RFID JOURNAL VIRTUALLY LIVE!

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Preventing Patient Injuries with Wearable Sensors

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Acknowledgements This work is sponsored in part by Florida High Tech Corridor Research Grant FHT 19-06 titled "Algorithmic Prediction and Recognition of Human Activity and Falls from Wireless Accelerometer Data".

A quick word about my university

University of South Florida – Bull Pride !

- Ranks **1st** in Florida, **7th** in the nation and **16th** world-wide among all universities for granted U.S. patents (Intellectual Property Owners Association)

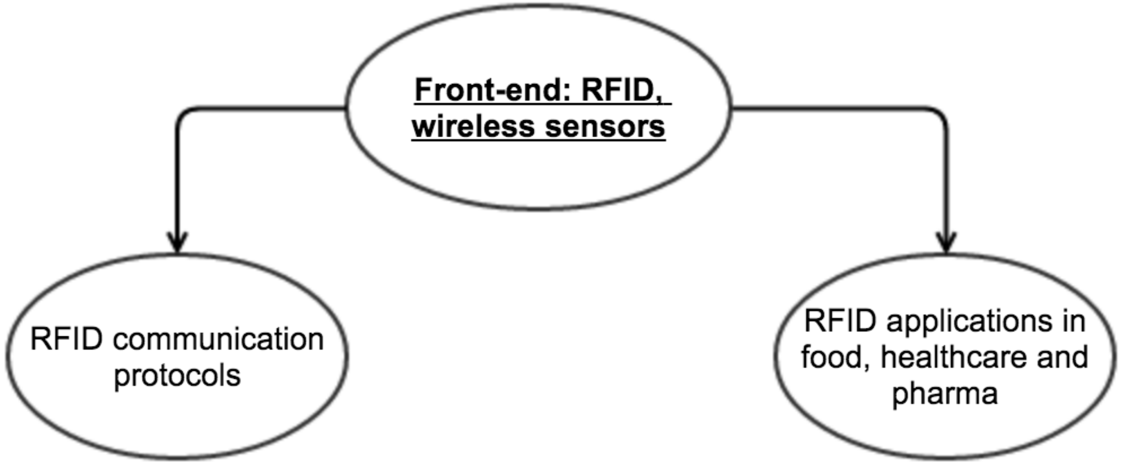
- **$525.4 million** in externally funded research grants and contracts in FY 2019 !

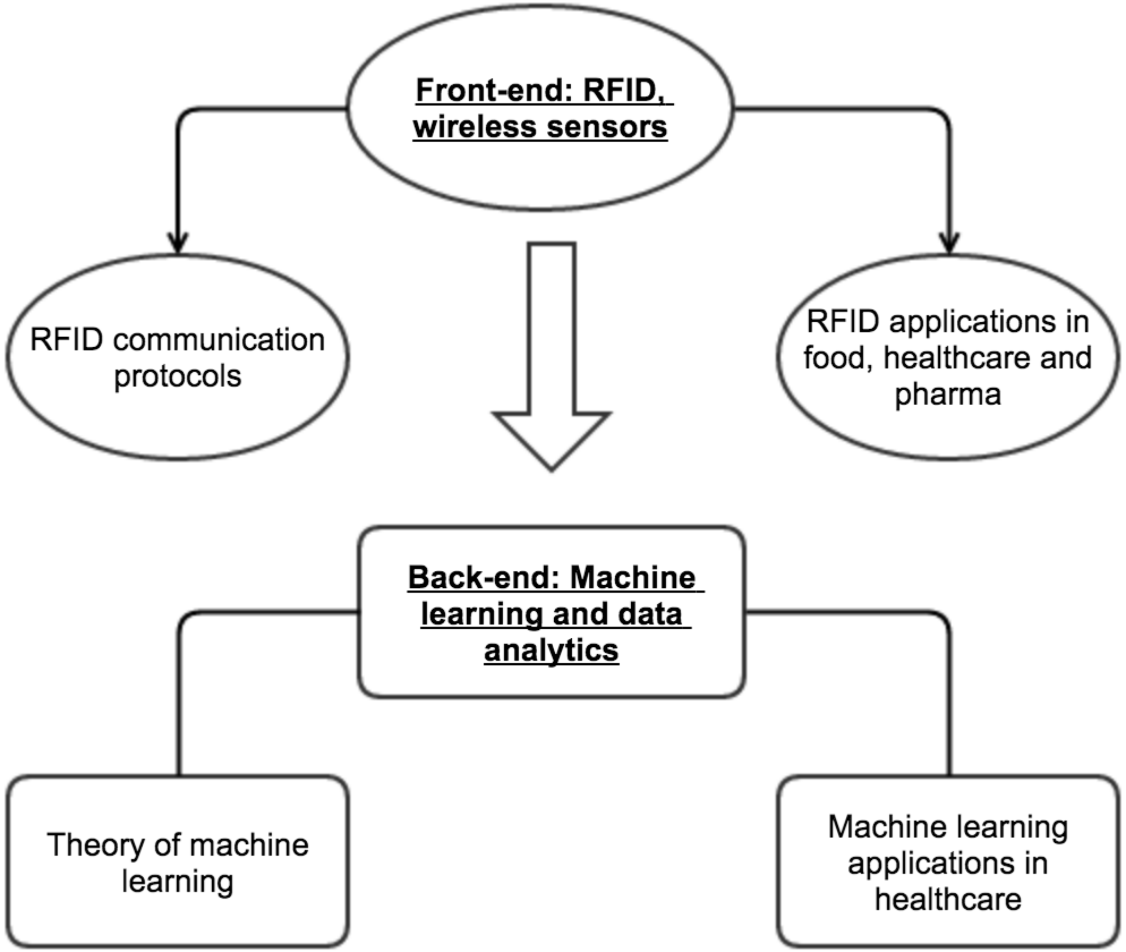
- Consistent and strong emphasis on **« applied research »**, strong collaborations and partnerships with industry !

