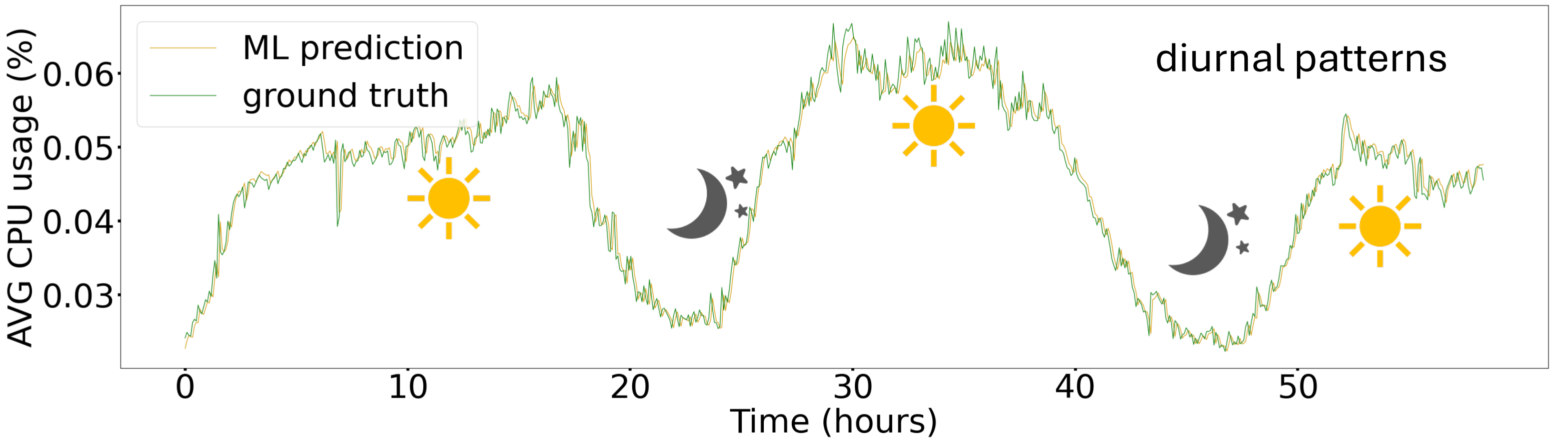
Hardware in the “Cloud”



Monitor
User Behavior
Workload Patterns

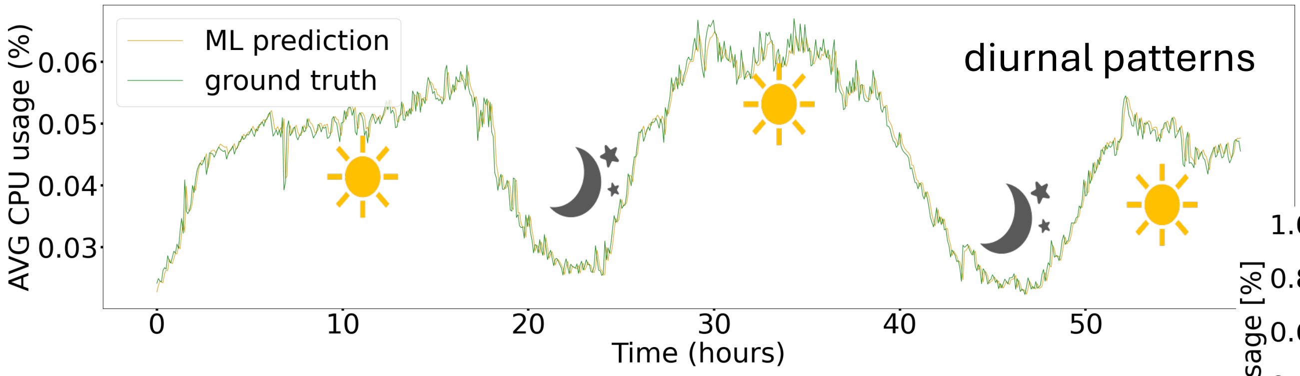
Predictor

Future
resource usage,
demand, load.

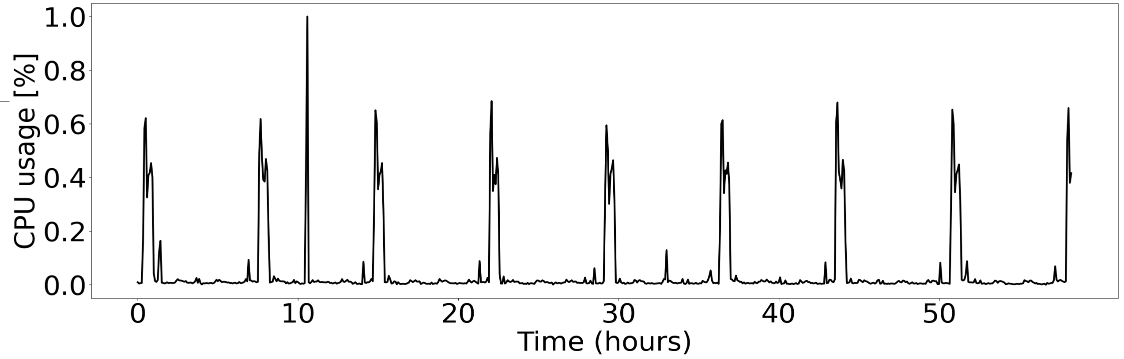


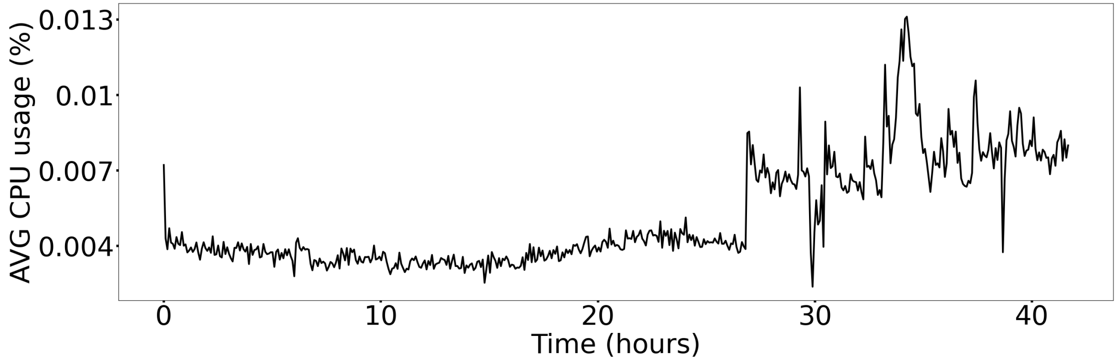
Accurate Predictiors → Timely and Effective Resource Management → Resource Efficiency.

