



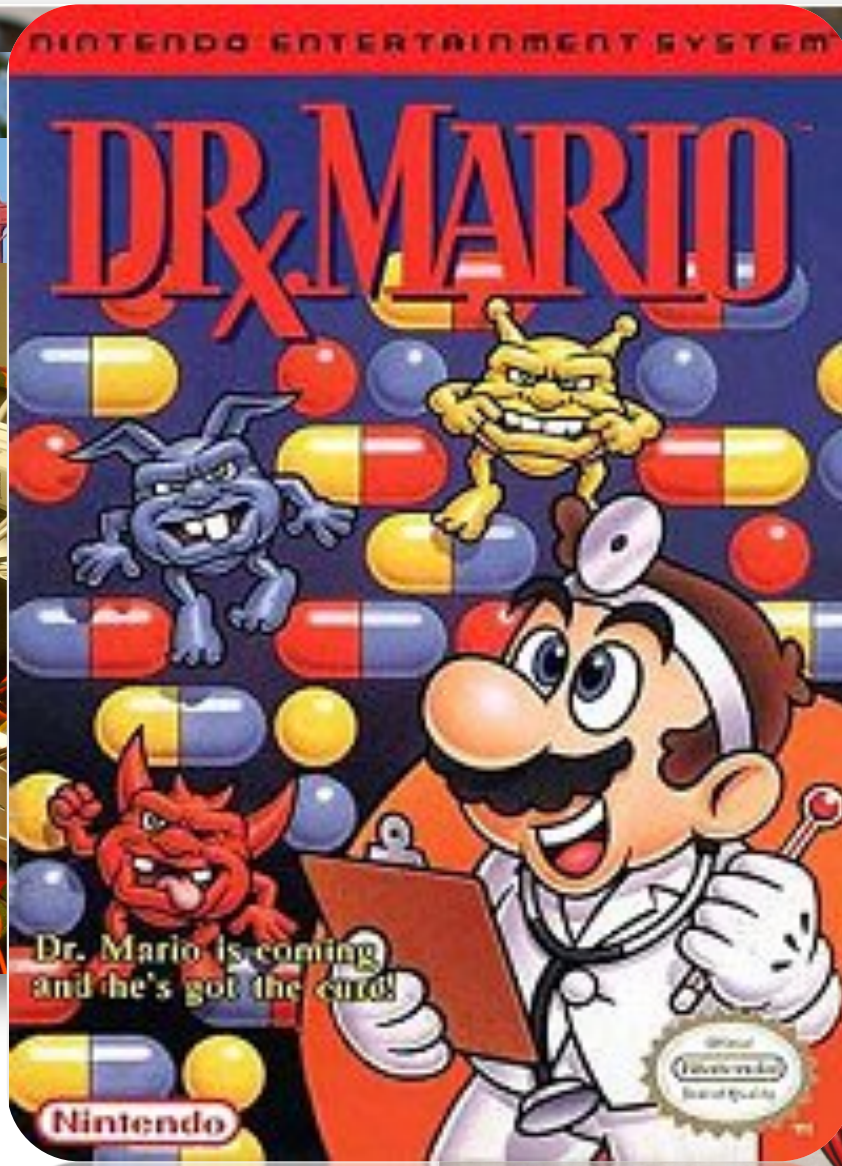
Lecture #1: Course Introduction

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



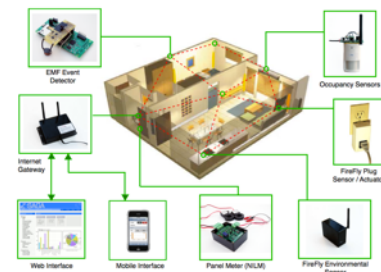
Came to



to merge my degree with



Now doing research on smart infrastructure



Carnegie Mellon

About you

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

- __ Professionals?
- __ Students?

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?



<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 and execution (10%)
- Demonstration (10%)

Class Policy



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

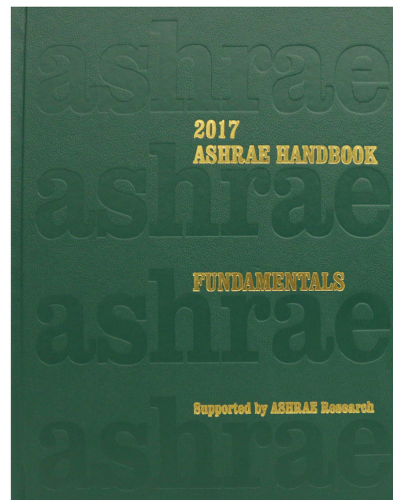
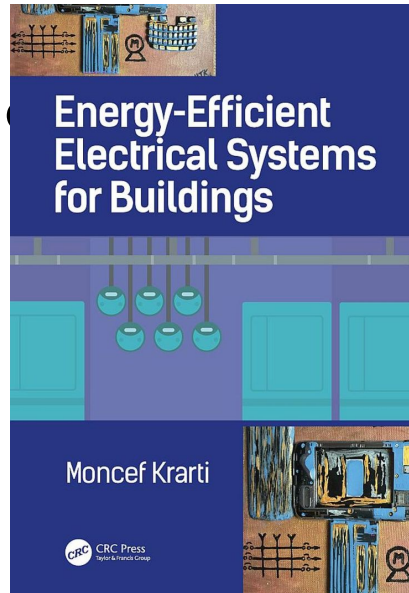
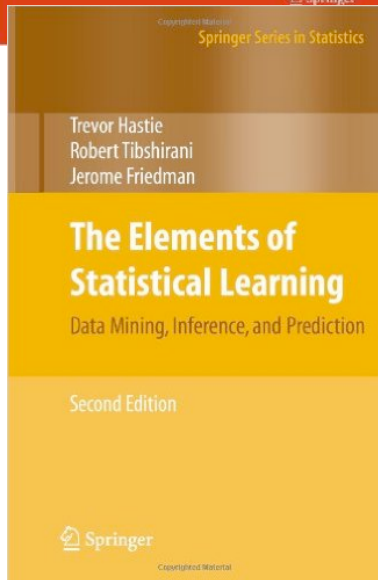
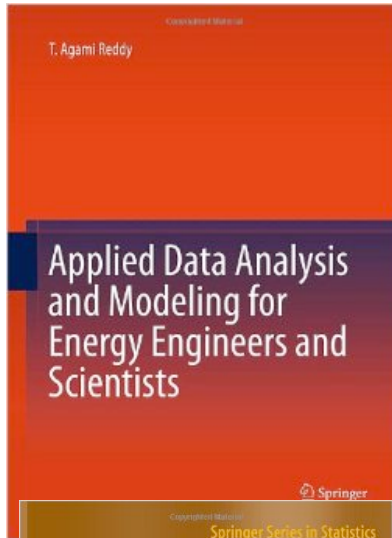
- Final third (4/4 – 4/27):
 - Lecture #23: *Project Progress Reports*
 - Lecture #24: *Project Feedback / Guidance*
 - Lecture #25: *Project Feedback / Guidance*
 - Lecture #26: *Project Feedback / Guidance*
 - Lecture #27: *Guest Lecture: What can I do with these skills in the job market?*

