Lecture #1: Course Introduction

Mario Bergés
Professor

12-770: Autonomous Sustainable Buildings: Theory to Practice

Civil & Environmental
ENGINEERING
Carnegie Mellon

Who Google thinks I Am

About me

Born and raised in

Became a Civil Engineer there

Came to

to merge my degree with

Now doing research on smart infrastructure

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About you

- CEE ……. 10 (10 MS)
- Architecture 3 (3 MS)
- MechE….. 1 (1 MS)

- __ Professionals?
- __ Students?

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Student Introduction

- Good opportunity to get to know your classmates.
- Your program and year (undergraduate or graduate).
- Interest for this class (why you are taking this course).
- Future plan (going to industry or continuing for Ph.D.).
- Other information that you like to share with others.

WHY ARE YOU HERE?

Objectives

Grading

- Assignments 40%
- Written Knowledge Contribs. 5%
- Project Progress Report 15%
- Final Project 40%
  - Written report (30%)
  - Demonstration (10%)

Where to get your information?

canvas
BY INSTRUCTURE

https://sites.inferlab.org/courses/12-770

Project Progress Update

- 10% for a team-authored progress report
- 10% for individual meetings with instructors

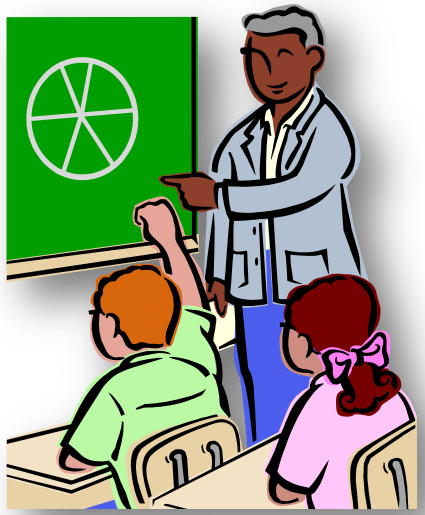
Final Project Deliverables

- Written report (30%)

- Formatting and organization (15%)
- Grammar, clarity and accuracy of ideas (15%)
- Display of mastery of concepts covered in class (35%)
- Creativity expressed in the solution (10%)
- Depth of discussion related to the pros/cons of the implemented solution (15%)
- Overall assessment of the project's idea nd execution (10%)

- Demonstration (10%)

Class Policy



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Course Outline

- First third (1/16 – 2/22):
  - Lecture #1: *Course Introduction*
  - Lecture #2: *Setting up your learning / tinkering computer environment*
  - Lecture #3: *Review of Data Acquisition*
  - Lecture #4: *Setting up your RPi and Shields*
  - Lecture #5: *Building Thermodynamics: Part I*
  - Lecture #6: *Building Thermodynamics: Part II*

Course Outline

- First third (1/16 – 2/22):
  - Lecture #7: *Occupant Thermal Comfort*
  - Lecture #8: *Basics of Energy Simulation: Part I*
  - Lecture #9: *Basics of Energy Simulation: Part II*
  - Lecture #10: *Simulating Occupant Loads*
  - Lecture #11: *Designing Controllers with Simulation Engines*
  - Lecture #12: *Building Energy Simulation Wrappers*

Course Outline

- Second third (2/27 – 3/26):
  - Lecture #13: *Project Proposals*
  - Lecture #14: *Smart Thermostats*
  - Lecture #15: *Occupancy Estimation*
  - Lecture #16: *Thermal Comfort Estimation*
  - Lecture #17: *Autonomous HVAC Control for Buildings*

Course Outline

- Second third (2/27 – 3/30):
  - Lecture #18: *TBD*
  - Lecture #19: *TBD*
  - Lecture #20: *Automated Demand Response*

Course Outline

- Final third (4/3 – 4/26):
  - Lecture #21: *Environmental Monitoring Kit*
  - Lecture #22: *Occupancy Estimation Kit*

Course Outline

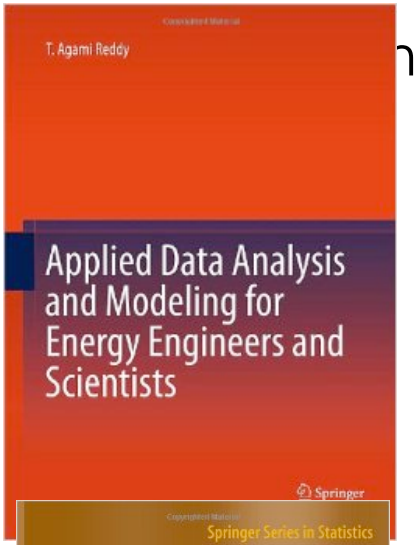
- Final third (4/4 – 4/27):
  - Lecture #23: *Project Progress Reports*
  - Lecture #24: *Project Feedback / Guidance*
  - Lecture #25: *Project Feedback / Guidance*
  - Lecture #26: *Project Feedback / Guidance*
  - Lecture #27: *Guest Lecture: What can I do with these skills in the job market?*

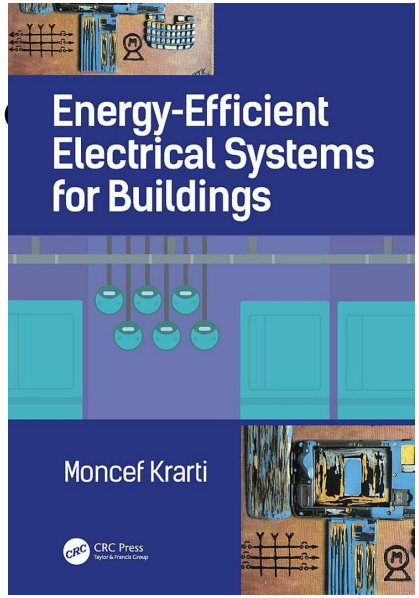
Tuesday	Thursday
Jan 16th **1** **Lecture #1**	Jan 18th **2** **Lecture #2**
Jan 23rd **3** **Lecture #3** Assignment #1 Out	Jan 25th **4** **Lecture #4**
Jan 30th **5** **Lecture #5**	Feb 1st **6** **Lecture #6**
Feb 6th **7** **Lecture #7**	Feb 8th **8** **Lecture #8** Assignment #1 Due Assignment #2 Out
Feb 13th **9** **Lecture #9**	Feb 15th **10** **Lecture #10**
Feb 20th **11** **Lecture #11**	Feb 22nd **12** **Lecture #12**

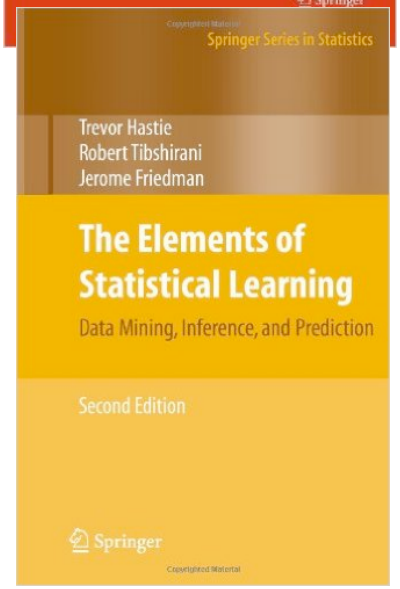
Feb 27th **13** **Lecture #13**	Feb 29th **14** **Lecture #14** Assignment #2 Due Assignment #3 Out
Mar 5th **15** **SPRING BREAK** No Class	Mar 7th **16** **SPRING BREAK** No Class
Mar 12th **17** **Lecture #15**	Mar 14th **18** **Lecture #16**
Mar 19th **19** **Lecture #17**	Mar 21st **20** **Lecture #18**
Mar 26th **21** **Lecture #19** Assignment #3 Due Assignment #4 Out	Mar 28th **22** **Lecture #20**

