18-848 RadarML

L1: Intro & Logistics

Tianshu Huang

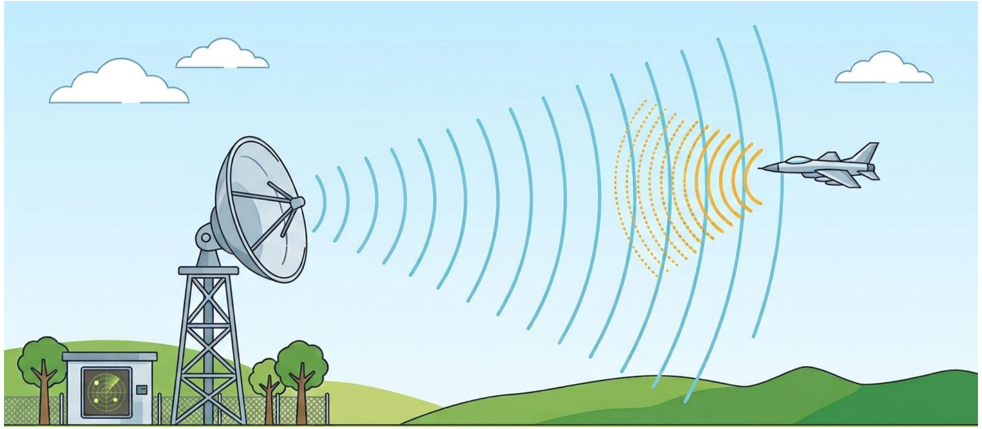
Today’s Lecture

- What is RadarML? Why bother?
- About this class
- A brief history of radar

RadarML = Radar + ML

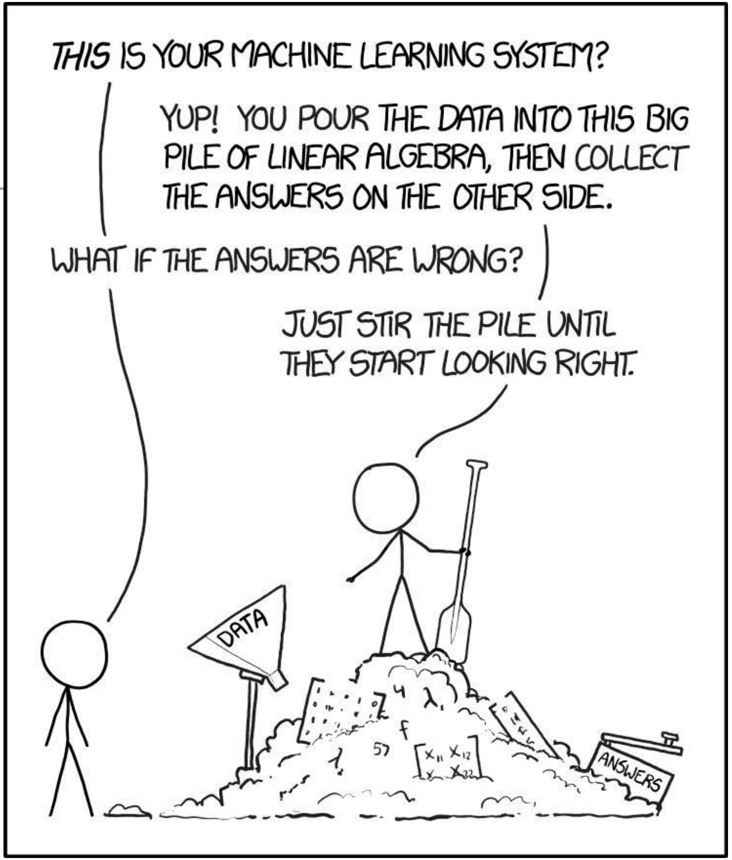
Radar

using reflected radio waves to detect objects, and the time-of-flight of these waves to determine their distance