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

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

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

Readings



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

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

People Inside: 0

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

IN2WIBE-AI Workshop

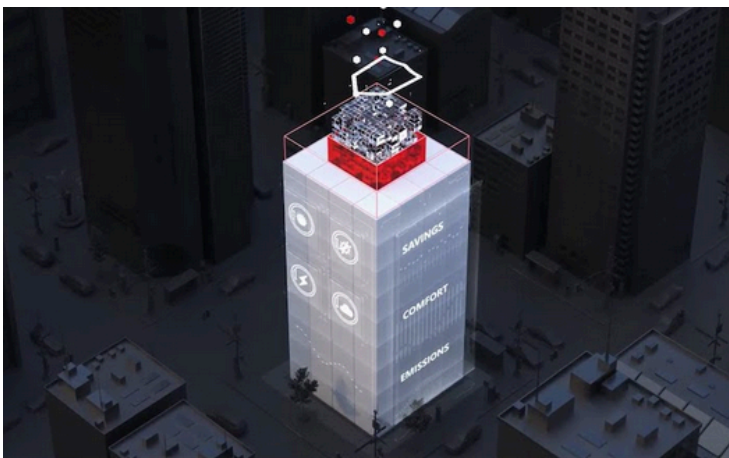
Mario Bergés

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](#)

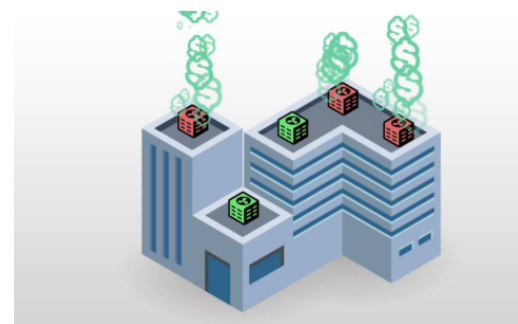
AI-enhanced Energy Management Tech

Encycle expands Swarm Logic® to include HVAC system optimization for 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?



[HOME](#) [SERVICES](#) [NEWS](#) [EDUCATION](#) [ABOUT US](#)

Search

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...

THE X-10 POWERHOUSE DOES EVERYTHING BUT PUT OUT THE CAT.

THE X-10 POWERHOUSE INTERFACES WITH YOUR APPLE TO CONTROL YOUR HOME...FOR SECURITY, COMFORT AND ENERGY SAVINGS.

This remarkable interface lets you run your home through your Apple Ix or Iic and a mouse, keyboard or joystick.

When you're away, it makes your home look and sound lived in. When you're home, it can turn off the TV at night and wake you up to stereo and fresh brewed coffee in the morning. It can even turn on your air conditioner and control your heating.

SPECIAL COLOR GRAPHICS MAKE PROGRAMMING A SNAP. You simply pick a room from the display screen. Use your mouse, joystick or keyboard to position graphics of lights or appliances. Then follow on-screen instructions to program any light or appliance to go on or off whenever you choose. You can even control thermostats, light intensity and more.

THE WAY IT WORKS. The X-10 Powerhouse Interface is cable-connected to the Apple RS-232 port and plugged into a standard 110V outlet. After it is programmed, the Interface sends digitally encoded signals through your home wiring to special X-10 Modules. To control a lamp or appliance, you simply plug the electrical device into a Module and then plug the Module

into an outlet. The Interface can control up to 256 Modules throughout your home and won't interfere with normal use of lights and appliances. There are plug-in Appliance Modules, Lamp Modules, Wall Switch Replacement Modules and Special 220V Modules for heavy duty appliances such as water heaters and room air conditioners. Plus Thermostat Controllers for central heating and air conditioning, Telephone Responders to control your home from any phone, and much more.

IT WON'T TIE UP YOUR COMPUTER. Use your computer only for programming. When you're finished, disconnect the interface from the RS-232 port and keep it plugged into any convenient power outlet in your home. It will operate as a stand-alone controller with battery back-up and will run your home automatically.

SURPRISINGLY INEXPENSIVE. A Powerhouse System including the interface, software and connecting cables costs less than \$150. X-10 Modules are less than \$20 each.

For the Dealer Nearest You Call: **1-800-526-0027**
or, write to: X-10 (USA)
185A Legrand Avenue
Northvale, NJ 07647

X-10 POWERHOUSE
LEARN HOW TO HOME ELECTRICAL

Apple, Apple IIe and Apple IIc are registered trademarks of Apple Computer Inc.

CIRCLE NUMBER 2

Source: eBay users aghound64 and answerking

HAL2000
Home Automated Living's system of the Future

Home Automated Living™
The most sophisticated piece of Home Automation Equipment is right under your nose.

Designed for Windows 95®

Set the thermostat to 68 degrees.

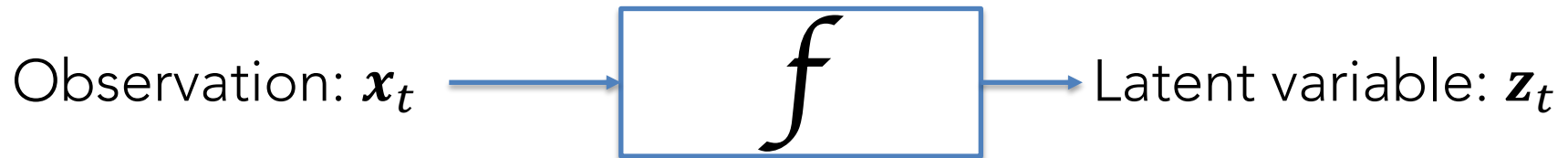
I have set the thermostat to 68 degrees.

Open A World Of Possibilities, Just By Opening Your Mouth.