Accurate Resource Usage Forecasting is Challenging

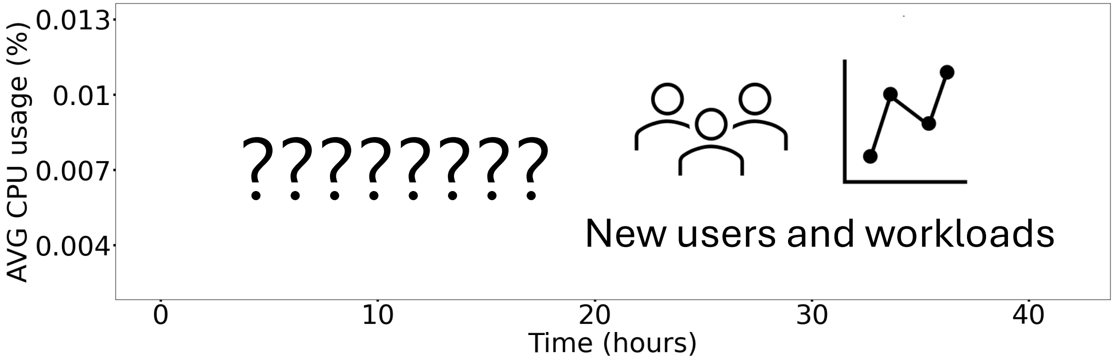


Stable, periodic, diurnal patterns are **predictable.**





Sudden changes, spikes, high dynamicity, are **hard to predict.**



Unseen patterns could be completely **unpredictable.**

Predictors for Resource Overcommitment

Existing Predictors
Future Usage =

1. Borg
90% * **Limit**

2. Resource Central
sum of the 99-th%-ile

3. N-Sigma
U+$N*std$(**U**)

4. Take-it-to-the-limit (TITTL) = Max (1, 2, 3)

Why Max?

To eliminate potential *under*-estimations, which may cause:

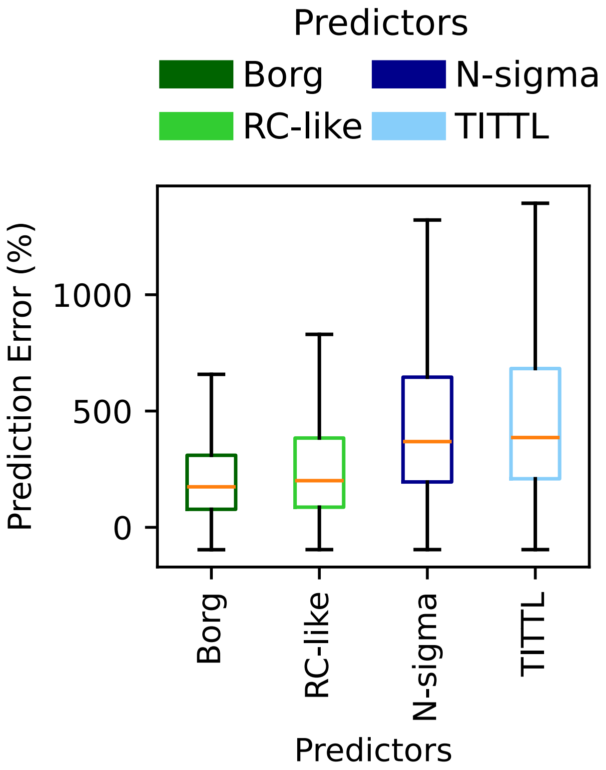
- Degraded workload performance.
- Unecessary resource auto-scaling.
- User SLA violations.

Simple, lightweight, explainable and easy to engineer in production-level.

Do they accurately predict resource usage or just protect from under-estimations??

[EuroMLSys '24] *Do Predictors for Resource Overcommitment Even Predict?* Georgia Christofidi and Thaleia Dimitra Doudali.

Do they Even Predict?



😱 Prediction error is extremely high, especially for TITTL.

😱 **Predicted resource usage >> resource limit.**
🙅 The cloud provider will NEVER allocate to a user more resources than requested and paid for!

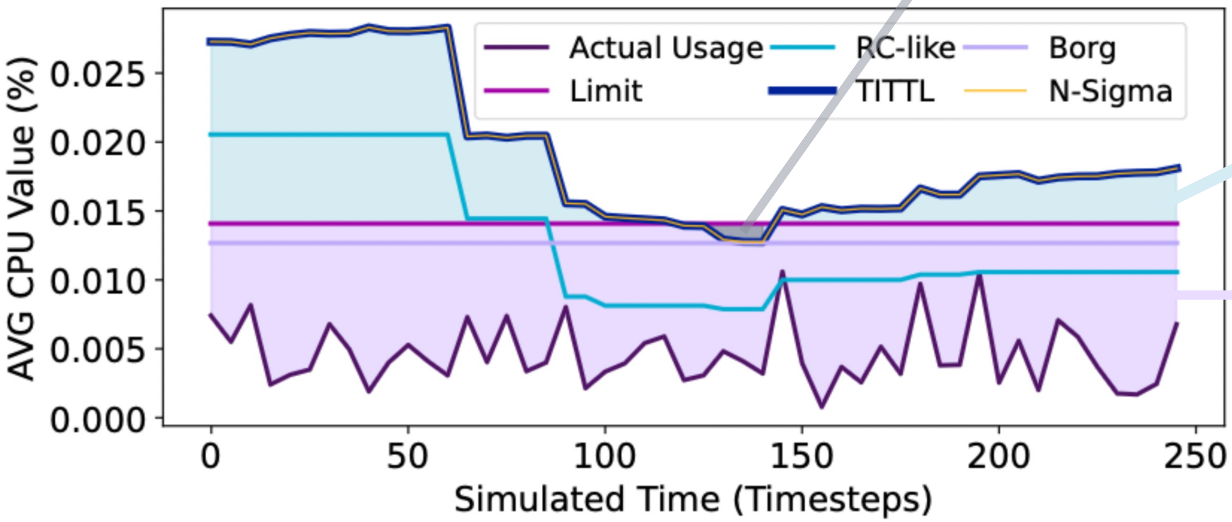
😬 **NO overcommitment** is happening for **94%** of the cases we examined, due to the predictor's **OVER-estimations.**

😱 Predictors just protect from under-estimations, ***allowing*** overcommitment **only 6%** of the times.