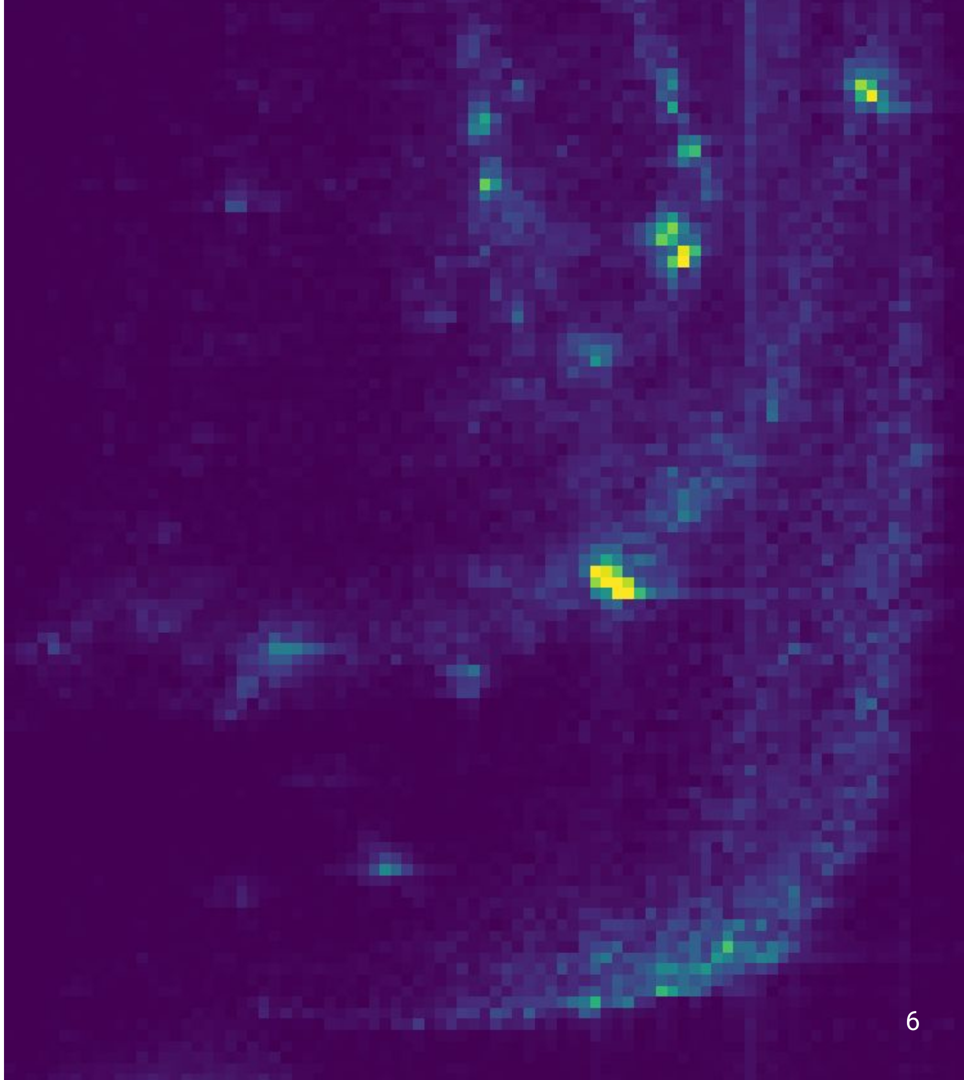


Machine Learning

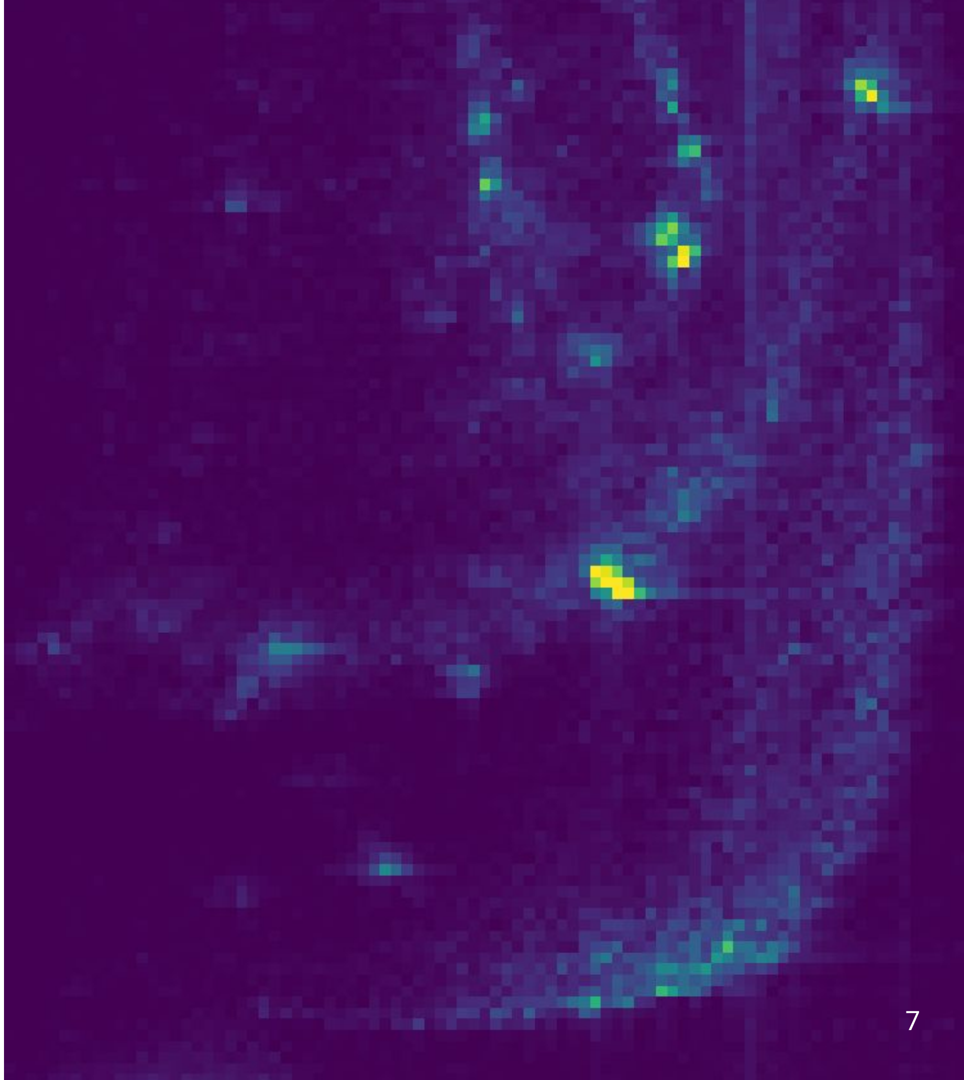
finding a model which best explains observed data, then using that model to generate predictions



Why RadarML?



Why ~~RadarML~~ Radar?