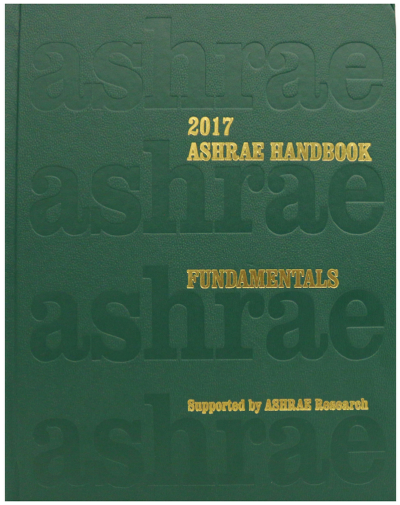
Apr 2nd **23** **Lecture #21**	Apr 4th **24** **Lecture #22**
Apr 9th **25** **Lecture #23** Assignment #4 Due	Apr 11th **26** **SPRING CARNIVAL** No Class
Apr 16th **27** **Lecture #24**	Apr 18th **28** **Lecture #25**
Apr 23rd **29** **Lecture #26**	Apr 25th **30** **Lecture #27**

Readings









- Right now, I don't have a full grasp of all the reading material, but I will post everything I can on Canvas.

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Useful skills to start with

- Familiarity with the command line and with Unix environments
- Version control systems, especially *git* and git-related workflows
- Experience with Python programming
- Measurement and instrumentation theory
- Familiarity with IoT devices and ecosystems
- LaTeX

Let’s get things started…

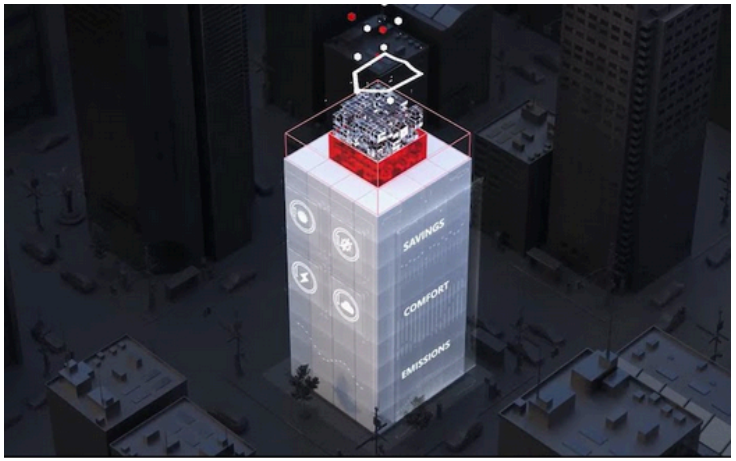
A LITTLE BIT ABOUT WHAT I DO

Autonomous Buildings: A Pipe Dream Until They Consider Human Values and Expertise

IN2WIBE-AI Workshop

Mario Bergés
Professor
Carnegie Mellon University
https://inferlab.org

(How) Can AI help us design, construct, operate and use buildings in ways that promote well-being?



AI analytics in building management systems will help make buildings smart and responsive

By **Nicholas Nhede** - Jan 20, 2020

ABB unveils new AI-enabled corporate and business office in its Bangalore-based Peenya campus; Stock hits new high

The facility, named Disha, will house the corporate office, along with the offices of Electrification and Motion businesses alongside Process Automation business in the same campus.

BrainBox AI raises $24 million to expand into building automation

NOVEMBER 2, 2021 BY DAVID EDWARDS — LEAVE A COMMENT

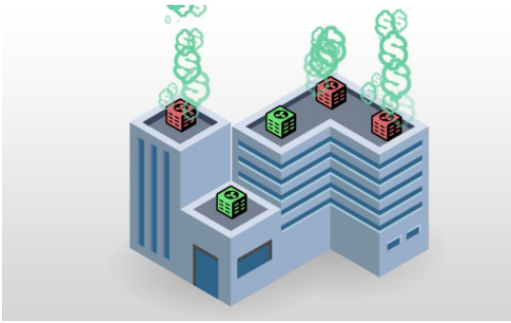
AI-enhanced Energy Management Tech

Encycle expands Swarm Logic® to include HVAC system optimization fo heating

October 25, 2021

NREL pilots new AI-enabled Smart Community concept in Colorado

By **Nicholas Nhede** - Nov 4, 2021



How Artificial Intelligence is Transforming the HVAC Industry

Autonomous?

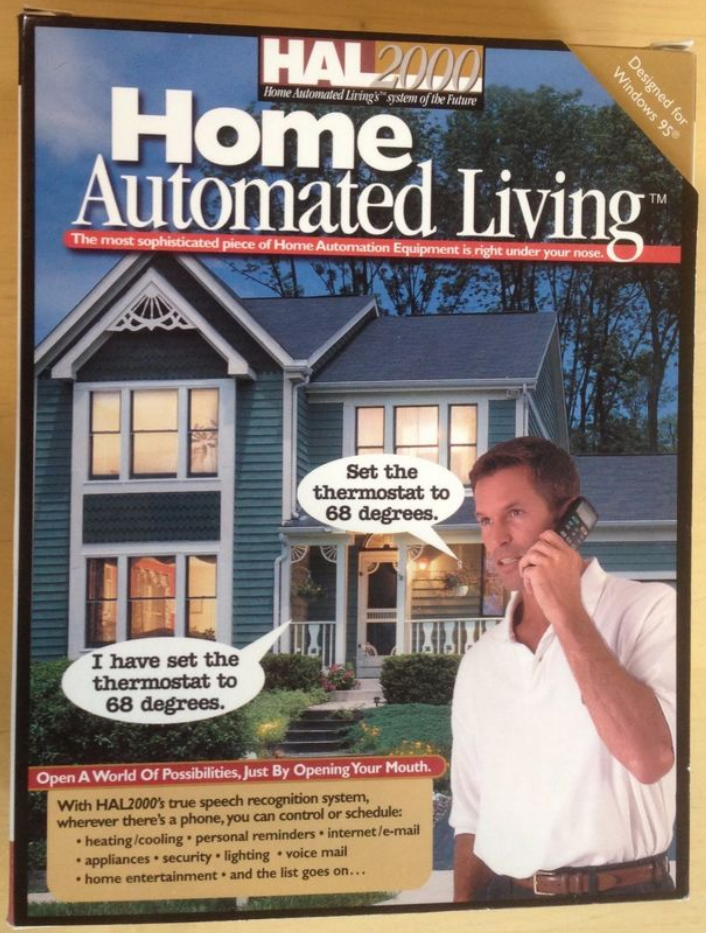
The Smart Home is Creating Frustrated Consumers: More than 1 in 3 US Adults Experience Issues Setting up or Operating a Connected Device

On average, consumers report spending 2.5 hours between self-help and customer support and speak with 3 different people to resolve an issue; 22 percent give up and return the product for a refund