[EuroMLSys '24] *Do Predictors for Resource Overcommitment Even Predict?* Georgia Christofidi and Thaleia Dimitra Doudali.

Missed Opportunity for Resource Savings

Usable resources.
Resource savings **(2%)**



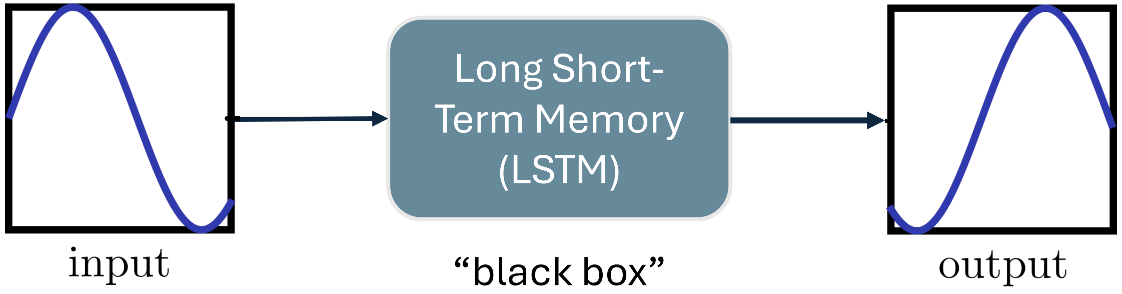
Completely wasted resources.

Maximum possible resource savings **(61%)** with an **accurate** predictor.

Here it seems to be ***necessary*** to have a more **accurate** and **intelligent** predictor!
At least a predictor that actually predicts!

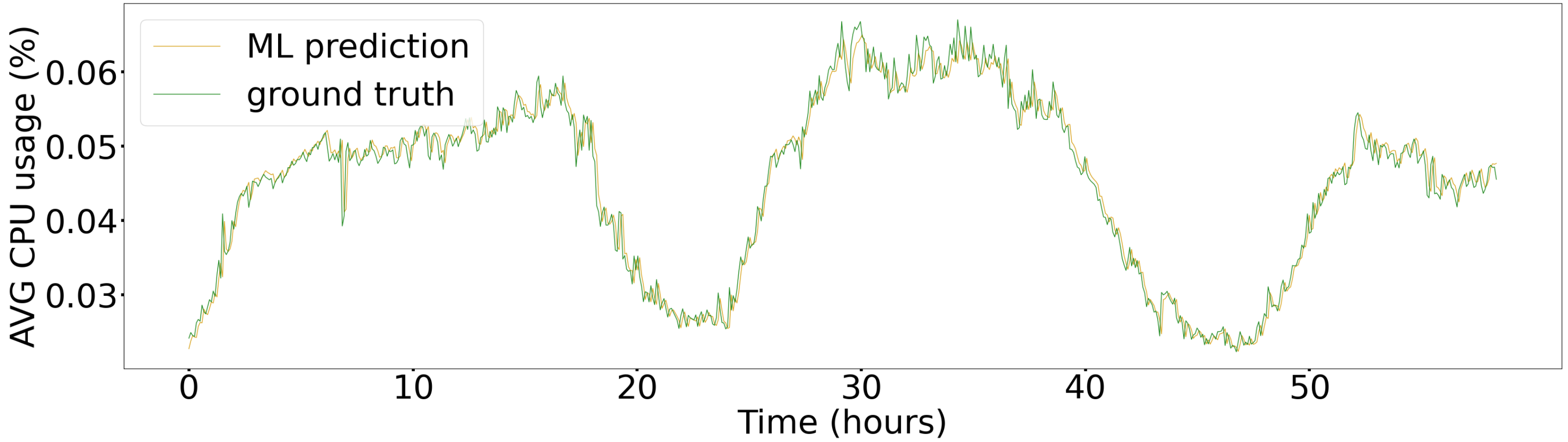
[EuroMLSys '24] *Do Predictors for Resource Overcommitment Even Predict?* Georgia Christofidi and Thaleia Dimitra Doudali.

Use Machine Learning? Let's use LSTMs!



Predict with high accuracy:

Traffic Conditions   Stock Market Prices   Weather

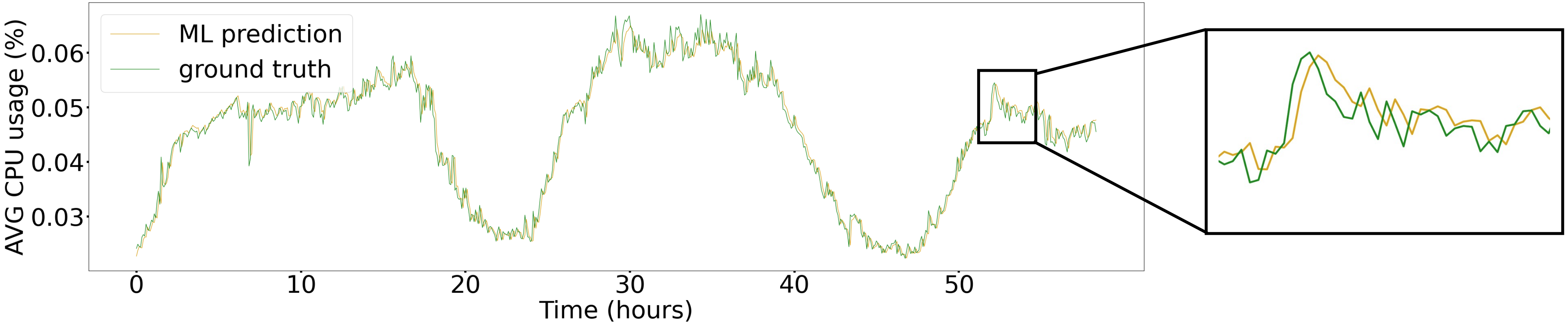


🥳 Looks quite accurate for cloud resource usage!!