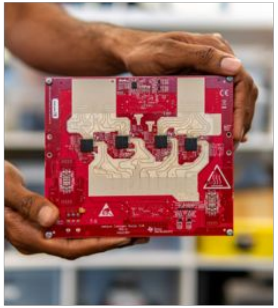
1. Radar is robust to environmental conditions

2. Radar is inexpensive

$ | $$ | $$$+


Single-Chip Radar


Cameras


Imaging Radar


FMCW Lidar

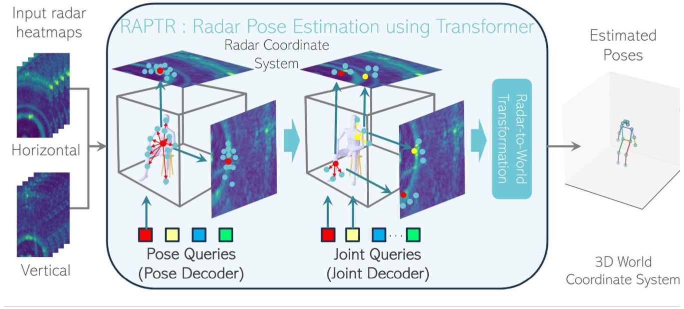

Traditional Lidar

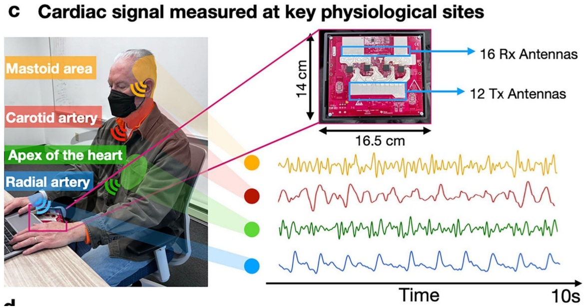
3. Radar is orthogonal to other sensors

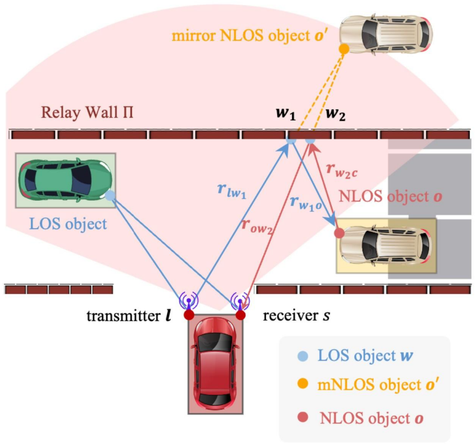
	Radar	Camera	Lidar
Angular Ambiguity	✗ High	✓ Low	✓ Low
Range Ambiguity	✓ Low	✗ High	✓ Low
Velocity Ambiguity	✓ Low	✗ High	✗ High
Works in the Dark	✓ Yes	✗ No	✓ Yes
Robustness to Occlusions	✓ High	✗ Low	✗ Moderate

And more…

- Privacy preserving
- Unique material properties
- Long range
- Non-line-of-sight sensing
- Can be sensitive to small movements
- …