A quick word about my research

- Earlier research concentrated on wireless sensor technologies – such as RFID – for transportation, distribution, cold-chain, pharmaceuticals and healthcare.

- Current research focuses more on ***wireless sensor data analytics and artificial intelligence*** specifically for ***cold chain, healthcare, and other industrial applications of RFID.***


Front-end: RFID, wireless sensors
RFID communication protocols
RFID applications in food, healthcare and pharma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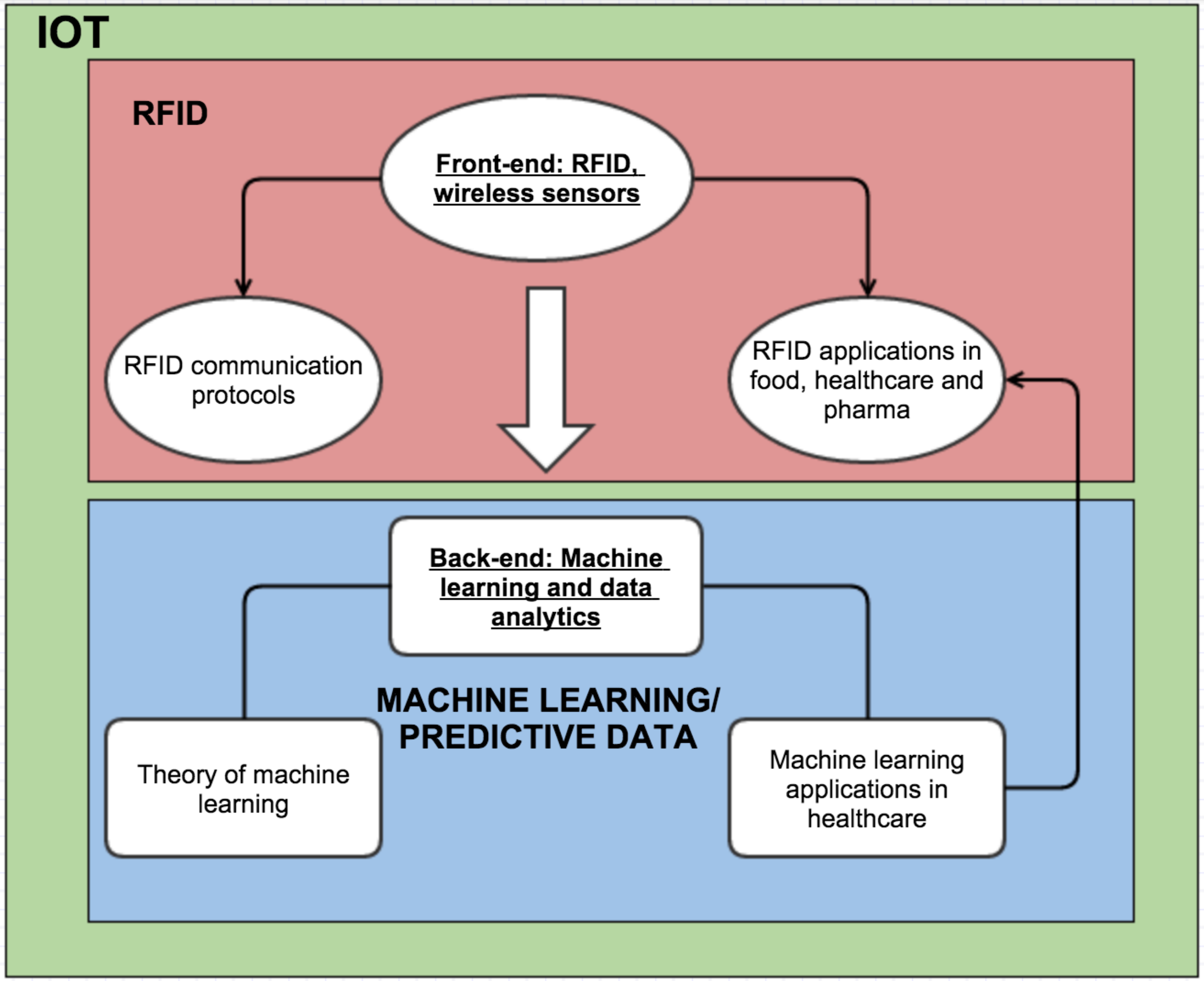
Back-end: Machine learning and data analytics
Theory of machine learning
Machine learning applications in healthcare