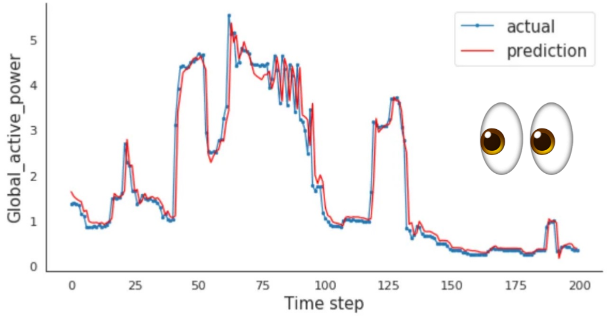
🥳 And seems to generalize well across patterns!

[EuroMLSys '23] Toward Pattern-based Model Selection for Cloud Resource Forecasting.
Georgia Christofidi , Konstantinos Papaioannou, Thaleia Dimitra Doudali.

Let's Take a Closer Look! 👀



Insight: LSTM predictions look like "shifted" versions of the real (ground truth) data.



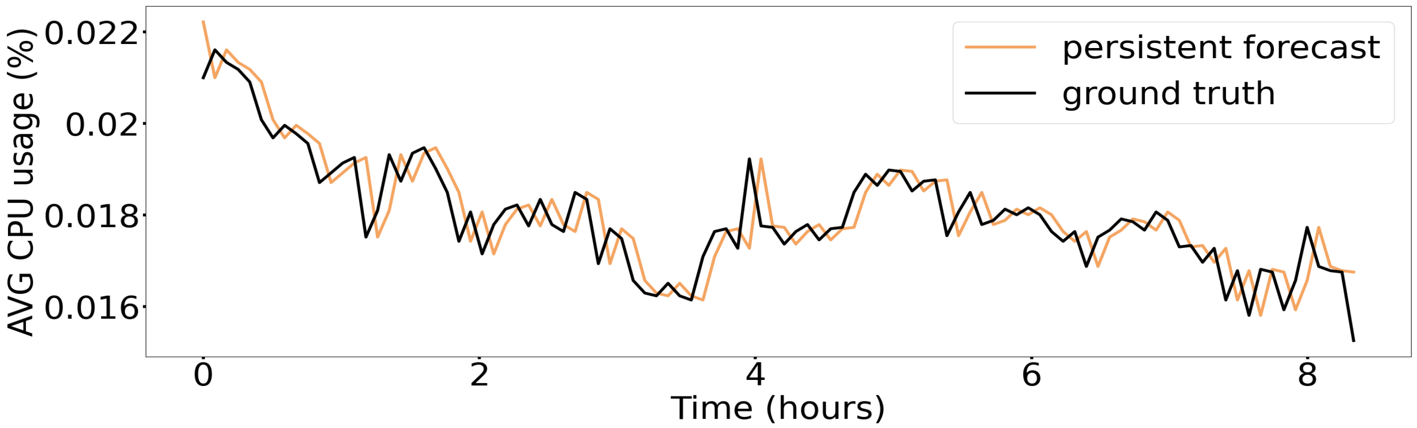
Source "Time Series Analysis, Visualization & Forecasting with LSTM" on towardsdatascience.com

<u>Lesson Learned</u>
Validate that ML *actually* learns!

[SoCC '23] *Is Machine Learning Necessary for Cloud Resource Usage Forecasting?*
Georgia Christofidi , Konstantinos Papaioannou, Thaleia Dimitra Doudali.

A Simple and Practical Predictor

Idea: Predict a shifted version of the ground truth, similar to the LSTMs.



Persistent Forecast**

Predicted Value(t) =

Ground Truth(t – 5 mins)

**[VLDB ‘21] Seagull: An Infrastructure for Load Prediction and Optimized Resource Allocation. By Microsoft.

Simple, lightweight, explainable and easy to engineer in production-level.

Does it accurately predict resource usage?

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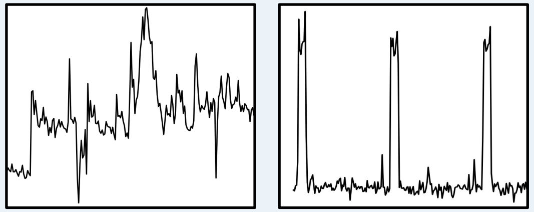
Extensive Experimental Evaluation

Public open-source datasets across different:

Cloud providers	Resource Types	Resource Levels	Usage Patterns	Frequency
Alibaba Cloud, Google Cloud, Microsoft Azure, Bitbrain	CPU, RAM	Physical Machine, Virtual Machine, Workload		Hourly/ Daily/ Weekly Windows

We calculate the **prediction error** of the persistent forecast.

... will it work or do we *need* some other machine learning method?

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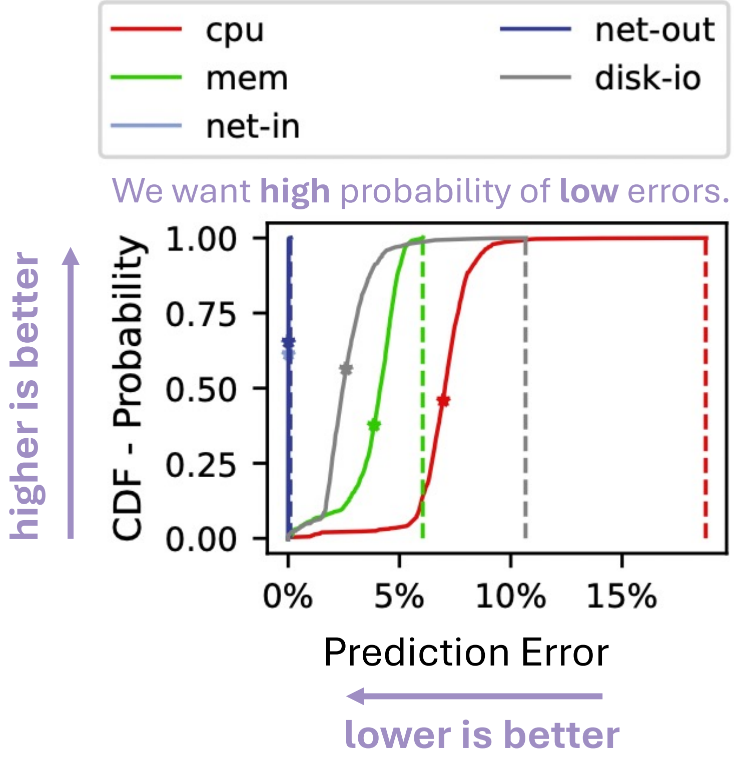
Results – Physical Machines