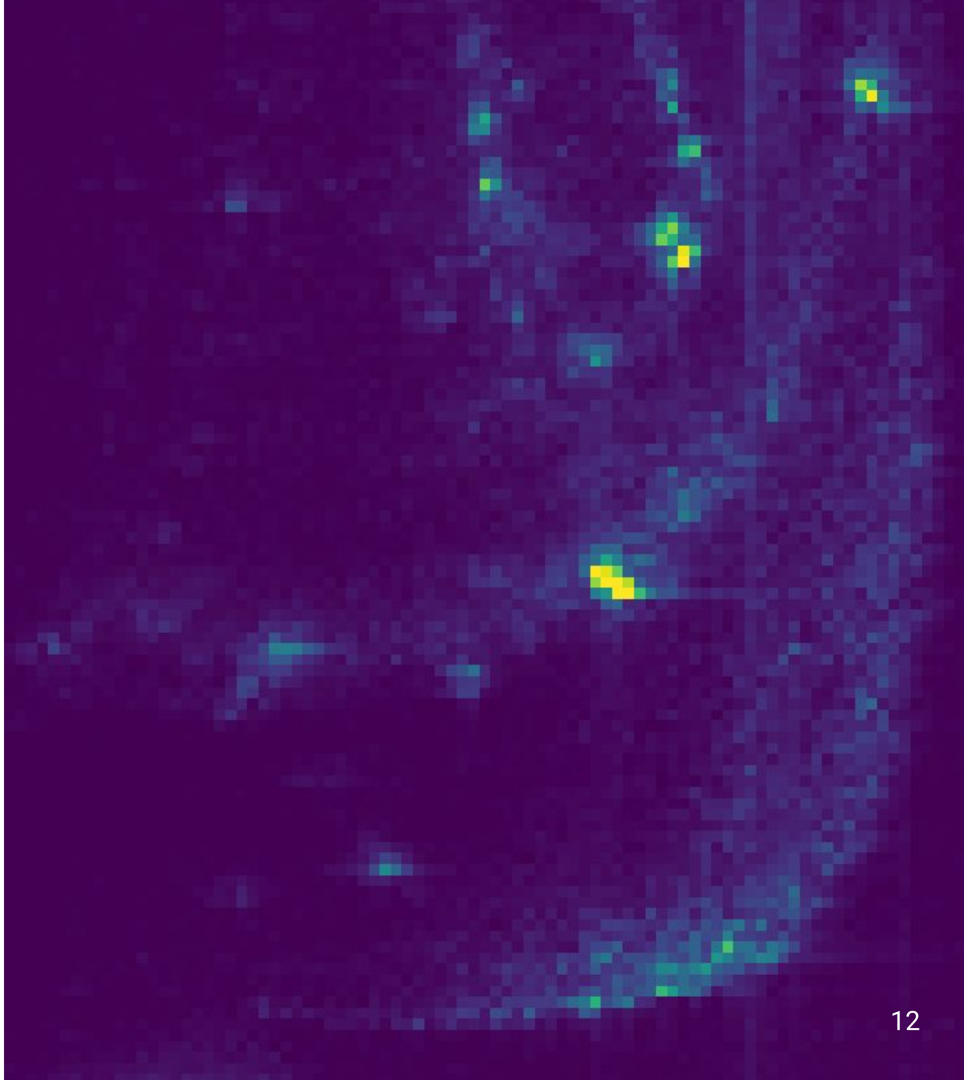




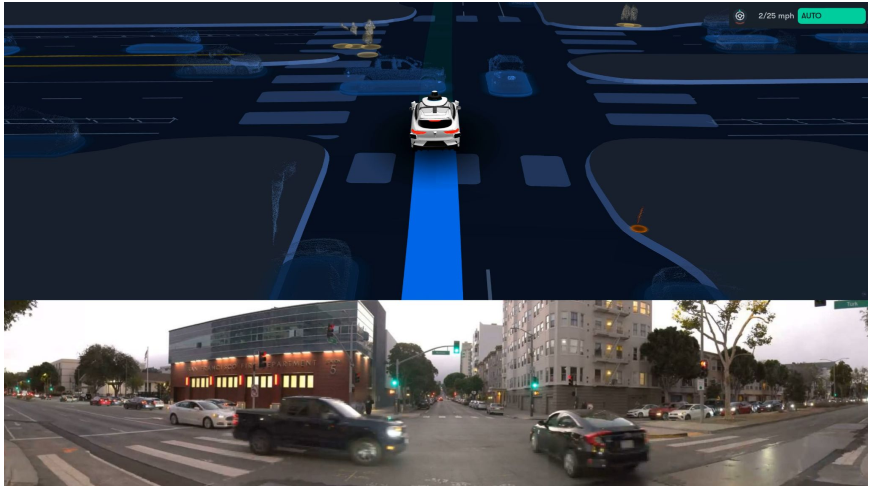
(a) Dry Leaf

(b) Wet Leaf

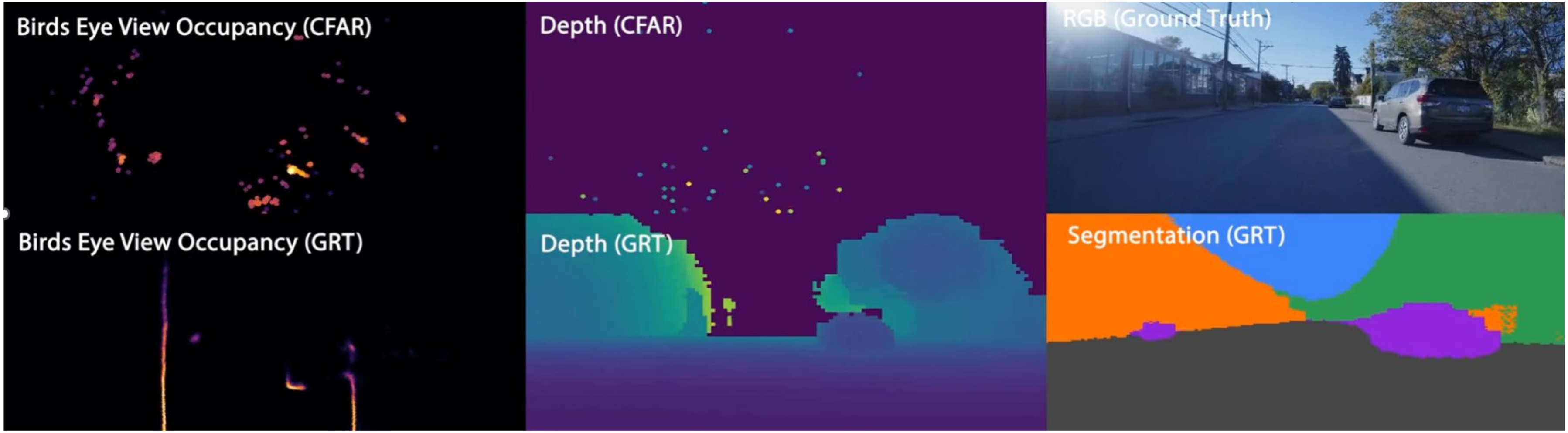
Why RadarML?