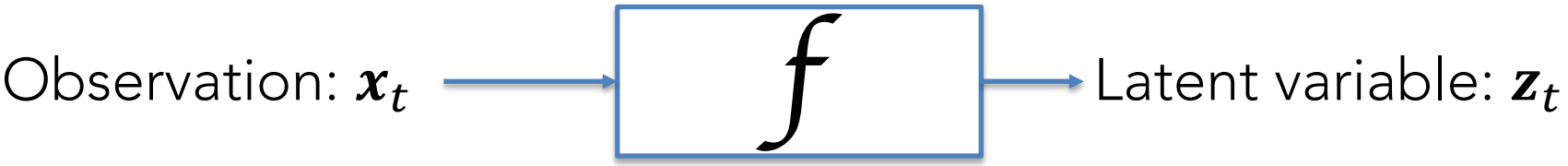
January 30, 2018 09:00 AM Eastern Standard Time

It’s not that new either…

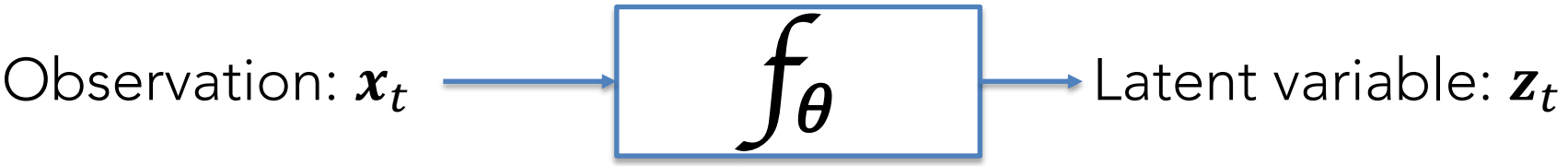
Source: eBay users aghound64 and answerking



Current AI is, largely, just very effective function approximation



We're just using data to fit (very complex) models

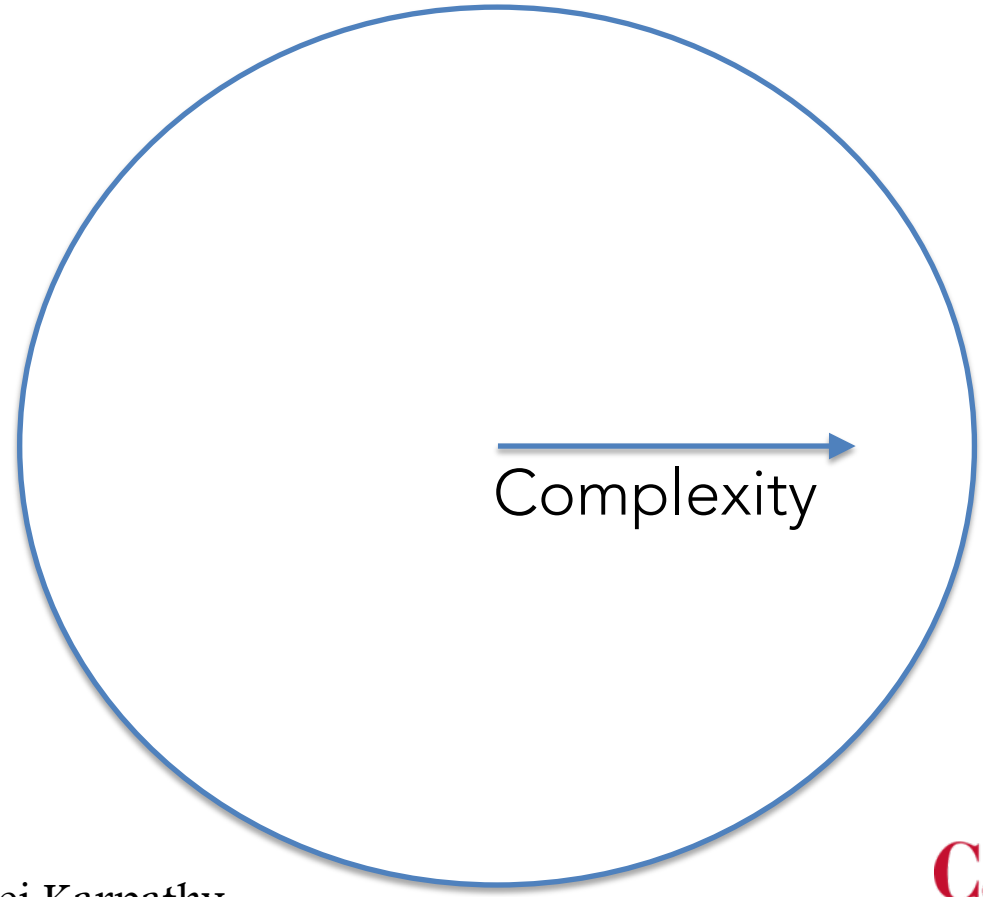


Supervised Learning
(regression, classification, even Reinforcement Learning[1]!)

[1] https://bair.berkeley.edu/blog/2020/10/13/supervised-rl/

Picking the right function family has consequences

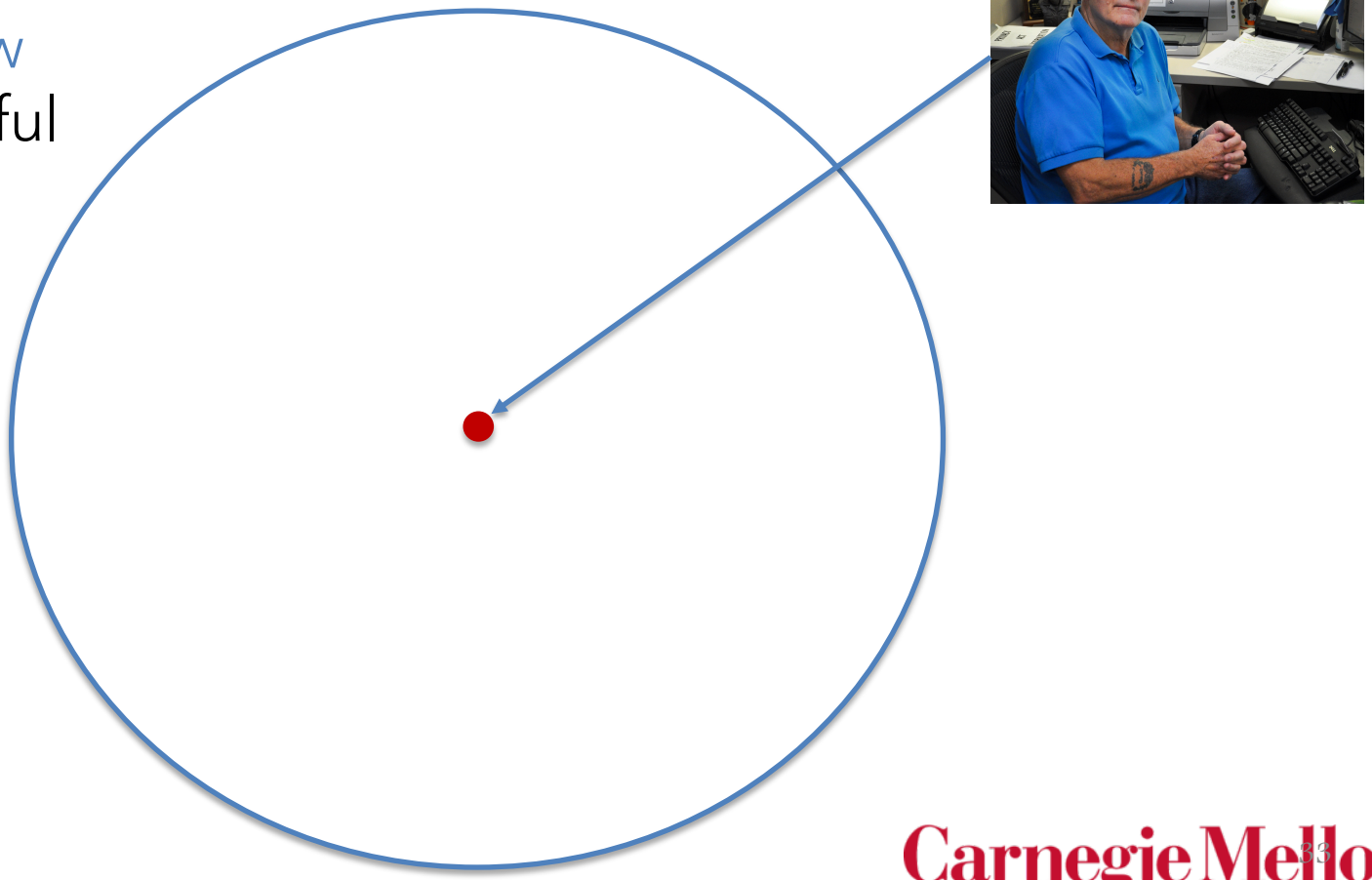
Space of all possible f functions:



Original idea by Andrej Karpathy

You can just use your existing knowledge, directly

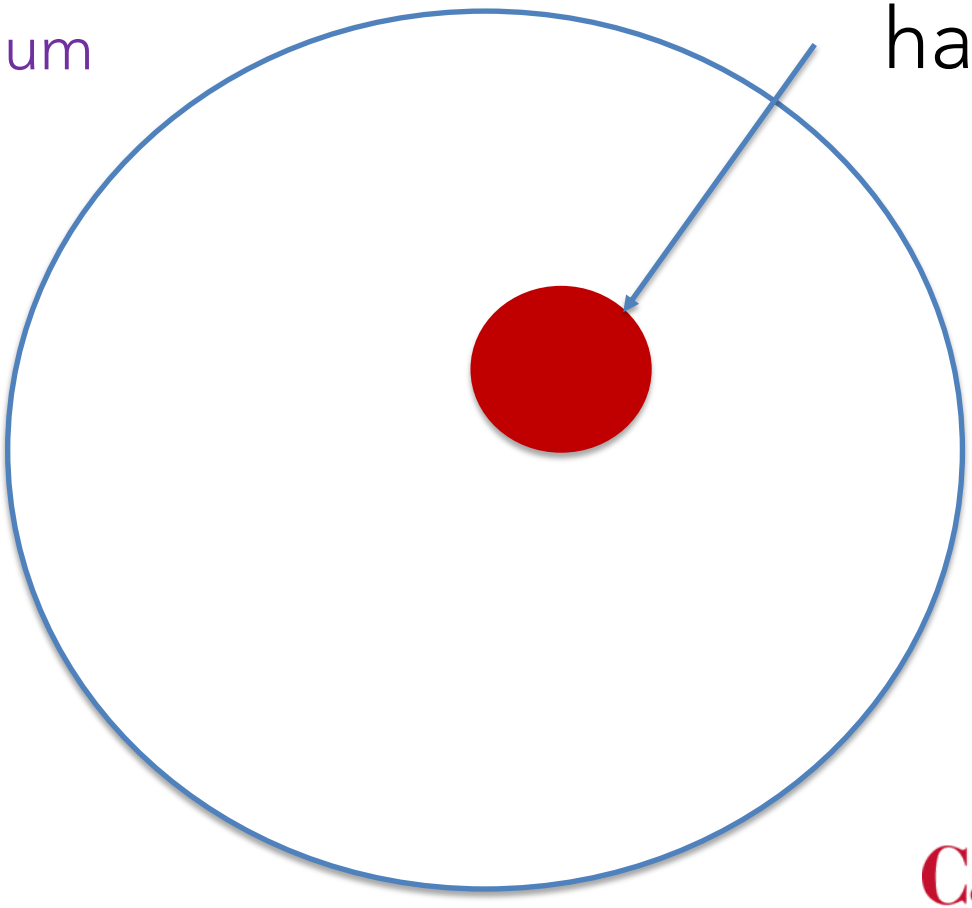
Bias: high
Variance: low
Data: not useful



Or you can let simple models learn the mapping

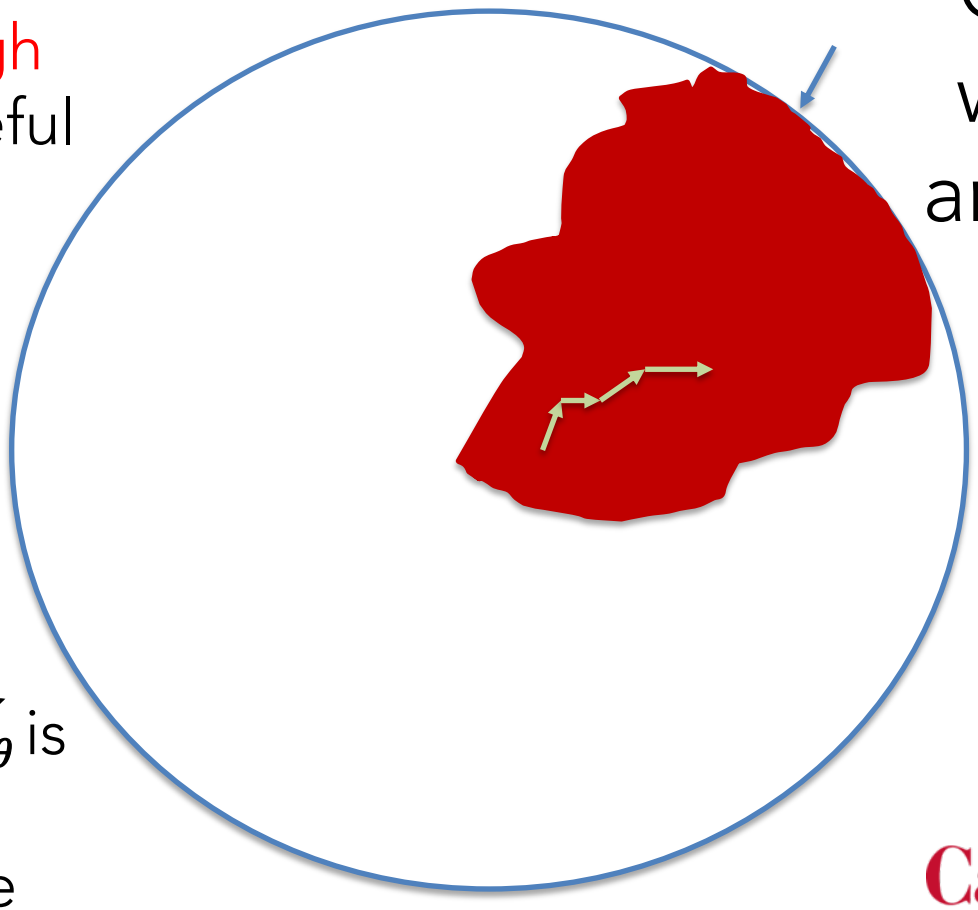
Bias: medium
Variance: medium
Data: useful