Physical Machine

Alibaba Dataset
Physical Machine Level



Observations:

- net-in, net-out } Error ~ 0 🤩
- disk-io, mem } Avg. Error < 4 % Short tail. 😁
- cpu } Avg. Error ~ 7 % Longer tail. 😃

<u>Physical Machines</u>
Have **stable** load.

Persistent Forecast is **very** accurate!

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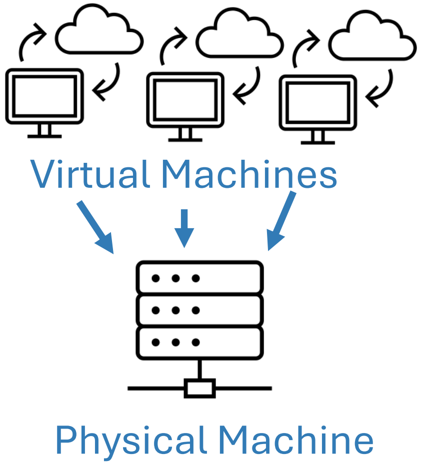
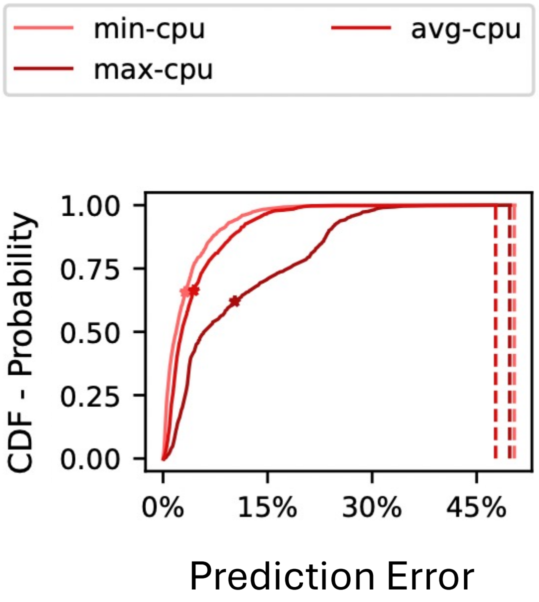
Results – Virtual Machine

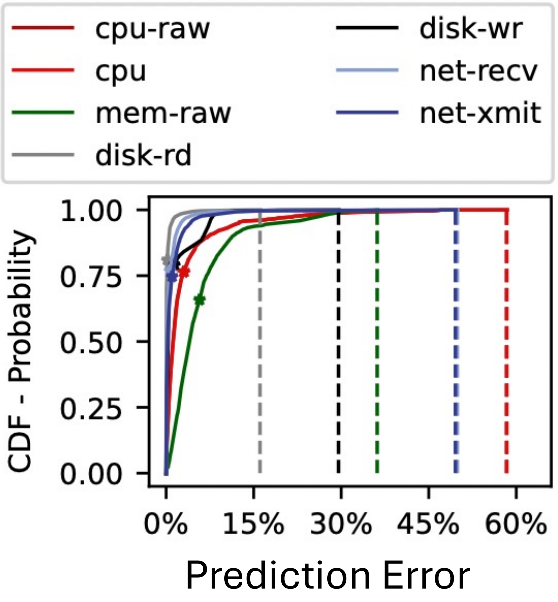


Azure Dataset
Virtual Machine Level

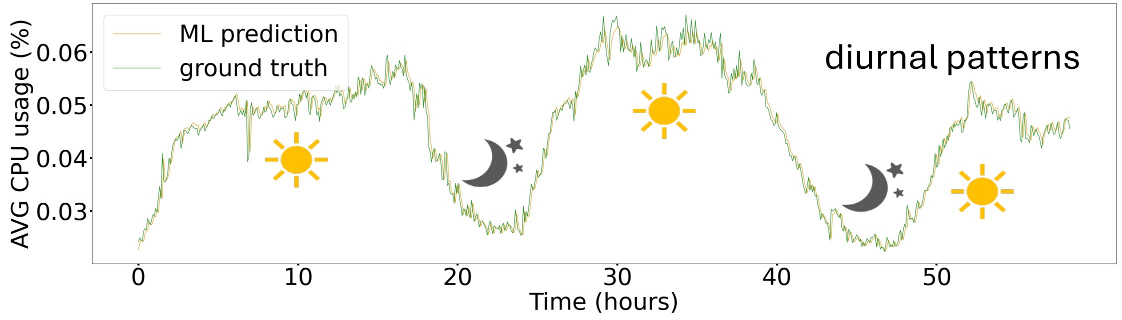


Average Prediction Error < 10%

Bitbrains Dataset
Virtual Machine Level



Average Prediction Error < 6 %



<u>Virtual Machines</u>
On average, **stable and periodic** load.
Patterns start becoming more dynamic.
(longer tails in the error)