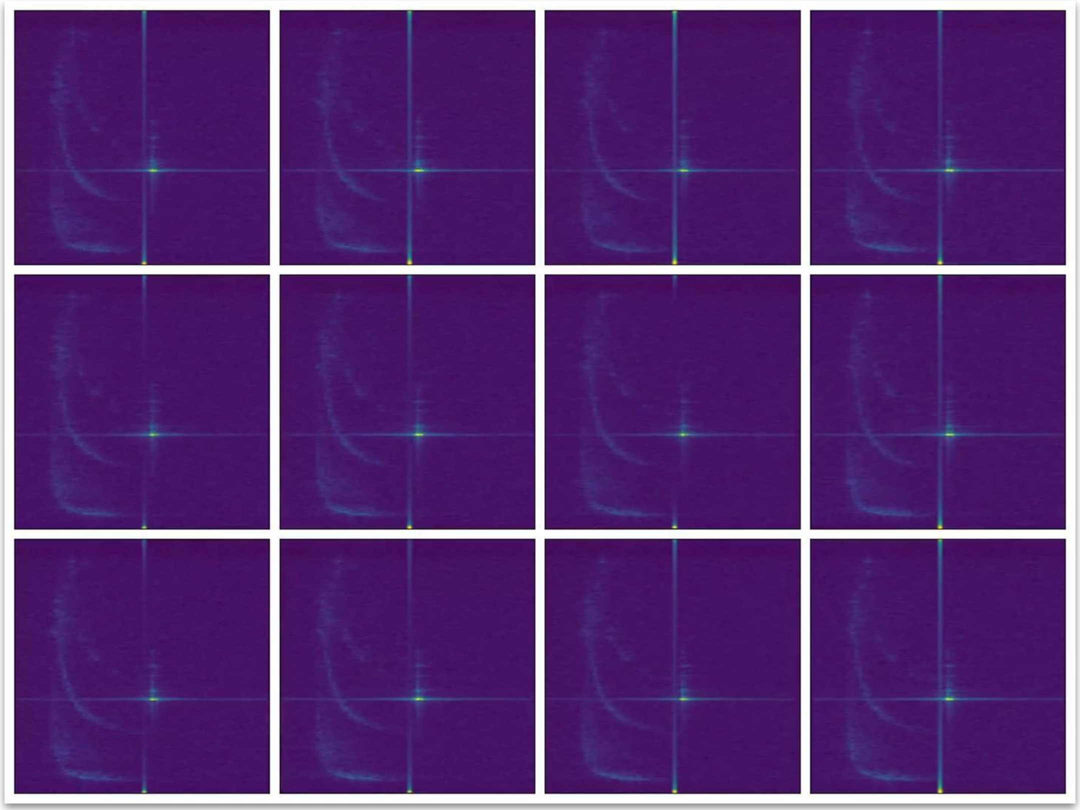
Modern Perception Needs ML

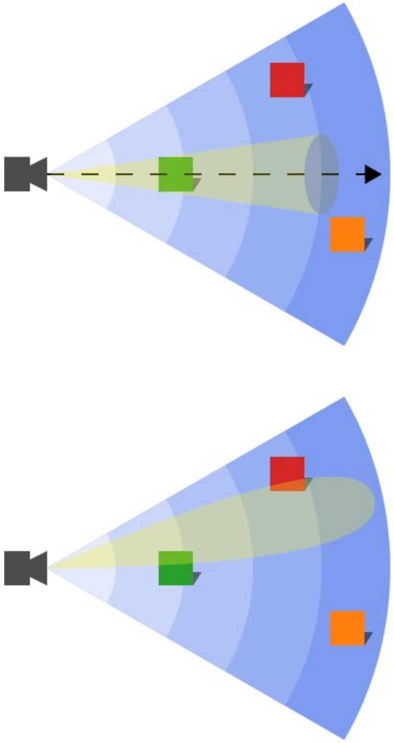


ML is needed to maximize the capability of radar



Radar data does not map 1:1 with other modalities





Course Overview

radarml.github.io/18848/

Course Resources

Website: https://radarml.github.io/18848/

- Up-to-date schedule
- Assignments, course policies
- Slides & other public assets

Canvas: https://canvas.cmu.edu/courses/54965

- Submit assignments, post grades
- Some slides/resources may also be posted here

This is not a normal class.

- Few public materials exist; public materials are often incomplete or unreliable
- We will cover topics which are not well understood
- We do not expect you to fully understand everything

Course Format

- Introductory Lectures
  - Wireless, radar, & ML fundamentals
  - What modern radar & ML actually looks like
- Seminar & Discussion
  - Read, present, and discuss papers
  - Most likely 1 paper/topic per student
- Guest Lectures
  - Industry & academia
  - Radar, wireless, & adjacent fields

Current Guest Lineup

Justin Chan
Assistant Professor, CMU S3D & ECE

Matthew O'Toole
Associate Professor, CMU RI & CSD

Matthias Hagedorn
Chief Technology Officer for Radar, Bosch

Michael Ulrich
Senior Expert, AI Perception & Signal Processing, Bosch

Ray Huang
PhD Student, CMU RI

Thomas Huang
Research Scientist, Waymo AI Foundations

Note: We will likely add 1-2 additional guests

Lecture Materials

In-person only; lectures will not be recorded

- Slides may be available after each lecture at the speaker's discretion
- We will not publish lecture notes

Some materials may contain unpublished or otherwise privileged material

- We will clearly state when these limitations exist

Assignments & Grading

30%	2 introductory labs
15%	Paper presentation
50%	Course project
5%	Course participation

Assignments & Grading

30%	2 introductory labs
15%	Paper presentation
50%	Course project
5%	Course participation

→

15%	Radar lab
15%	ML lab

Focus is on hands–on experience; all core functionality will be provided.

- Configuring, deploying, & processing data from a radar system
- Running basic sweeps

Assignments & Grading

30%	2 introductory labs
15%	Paper presentation
50%	Course project
5%	Course participation

Each student will read, critique, and present ~1 paper

- Exact parameters pending guest availability
- Topics include wireless sensing, learning on spectrum, imaging/simulation

Assignments & Grading

30%	2 introductory labs
15%	Paper presentation
50%	Course project
5%	Course participation

→

10%	Project proposal
10%	Midterm report
10%	Final presentation
20%	Final report

Groups of up to 4

- Must collect and/or deploy on an actual radar/wireless system
- Must train and/or run a ML-based system
- Integrating your own research is allowed and encouraged

Possible Project Domains

- Robotics, autonomous systems
- Human sensing, indoor sensing
- Imaging and 3D reconstruction
- Simulation and rendering

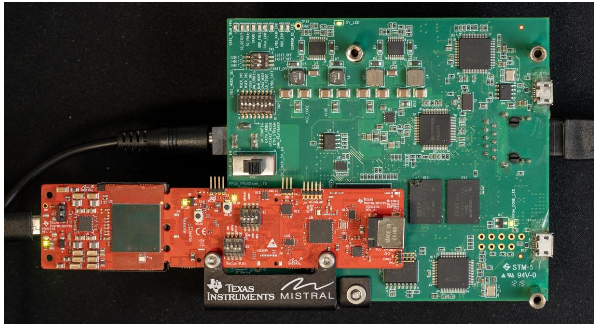
Project Resources

Compute

- PSC
    - V100 & H100 w/ long queues
    - Possible extended outage
- Anything we can find lying around
    - Possibly some 3090s etc.
- BYO compute

Radar

- AWR1843AOP + DCA1000EVM
    - Short range, roughly hemispherical, low-resolution
    - Can collect time signal
- Other TI radar development kit
- BYO radar/wireless system