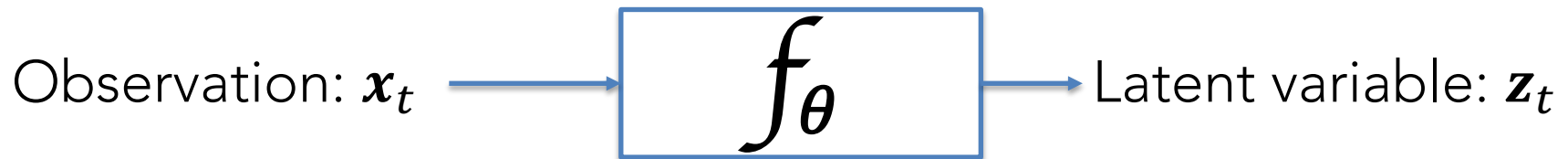
With HAL2000's true speech recognition system, wherever there's a phone, you can control or schedule:

- heating/cooling • personal reminders • internet/e-mail
- appliances • security • lighting • voice mail
- home entertainment • and the list goes on...

Current AI is, largely, just very effective function approximation



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

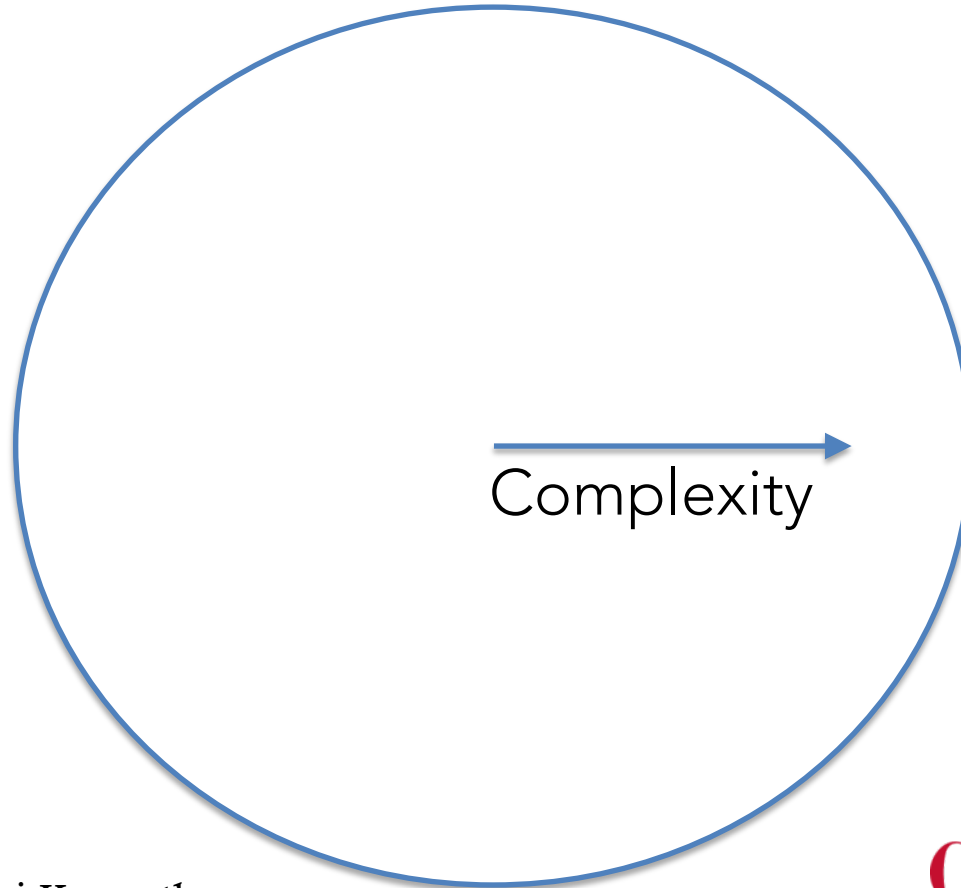


Supervised Learning
(regression, classification, even Reinforcement Learning¹!)

¹ <https://bair.berkeley.edu/blog/2020/10/13/supervised-rl/>

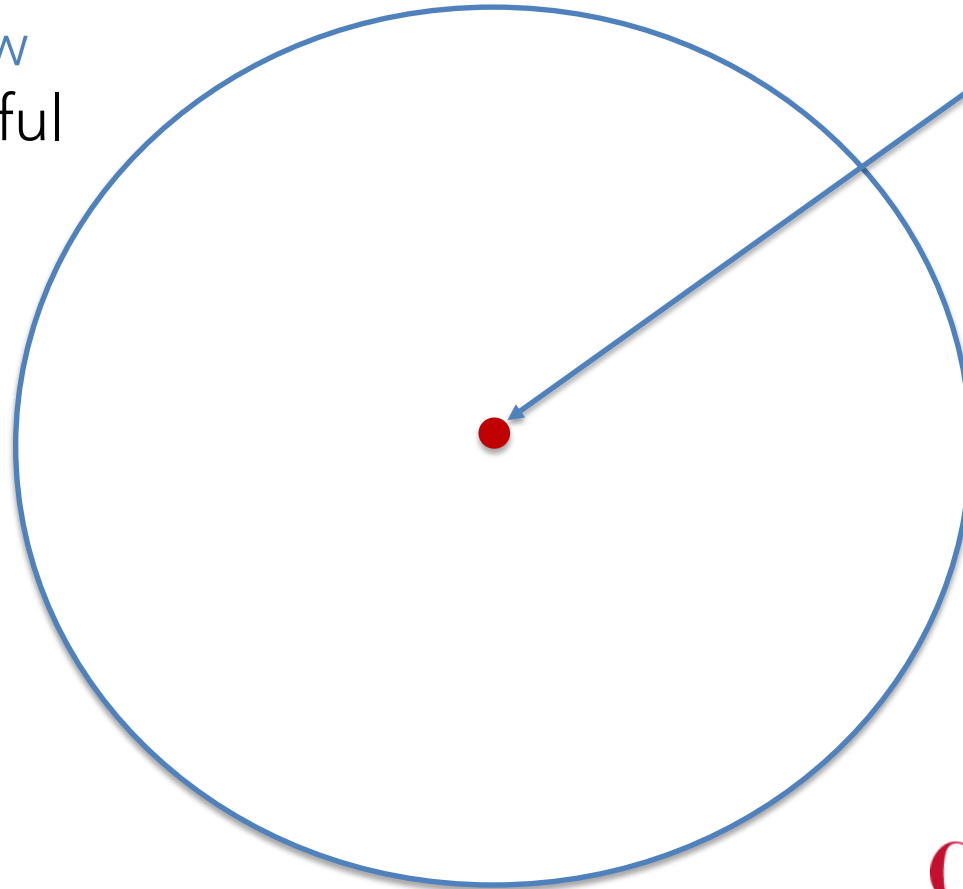
Picking the right function family has consequences