f_θ: SVM with hand-crafted features



Or fancier models models

Bias: low
Variance: high
Data: very useful

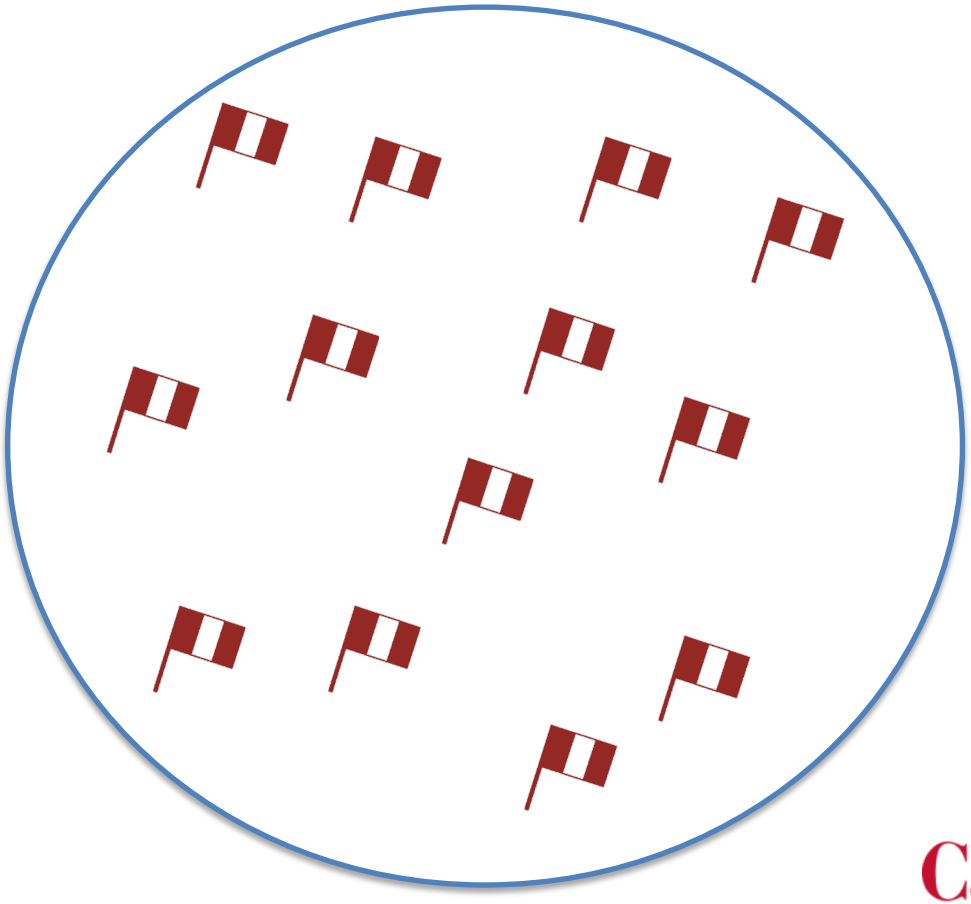


f_θ: deep ConvNets w/learned architecture

Note: it is convenient if f_θ is smooth and differentiable

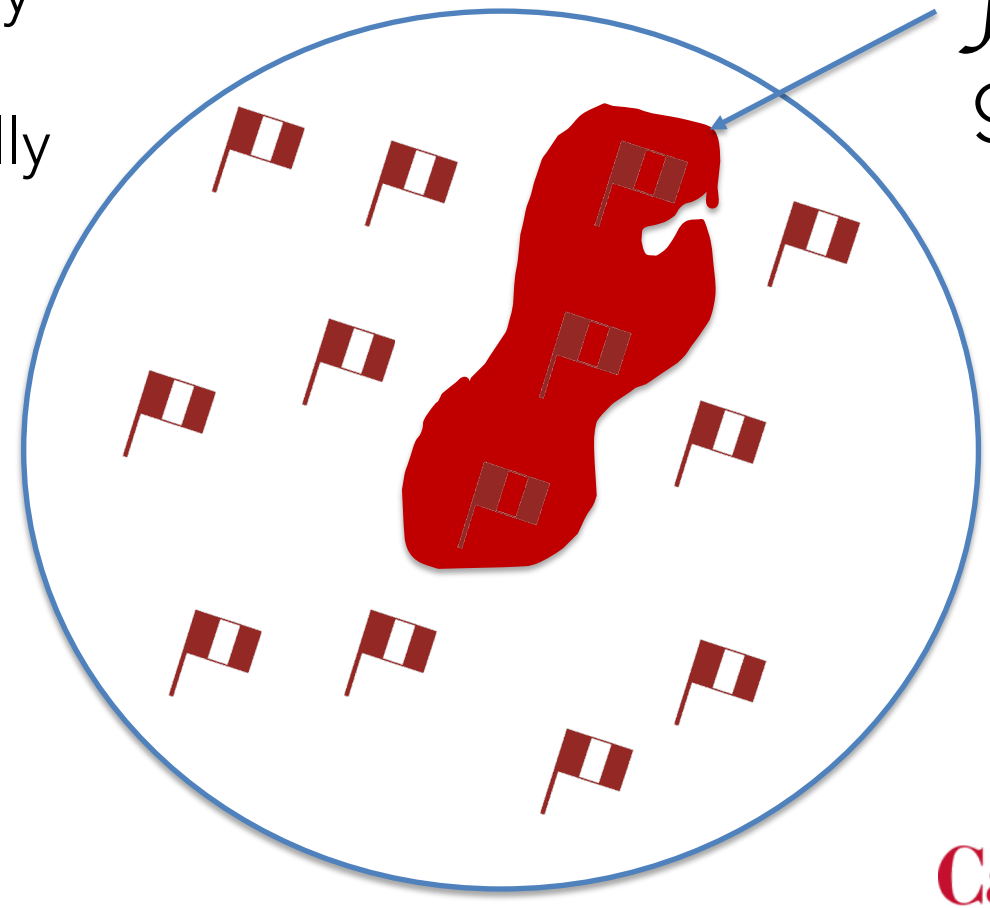
The Bad News:
The domain of f is HUGE!

(and gnarly)



We need to use our domain expertise AND human values to make the search more efficient

Note: still may lead to computationally intractable formulations



f_θ: a function grounded on physics, engineering knowledge, etc.

… and we haven't considered hyper-parameters!