Assignments & Grading

30%	2 introductory labs
15%	Paper presentation
50%	Course project
5%	Course participation

Attendance is required

- Please notify me in advance if you have a conflict
- Extra tasks (e.g., prepare discussion questions) may be assigned last-minute depending on guest requests

Tentative Schedule

radarml.github.io/18848/

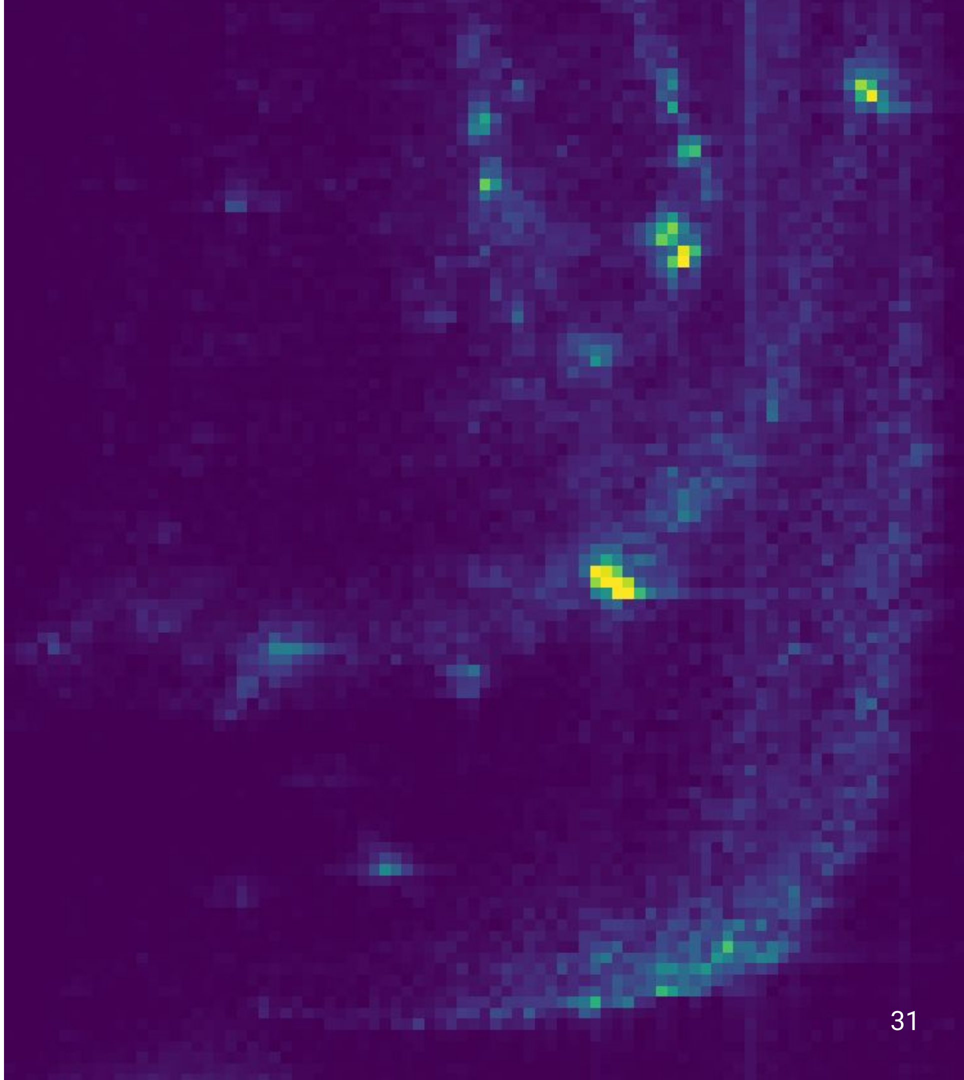
08/25	**Introduction & Logistics**
08/27	**Wireless Basics** A crash course in wireless communications, providing a high level overview for students without wireless background and a review for students with wireless background.
09/01	**Wireless Basics**
09/03	**Intro Radar** A crash course in radar systems and radar signal processing pipelines
09/08	**Intro Radar**
09/10	**Radar Hardware** What do modern mmWave radars look like? What are the key components, different types, and design considerations? *Lab 1/2 Due*
09/15	**Radar Hardware**
09/17	**Applied ML** Everything you need to know to get started with applied machine learning, with a focus on applied research.
09/22	**Applied ML** *Lab 2/2 Due*
09/24	**Guest Lecture — Michael Ulrich** From Blips to Bounding Boxes: The Evolution of Automotive Radar Perception
09/29	**Foundation Models & Signals** What does it mean to train a foundation model? What happens when you try to do this with signals?
10/01	**Guest Lecture — Thomas Huang**
10/06	**Introduction to Seminar & Discussion Topics** *Project Proposal Due*
10/08	**Guest Lecture — Justin Chan**
10/13	Fall Break
10/15	Fall Break
10/20	**Wireless Sensing**
10/22	**Guest Lecture** Approximate date; Guest TBD.
10/27	**Wireless Sensing**
10/29	**Guest Lecture** Approximate date; Guest TBD.
11/3	No class (democracy day)
11/5	**Learning on Spectrum** *Project progress report due*
11/10	**Learning on Spectrum**
11/12	**Guest Lecture** Approximate date; Guest TBD. *The CVPR deadline will likely fall near this date*
11/17	**Imaging & Simulation**
11/19	**Guest Lecture** Approximate date; Guest TBD.
11/24	**Imaging & Simulation**
11/26	Thanksgiving Break
12/1	**Final Presentations / Demos**
12/3	**Final Presentations / Demos**
12/4	*Final report due*