Space of all
possible f
functions:



You can just use your existing knowledge, directly

Bias: high
Variance: low
Data: not useful



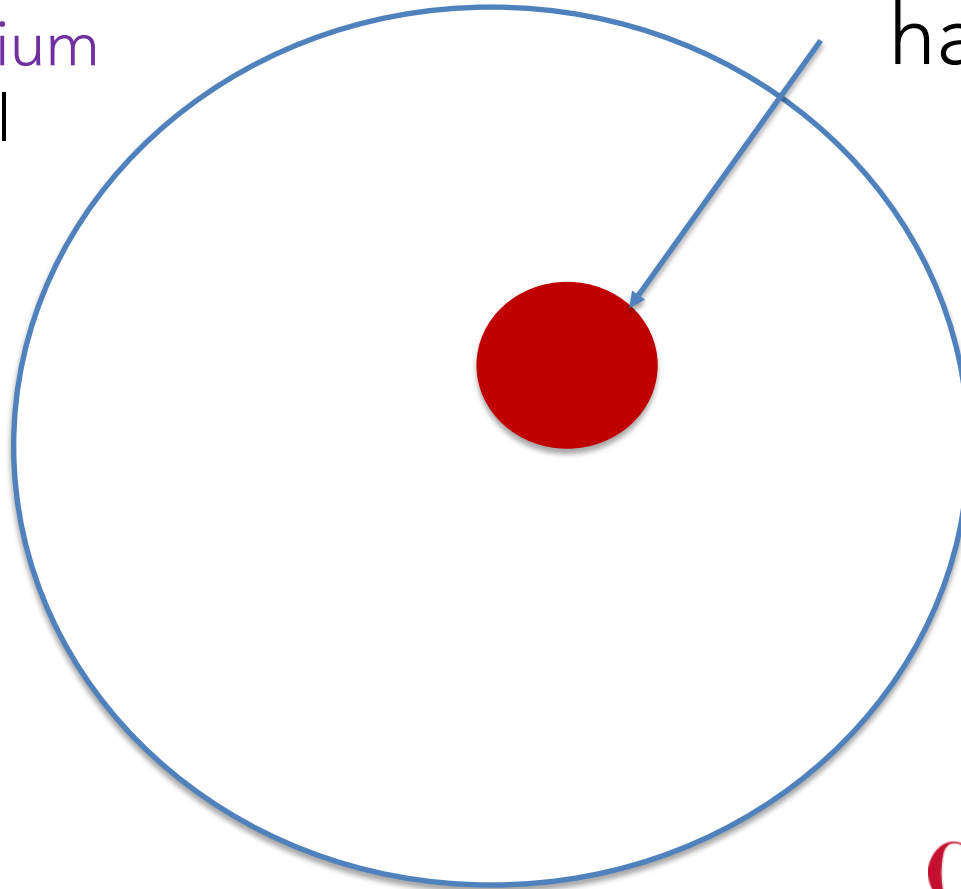
Or you can let simple models learn the mapping