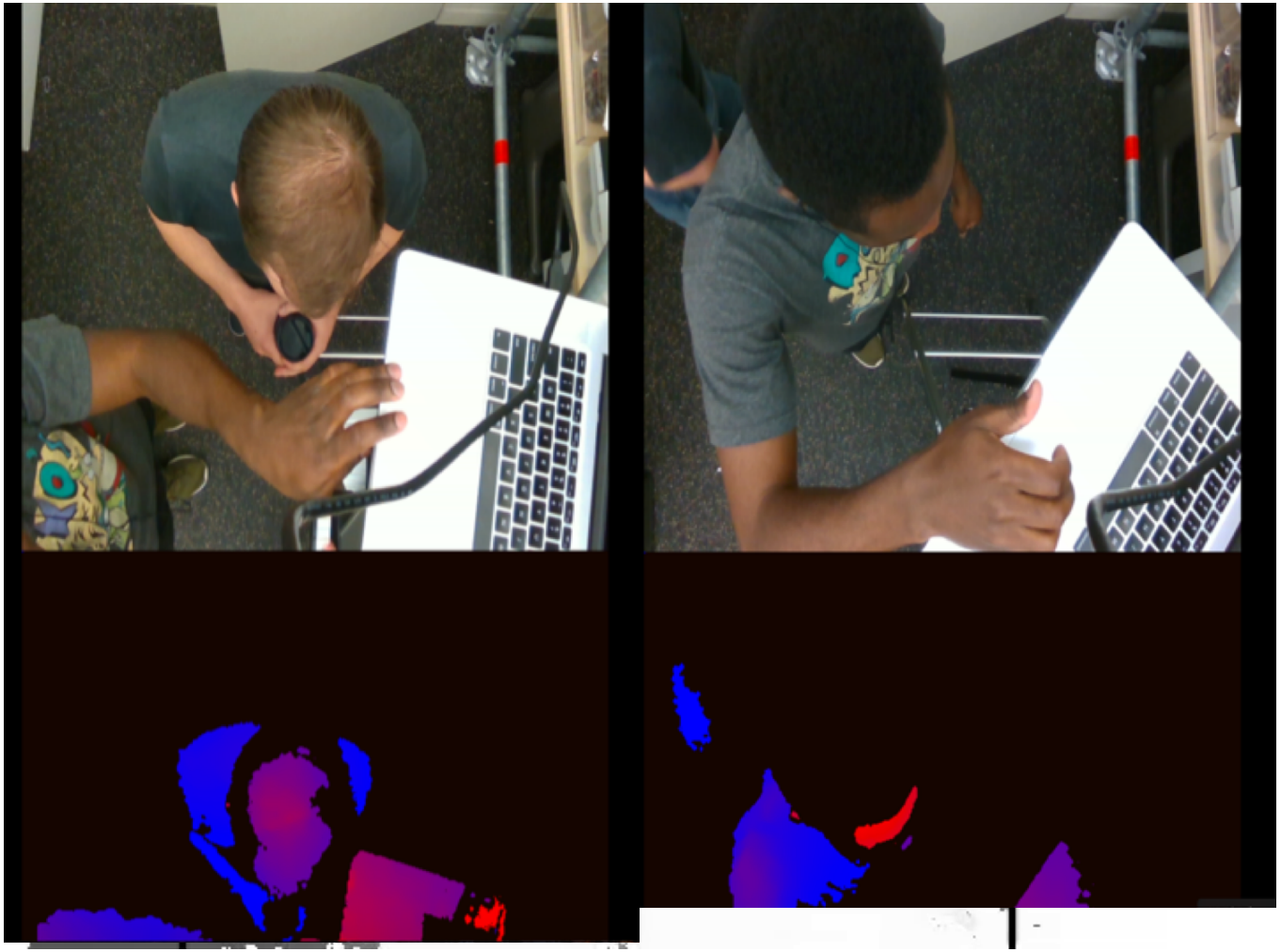
- We can learn functions that work well on test data, but still fail in real-world applications
- f_θ isn't just parametrized by theta:
  - System architecture
  - Dataset choice
  - Cosmic rays?

Relevant paper: https://arxiv.org/abs/2011.03395

So what can go wrong?

… a whole lot!

(Racial) Bias



Overconfidence on extrapolation!

- Conducted an 80-participant study for comfort data collection:
  - 3 hour sessions, 6 temperature set points
  - Experience sampling via mobile app, reporting comfort on a 5-point scale
  - Sensor data: wearables, building automation system, depth-imaging
- Preliminary data analysis shows a correlation between biometrics and comfort response.

Timeline:

1) Neutral – Hot – Neutral - Cold experiment

22^0C	28^0C	33^0C	22^0C	17^0C	15^0C
40 mins	30 mins	30 mins	30 mins	30 mins	30 mins

2) Neutral – Cold – Neutral – Hot experiment

22^0C	17^0C	15^0C	22^0C	28^0C	33^0C
40 mins	30 mins	30 mins	30 mins	30 mins	30 mins

Jonathan Francis, Matias Quintana, Nadine von Frankenberg, Sirajum Munir, Mario Bergés (2019). OccuTherm: Occupant Thermal Comfort Inference Using Body Shape Information. *Proceedings of the 6th ACM International Conference on Systems for Energy-Efficient Buildings, Cities, and Transportation.*

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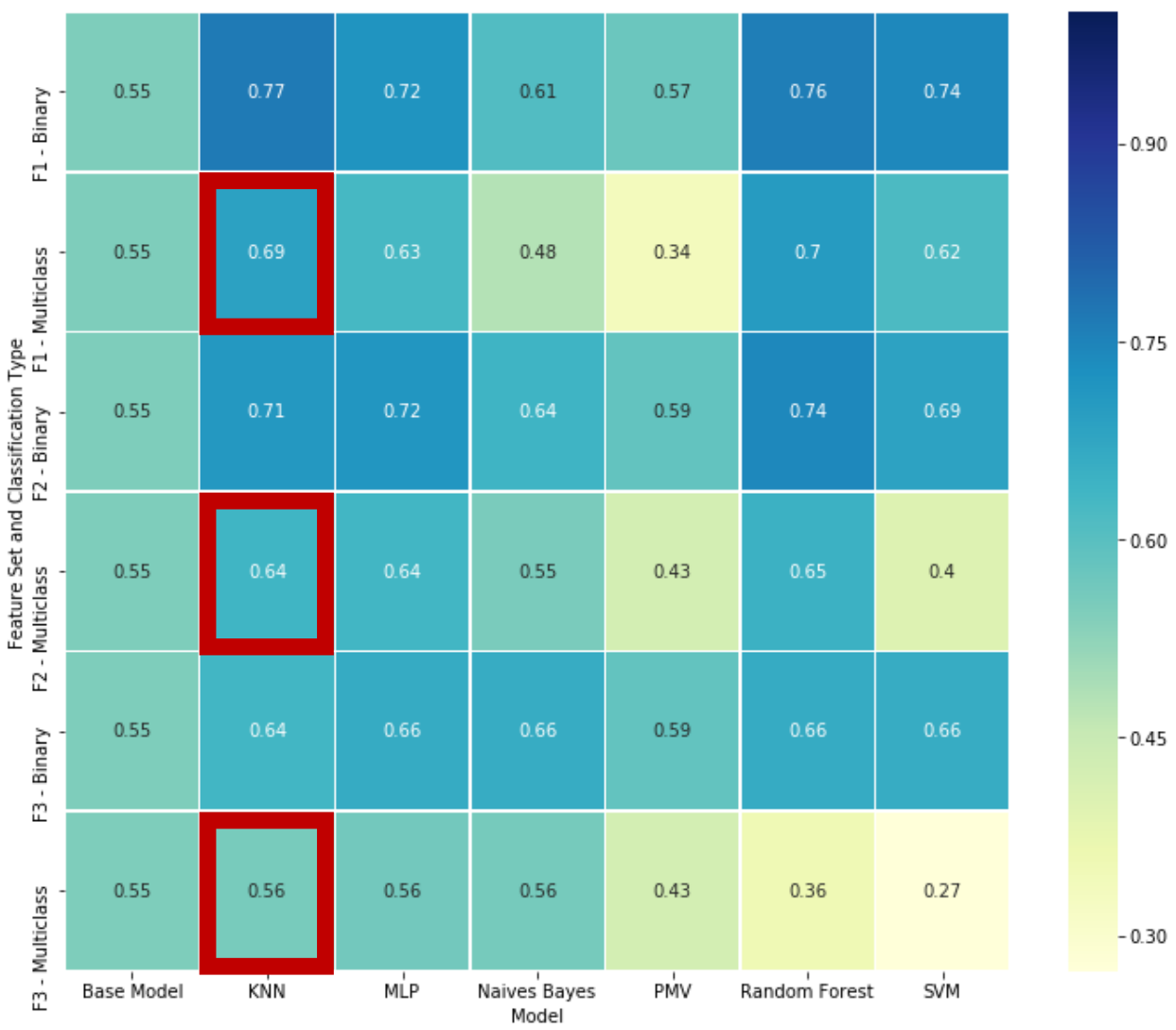
Results

Featureset 1 (**F1**):
ZoneTemp., ShoulderCirc., Height, Weight, SkinTemp., Clothing, HeartRate, Gender

Featureset 2 (**F2**):
ZoneTemp., ShoulderCirc., Height

Featureset 3 (**F3**):
ZoneTemp.