Background Survey

https://forms.gle/UVXmfMpL5Sf3NCA57

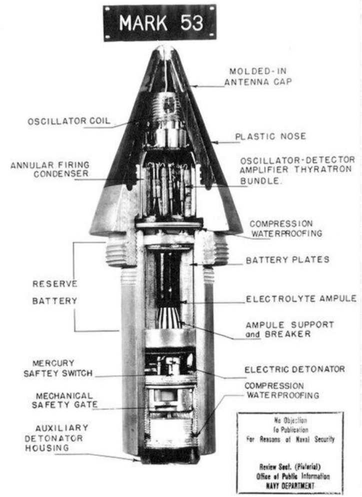
A Brief History of Radar

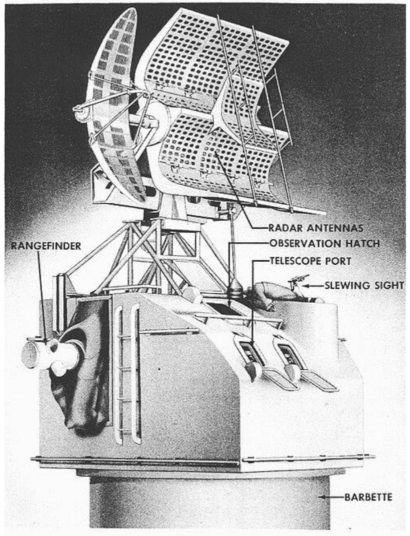
Radio Detection and Ranging

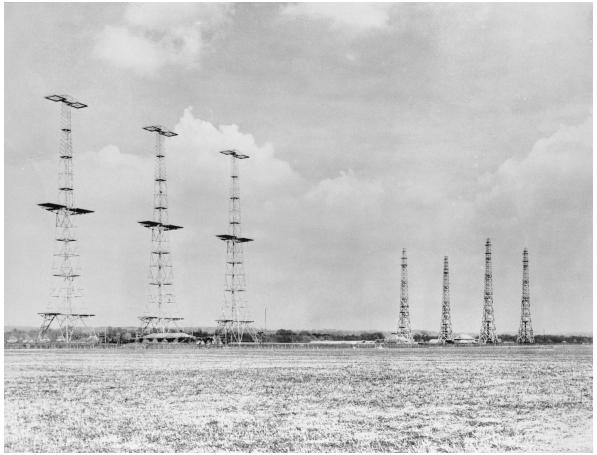


WWII

- Ground to air search radars
    - "Chain Home"
    - Wide beam transmitter
    - Mechanically scanned receiver
- Naval fire control
    - Narrow beam ranging
    - Visual angular tracking
- Bomb fuses
    - Omnidirectional proximity sensing



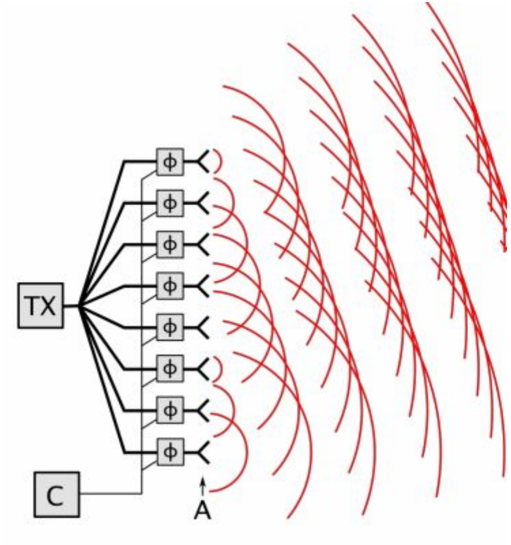




Towards Solid State

Single antenna with narrow beam

→ array of elements with electronic scanning



Civilian Technology

- Weather radar
- Synthetic aperture radar (satellite mapping)
- Ground penetrating radar

Automotive

- First explored in 60s-70s
- First commercially available in late 90s
- Adaptive cruise control (ACC), automatic emergency braking (AEB), blind spot detection

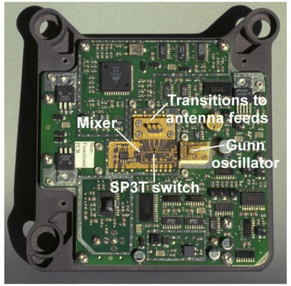


FIGURE 3. Front and back side of first commercial automotive ARS 100 radar by Mercedes Benz. Photographs by W. Menzel.

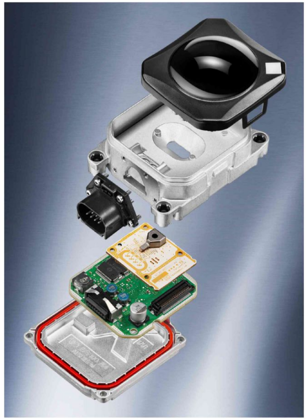


FIGURE 5. Exploded view on the Bosch LRR3 sensor and details of the planar antenna elements feeding the lens. Sensor photograph provided by Bosch.