Bias: medium

Variance: medium

Data: useful

f_{θ} : SVM with
hand-crafted
features



Or fancier models models

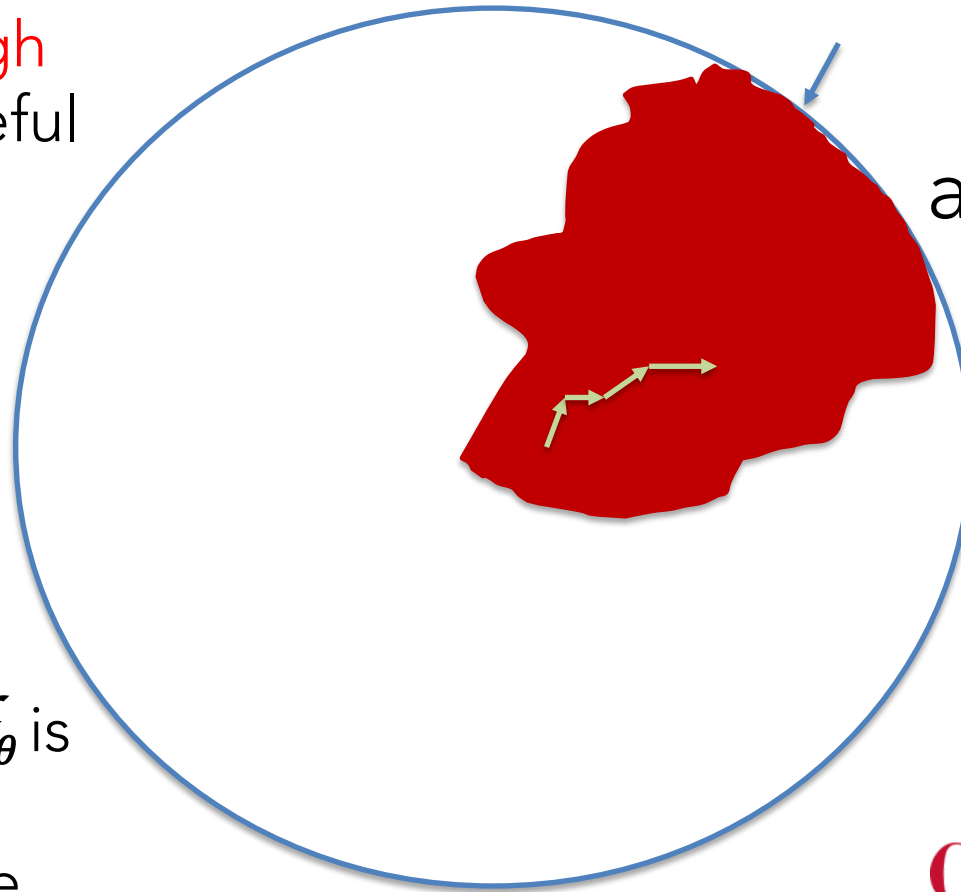
Bias: low

Variance: high

Data: very useful

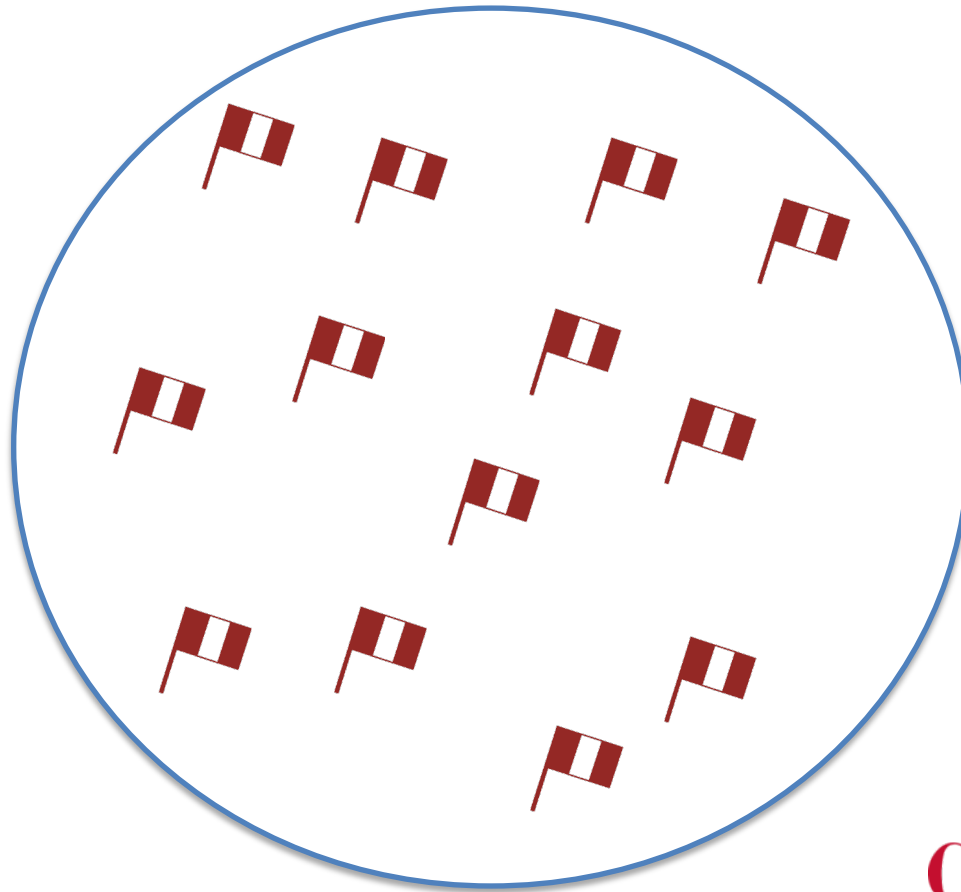
f_θ : deep
ConvNets
w/learned
architecture

Note: it is
convenient if f_θ is
smooth and
differentiable



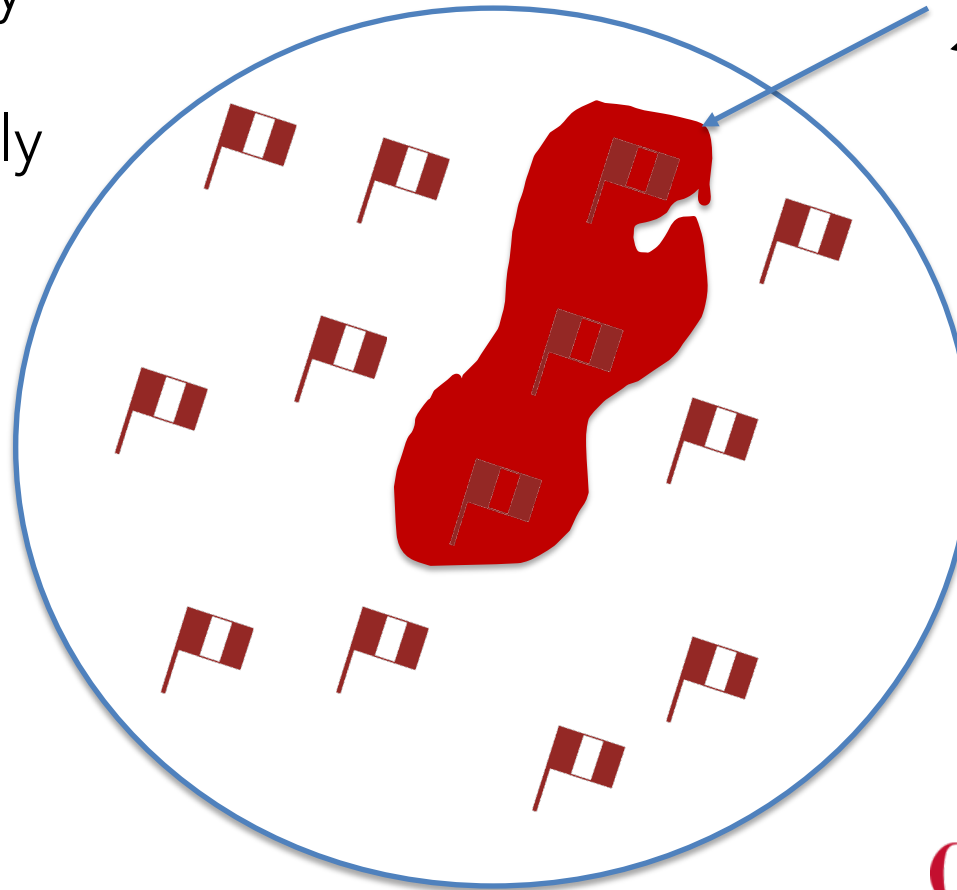
The Bad News: The domain of f is HUGE!

(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.