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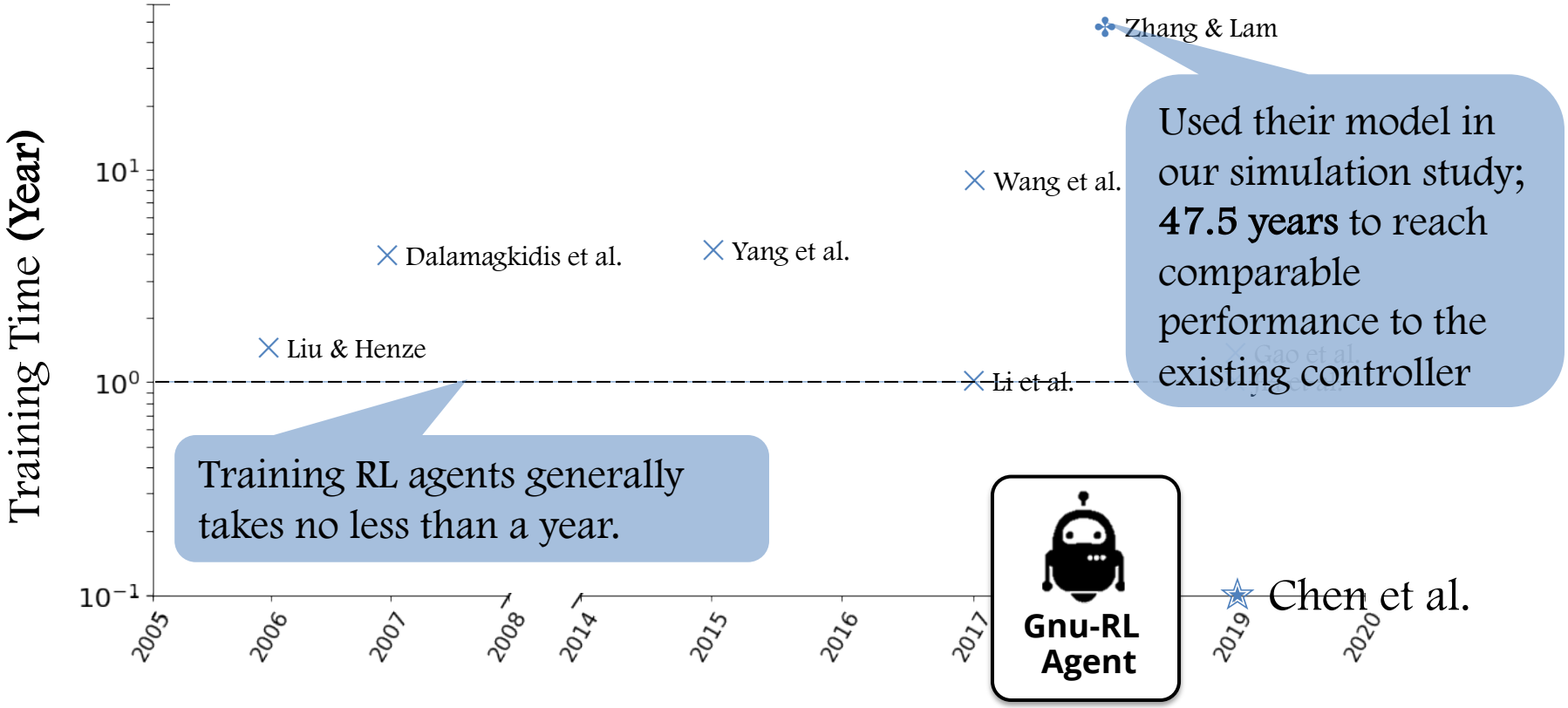
Hey Siri, can you lower my energy bill?

Model Predictive Control

Reinforcement Learning

You may still ignore the warning signs and go ahead… but you will fail!

Training Time in Literature for RL Control of HVAC Systems



Integrating Domain Knowledge and Human Values Helps

… if we can figure out how!

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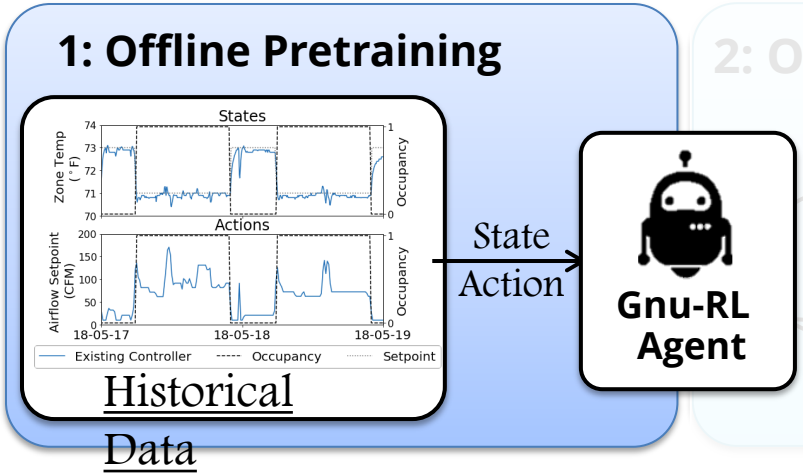
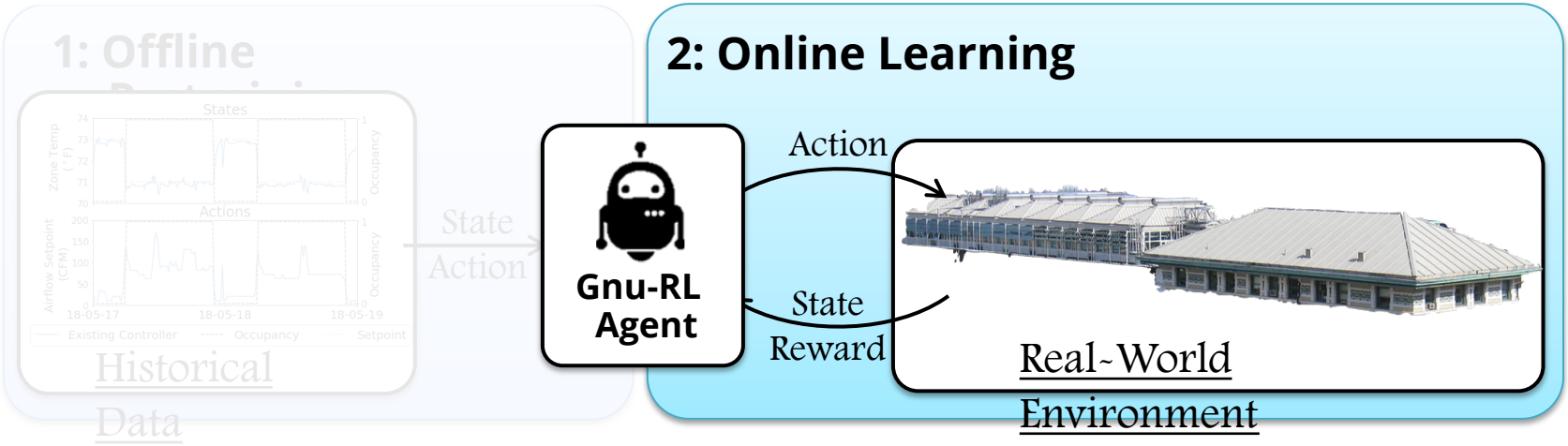
We expedite the training by imitating the existing controller.