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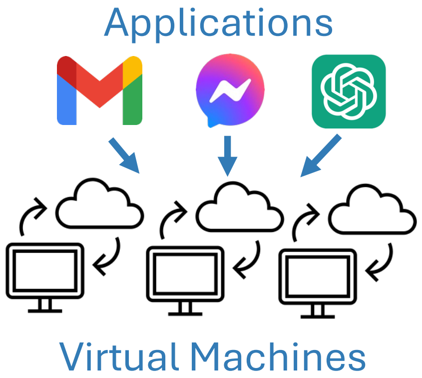
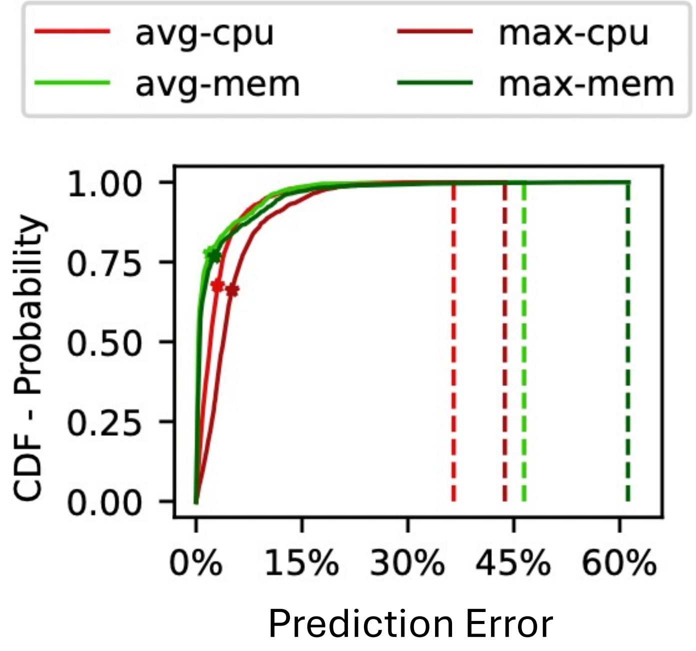
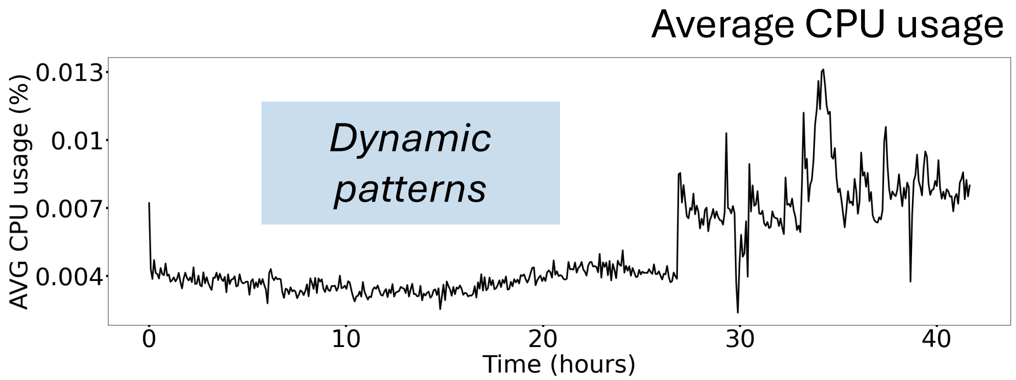
Results – Applications

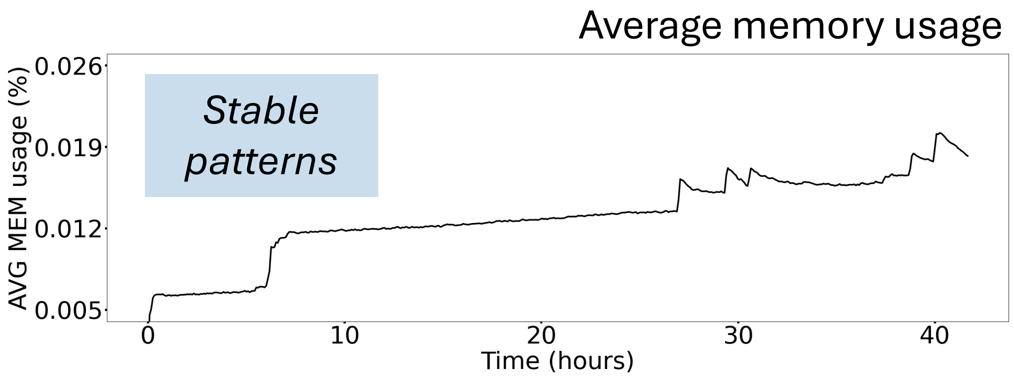


Google Dataset
Workload Level



Average Prediction Error < 6%





Applications

Most **dynamic** patterns.
(longest tails in the error)
Depends on the
type of resource!

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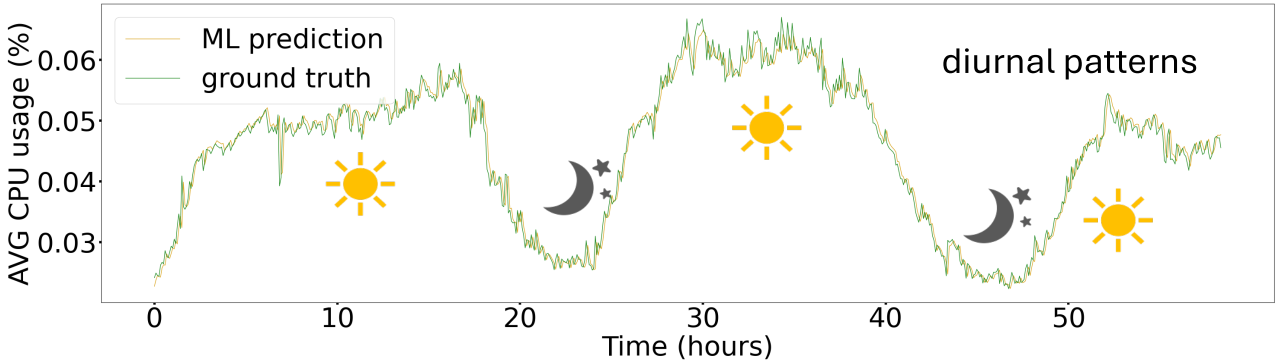
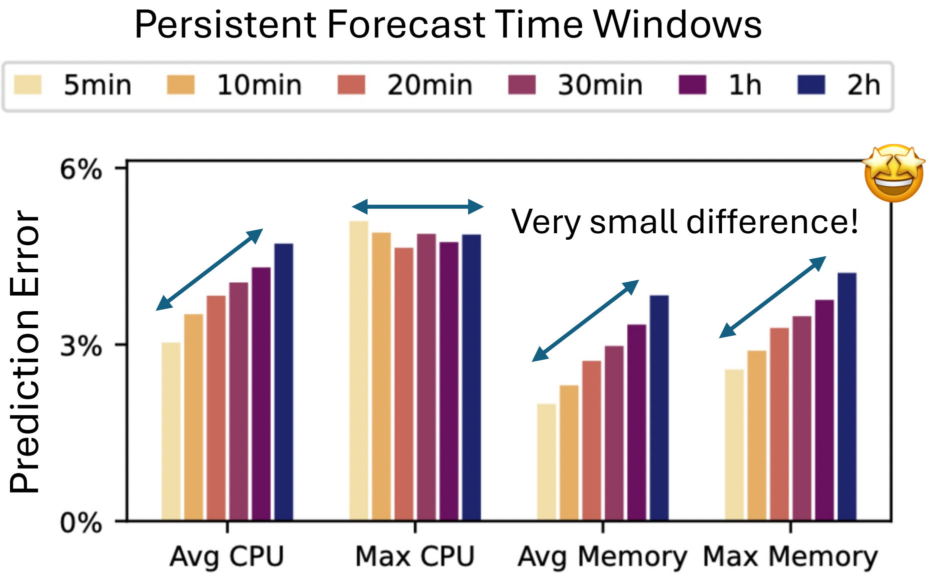
Why the Persistent Forecast Works?