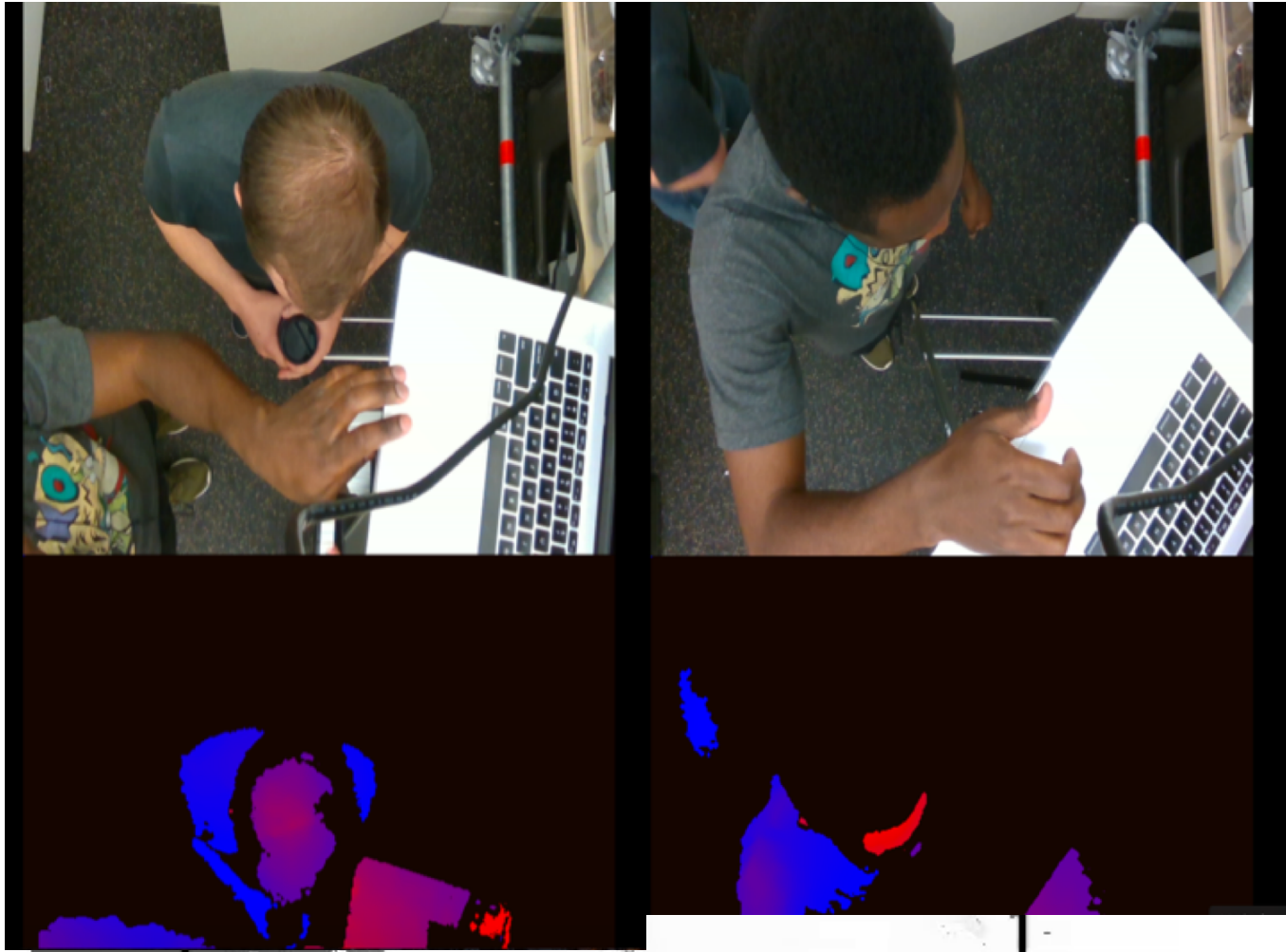
... and we haven't considered hyper-parameters!

- 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?

So what can go wrong?

... a whole lot!

(Racial) Bias



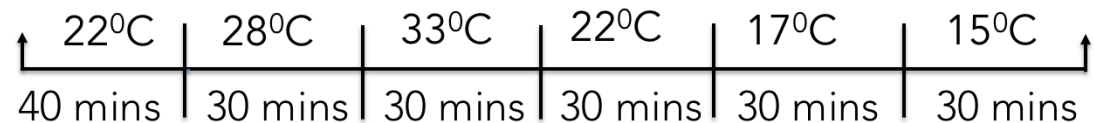
Overconfidence on extrapolation!

- 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.

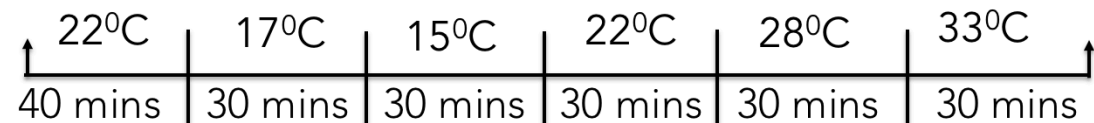


Timeline:

1) Neutral – Hot – Neutral - Cold experiment



2) Neutral – Cold – Neutral – Hot experiment



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.

Results

Featureset 1 (F1):

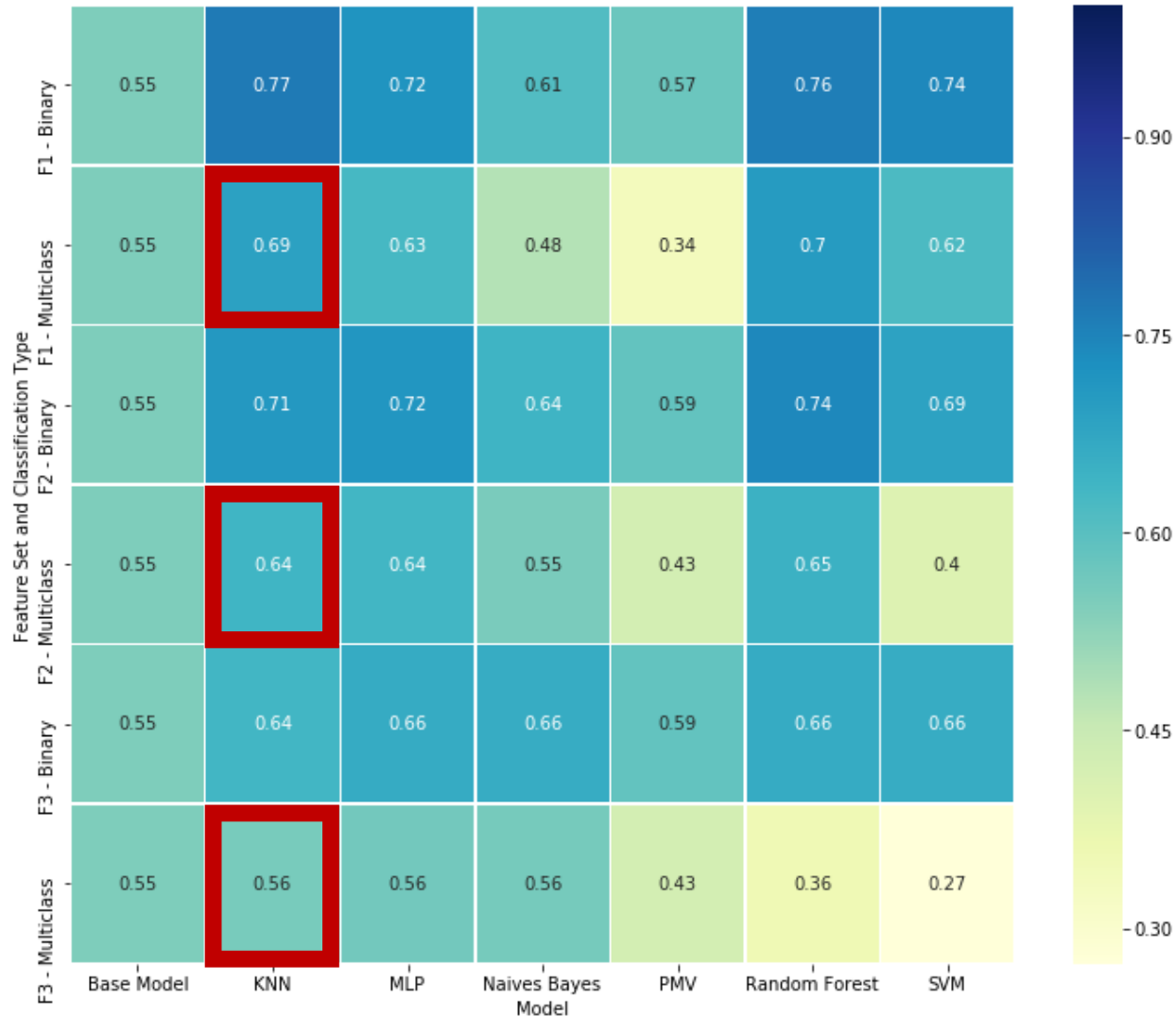
ZoneTemp.,
ShoulderCirc.,
Height, Weight,
SkinTemp., Clothing,
HeartRate, Gender