We expedite the training by using a policy that encodes knowledge on system dynamics and control.



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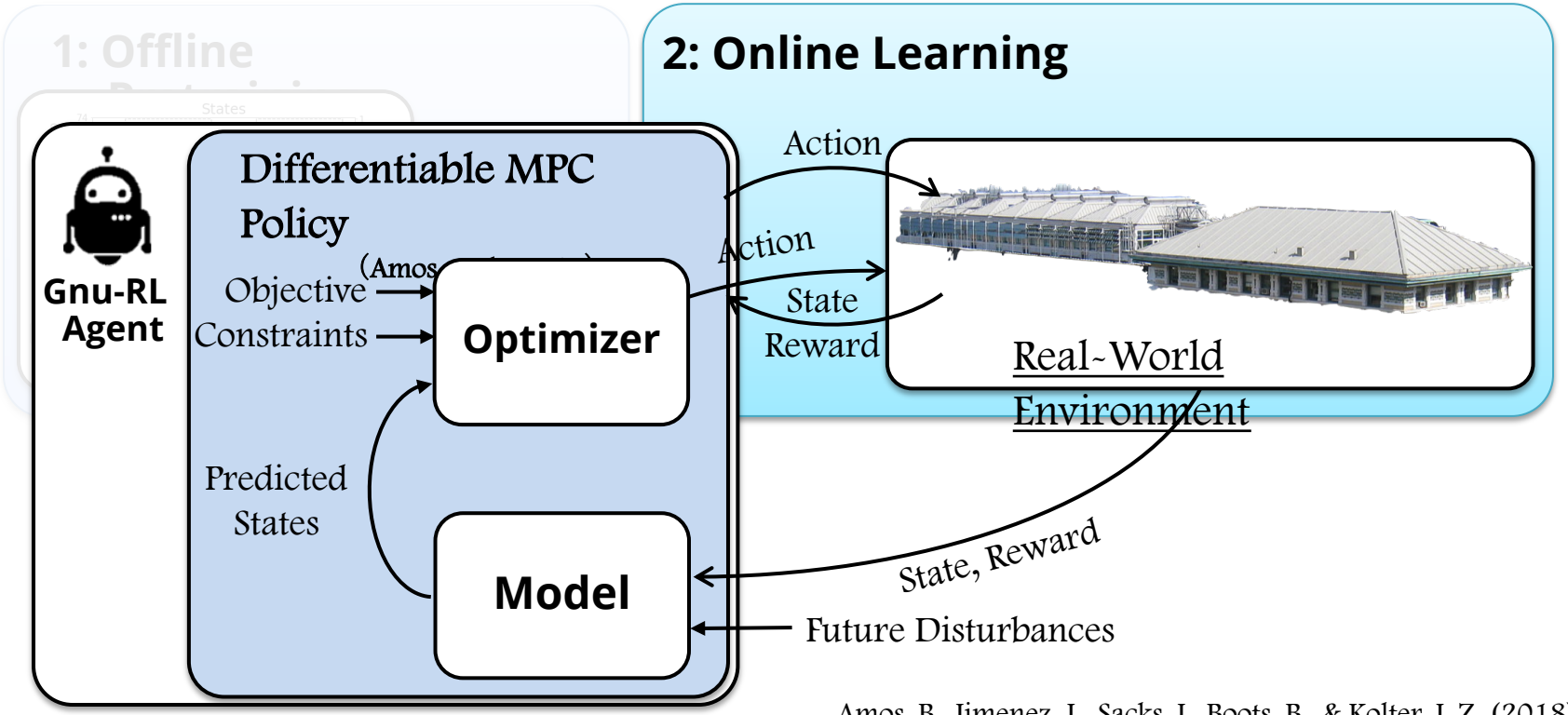

Amos, B., Jimenez, I., Sacks, J., Boots, B., & Kolter, J. Z. (2018). Differentiable MPC for End-to-end Planning and Control. In Advances in Neural Information Processing Systems (pp. 8289-8300).

Gnu-RL achieved significant energy savings without compromising thermal comfort.

	Total Heating Demand (kWh)	Predicted Percentage Dissatisfied Mean (%)	Predicted Percentage Dissatisfied STD (%)
Existing Controller	43709	**9.45**	5.59
Agent #6 (✤ Zhang & Lam, 2018)	37131	11.71	3.76
Gnu-RL	**34678**	9.56	6.39

Gnu-RL achieved **20.6%** energy savings compared to the existing controller and **6.6%** energy savings compared to the best published RL result in the same environment.

Bingqing Chen, Zicheng Cai, merges (2020). Gnu-RL: A Practical and Scalable Reinforcement Learning Solution for Building HVAC Control. *Frontiers in Built Environment*.

PDF Cite Code

If you are interested… there's more!

Bingqing Chen, Priya Donti, Kyri Baker, J Zico Kolter, Mario Bergés (2021). Enforcing Policy Feasibility Constraints through Differentiable Projection for Energy Optimization. *Proceedings of the Twelfth ACM International Conference on Future Energy Systems*.

PDF Cite Code DOI

Bingqing Chen, Jonathan Francis, James Herman, Jean Oh, Eric Nyberg, Sylvia L Herbert (2021). Safety-aware Policy Optimisation for Autonomous Racing. *arXiv preprint arXiv:2110.07699*.

Cite

Bingqing Chen, Zicheng Cai, merges (2020). Gnu-RL: A Practical and Scalable Reinforcement Learning Solution for Building HVAC Control. *Frontiers in Built Environment*.

PDF Cite Code

Mario Bergés, Henning Lange, Jingkun Gao (2018). Data-Driven Operation of Building Systems: Present Challenges and Future Prospects. *Intelligent Computing in Engineering and Architecture*.

Conclusions

- There is ample data out there that we can "opportunistically" harness and lots of AI tools that can use it, but not really solve the problems.
- We need to find ways to incorporate domain-knowledge and human values into the systems we are developing
- We need more advances in these new informed/constrained models that can learn from data in ways we deem useful.

Questions?

https://inferlab.org

marioberges@cmu.edu

Acknowledgments

BOSCH

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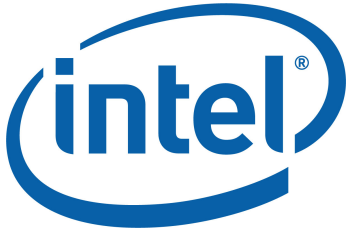

PTA

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The End

QUESTIONS?

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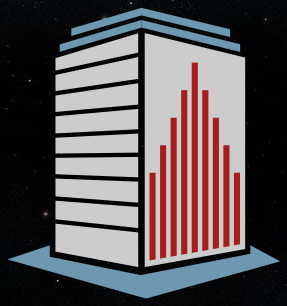

INFERLab

Intelligent Infrastructure Research Laboratory

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