Overall, on average, the persistent forecast is **very accurate**, prediction error < 6%. Why?





Because cloud resource usage is **highly persistent over time**, it changes very little every e.g. 5 minutes.

Low sensitivity to the time window length, reveals potential **repeating patterns** in the data.
This unlocks **opportunity** for even lower errors, if the time window matches the data periodicity.

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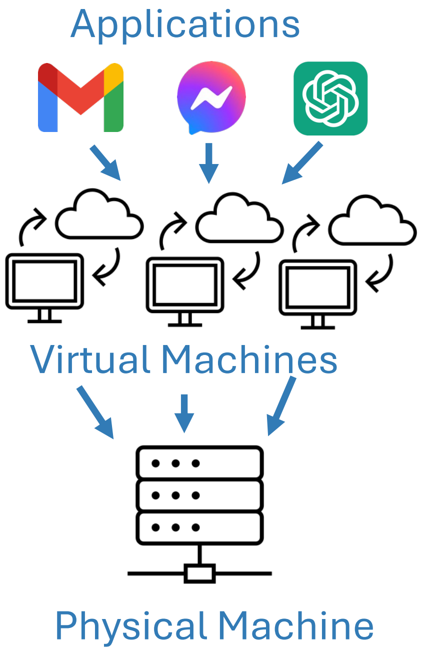
Is Machine Learning Necessary?



No!!

At least not always..

When is ML necessary?

Level	Pattern	ML?
Application	Dynamic	**Yes (?)**
Virtual Machine	Periodic	No
Physical Machine	Stable	No

Type	Pattern	ML?
CPU	Dynamic	**Yes (?)**
Memory	Stable	No
Disk	Stable	No
Network	Stable	No

ML can be useful for reacting to unseen patterns: (1) if similar-seen: predict (2) if unseen: learn.

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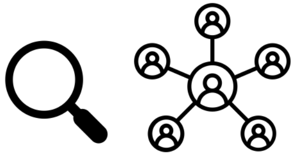
New Questions and Challenges to Adress

1. When to Use ML?



Build data-driven methods to identify whether to use ML or not, e.g., Pattern detection and classification.

2. Which ML to use?

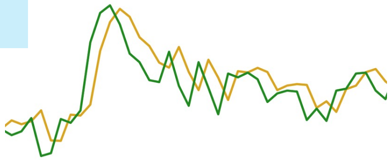
Probably not LSTMs.. 🫣 One of the current SOTA.. transformers? ChatGPT?

[AI4Sys @ HPDC 2024] *Toward Using Representation Learning for Cloud Resource Usage Forecasting*. Razine Ghorab, Thaleia Dimitra Doudali.

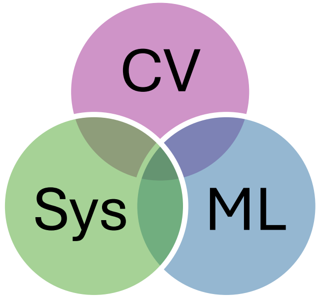
Production likes **simple and explainable**, e.g. decision trees?

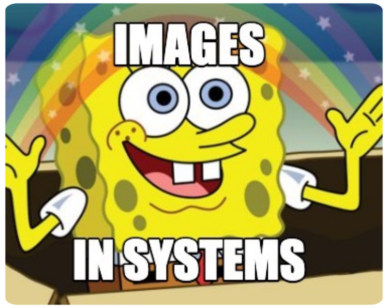
3. Validate ML actually learns!

Definitely use visual validation!