Featureset 2 (F2):

ZoneTemp.,
ShoulderCirc.,
Height

Featureset 3 (F3):

ZoneTemp.



Hey Siri, can you lower my energy bill?



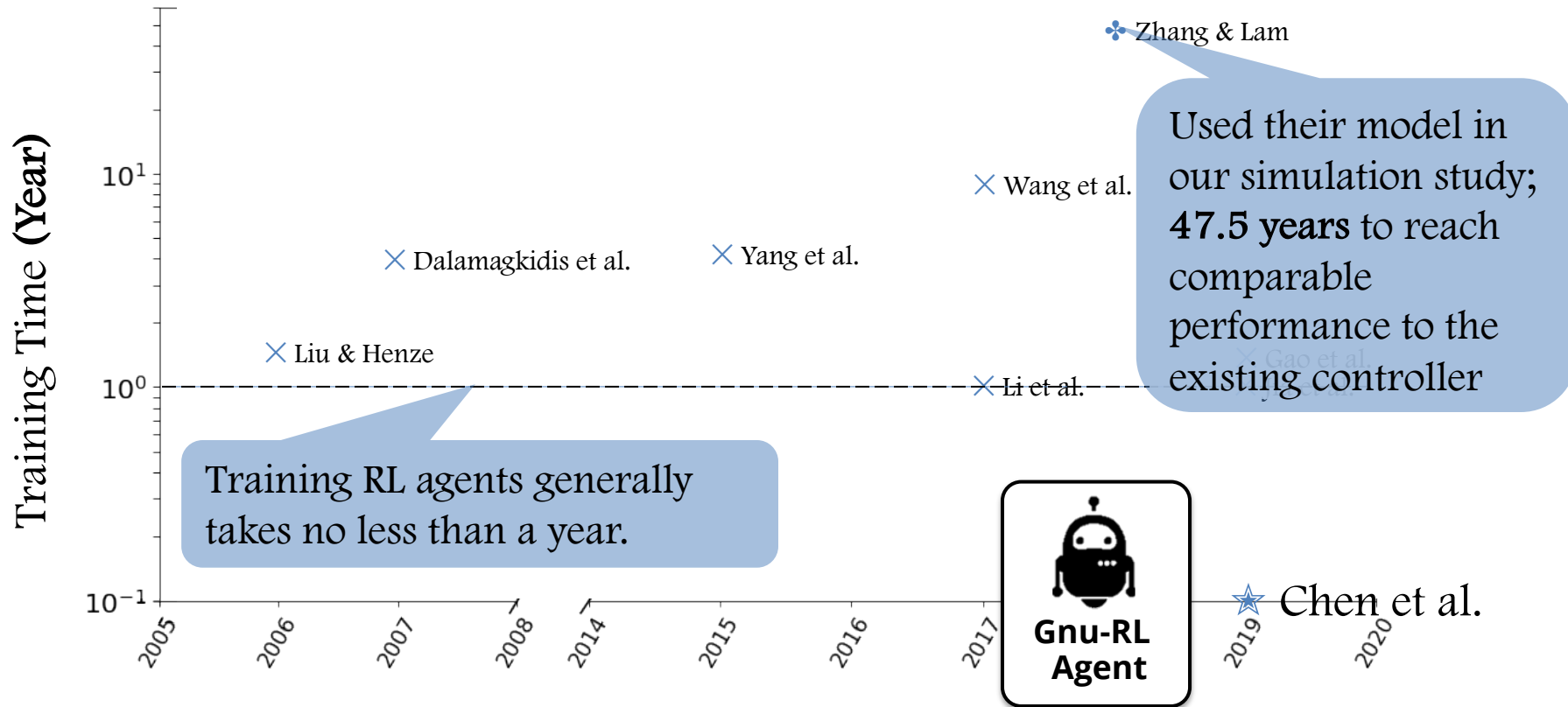
**Model Predictive
Control**



**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

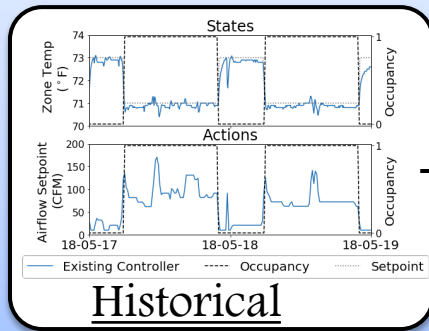


Integrating Domain Knowledge and Human Values Helps

... if we can figure out how!

We expedite the training by imitating the existing controller.