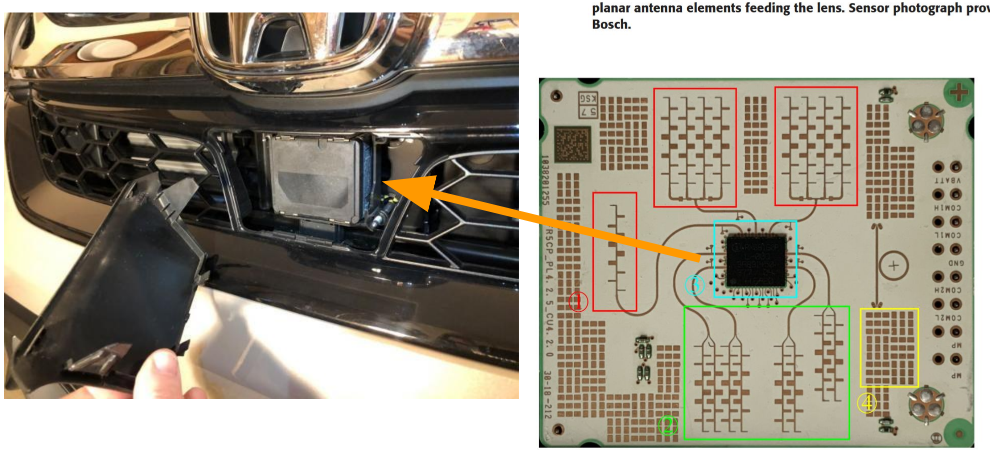
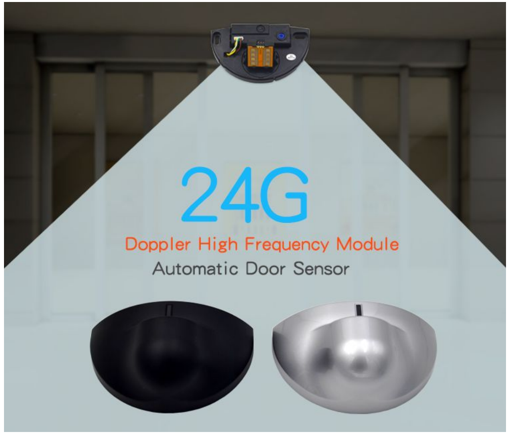


FIGURE 9. Bosch 5th generation radar PCB with ① transmit antennas, ② receive antennas, ③ frontend MMIC, ④ reflection reduction structures.

"Automotive Radar—From First Efforts to Future Systems," Waldschmidt et. al, 2020.

IoT

- Presence detection / light switches
- Automatic door openers
- Tank level monitoring
- …

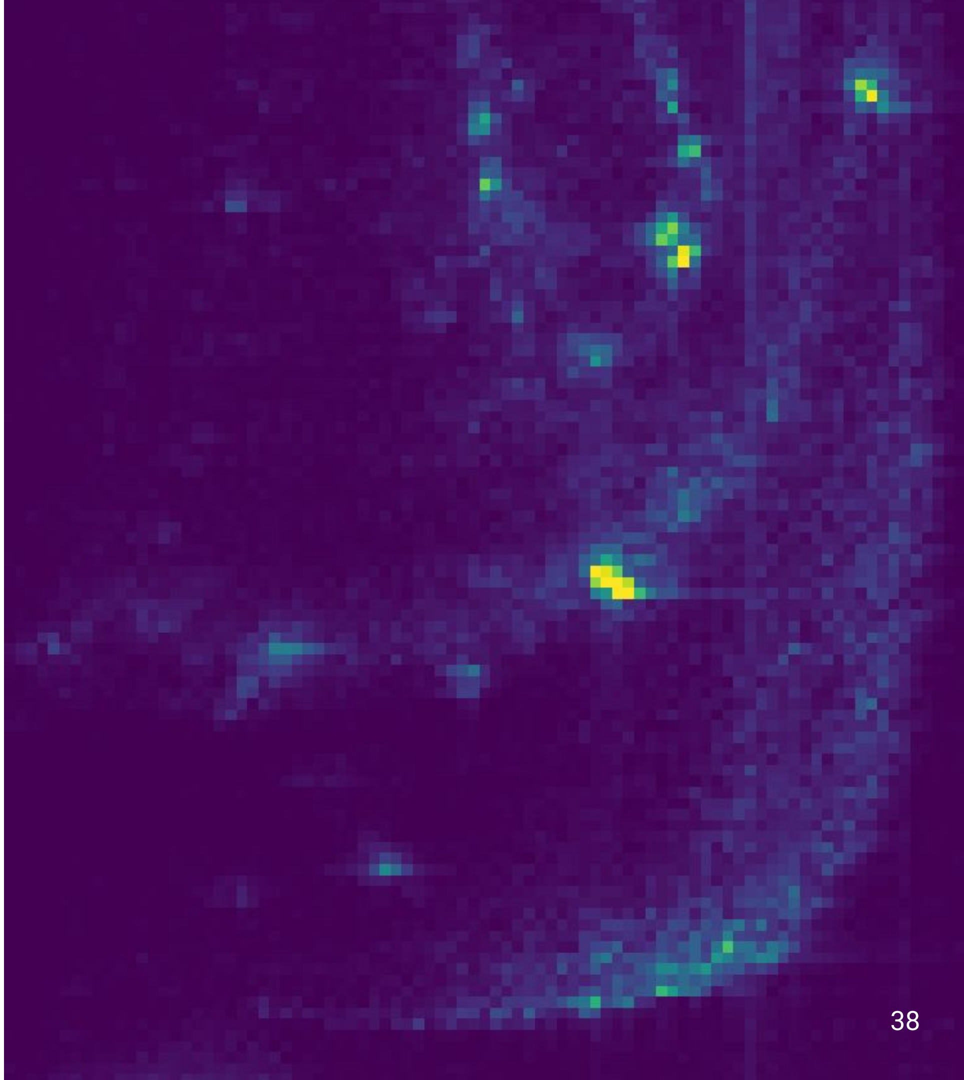


Takeaways

- Radar is no longer an exotic or expensive sensor
- Entry-level radars are and have been comparable to cameras in cost and prevalence
  - At volume, radars and cameras are ~$10–$50
  - My 2018 Honda CRV has 2 cameras and 3 radars

Aside:
What is this? →

Range-Doppler Plot



What

by the end of the introductory lectures, you will understand what these are!

Next Time: **Wireless Crash Course, Part 1**

1. Everything you need to know about electromagnetism
2. Time and Frequency domain
3. Signals and channel response