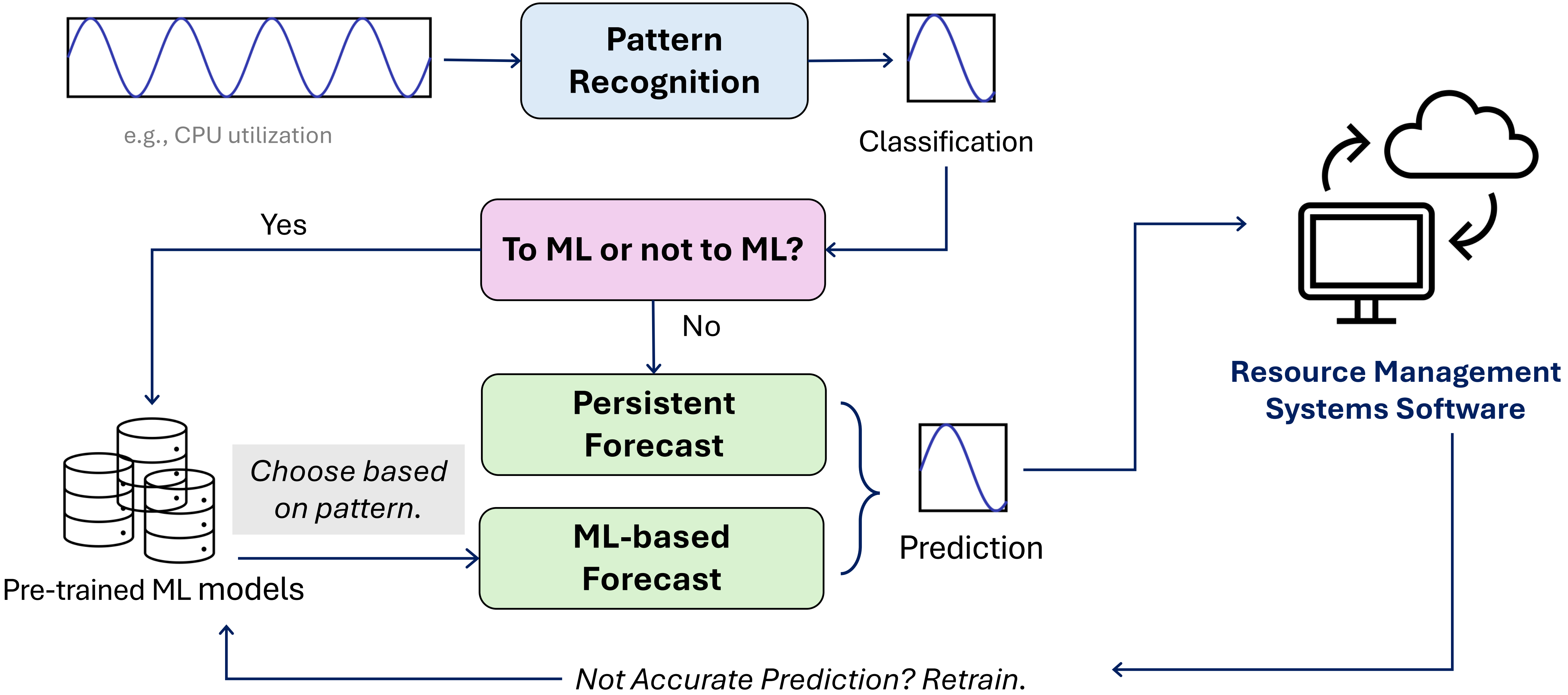
Maybe even some **Computer Vision (CV)** methods?





[Wild and Crazy Ideas @ ASPLOS 2022] A picture is worth a 1000… features!
Using Computer Vision alongside Machine Learning in Computer Systems Thaleia Dimitra Doudali.

Use ML to Augment, not Replace** - Our Vision

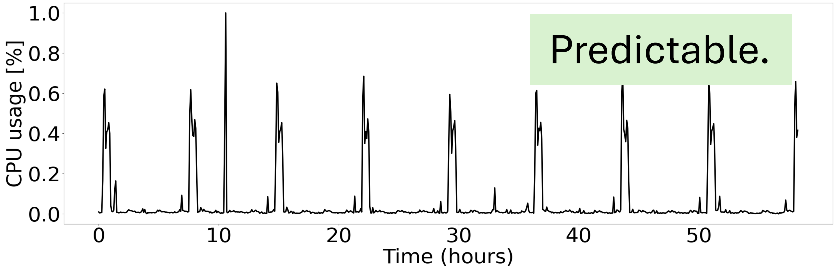


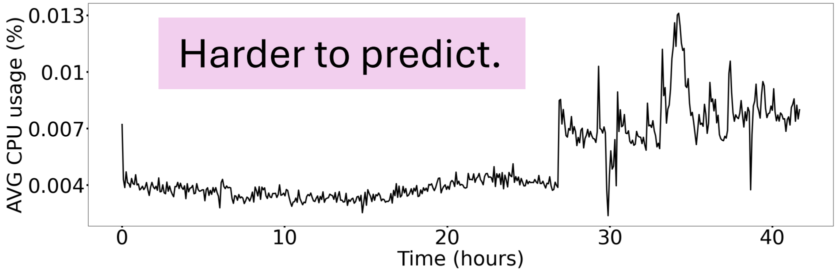
**[SIGMOD 2023 Companion] Towards Building Autonomous Data Services on Azure. (Microsoft agrees!)

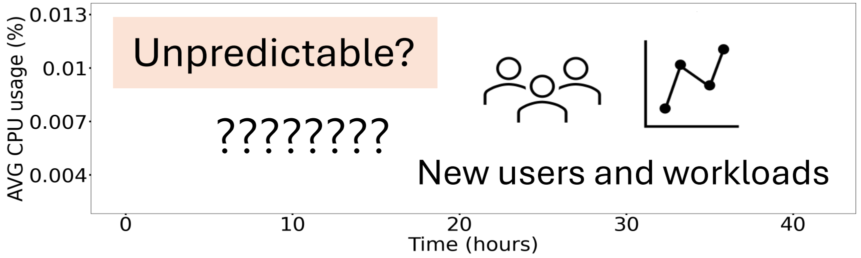
Summary

Machine Learning is *not always* necessary in cloud resource management.

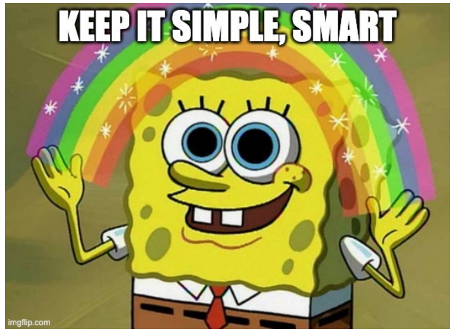
It all depends on the patterns.







Use **simple, explainable, lightweight** ML methods to **augment, not replace** robust analytical models, like the **persistent forecast.**



[SIGOPS Blog] KISS: Keep it Simple, Smart.
[SIGARCH Blog] Think Twice Before Using Machine Learning to Manage Cloud Resources.
Both written by Thaleia Dimitra Doudali

Thanks to my brilliant PhD students! 🫶

Georgia Christofidi

Konstantinos Papaioannou

Website

GitHub