1: Offline Pretraining



Historical
Data

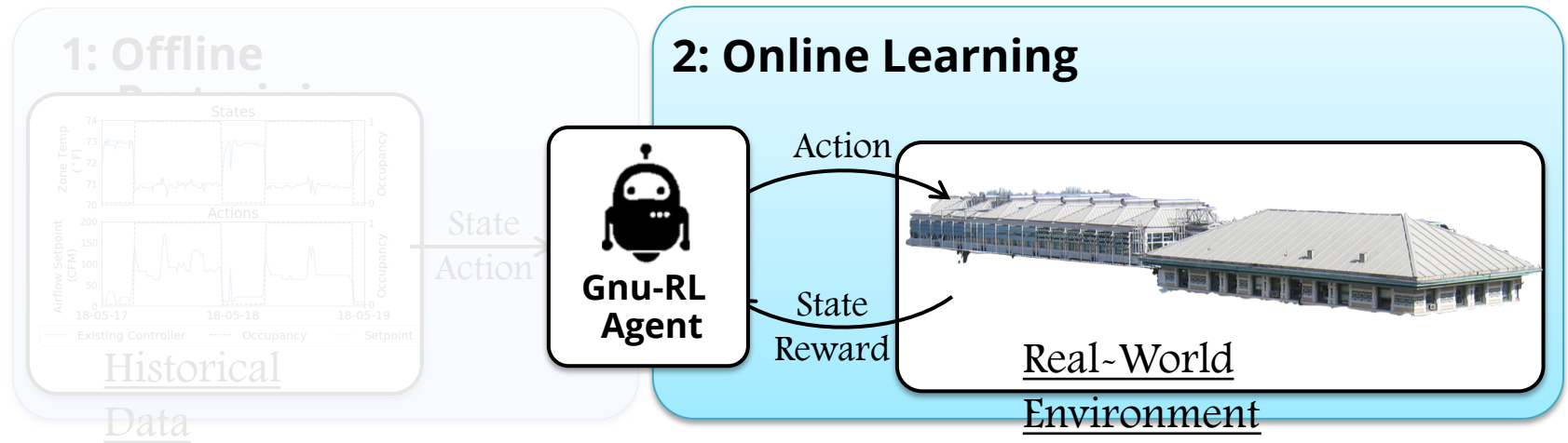
State
Action



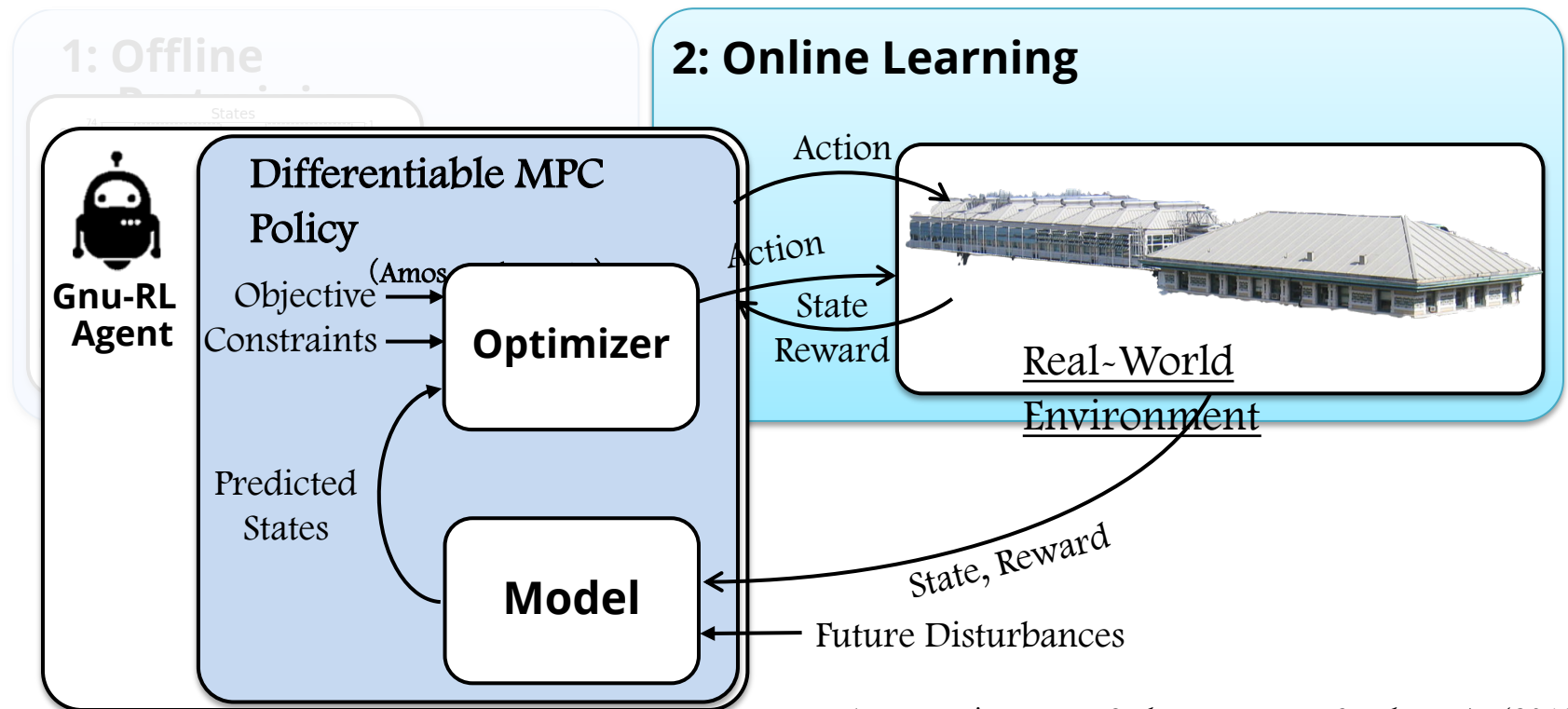
2: Online Training



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



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



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	Predicted Percentage Dissatisfied	
	(kWh)	Mean (%)	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.

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?

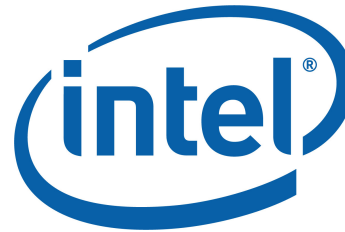
<https://inferlab.org>

marioberges@cmu.edu

Acknowledgments



BOSCH



PIA



U.S. DEPARTMENT OF
ENERGY



Carnegie Mellon

The End

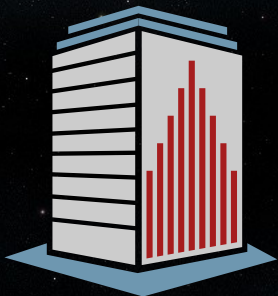
QUESTIONS?



@bergesmario



marioberges.com



INFERLab

Intelligent Infrastructure
Research Laboratory

Carnegie Mellon