IOT
RFID
Front-end: RFID, wireless sensors
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Back-end: Machine learning and data analytics
MACHINE LEARNING/ PREDICTIVE DATA
Theory of machine learning
Machine learning applications in healthcare

Past and present research sponsors

10th Year with RFID Journal Live !

- We believe that applied academic research is a key component of any innovation.
- RFID/IoT – some of the most innovative technologies of the past decade.
- We also believe academia and industry can and **should** work together to achieve the best outcome for any implementation.
- So…we're glad to be a part of this event since 2010 ☺

Today's Presentation

Facts of life

- The population of the United States is aging. There are approximately 50 million adults with ages 65 and older in the U.S.

- In 2050, this number is expected to almost double and reach 90 million.

- **Falls are the leading cause of both fatal and non-fatal injuries among older adults.**

But what about the facts of technology?

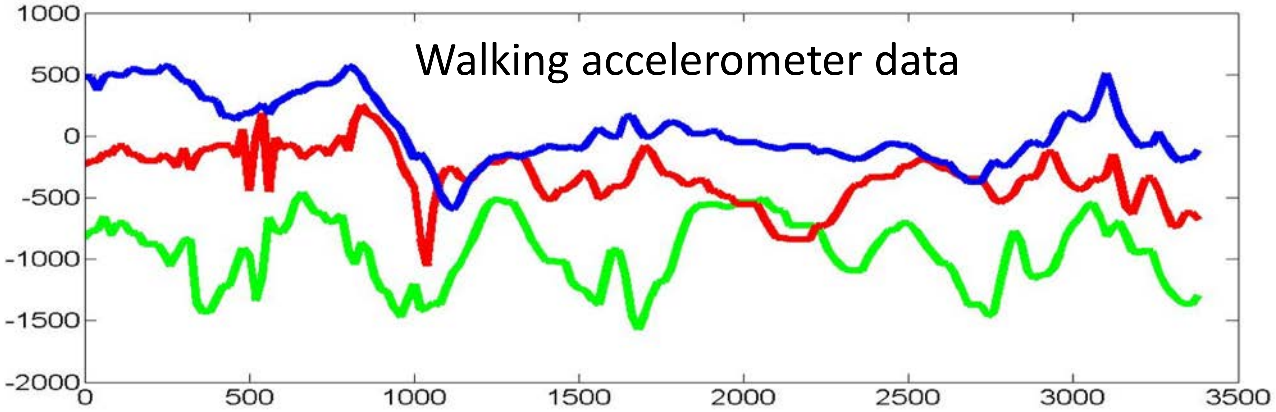
- Tremendous gain in popularity for mobile and personal health devices.
- Which means, more data is available to process and analyze.
- Can we do more with more data? Yes !
- More data => Big Data => Artificial Intelligence

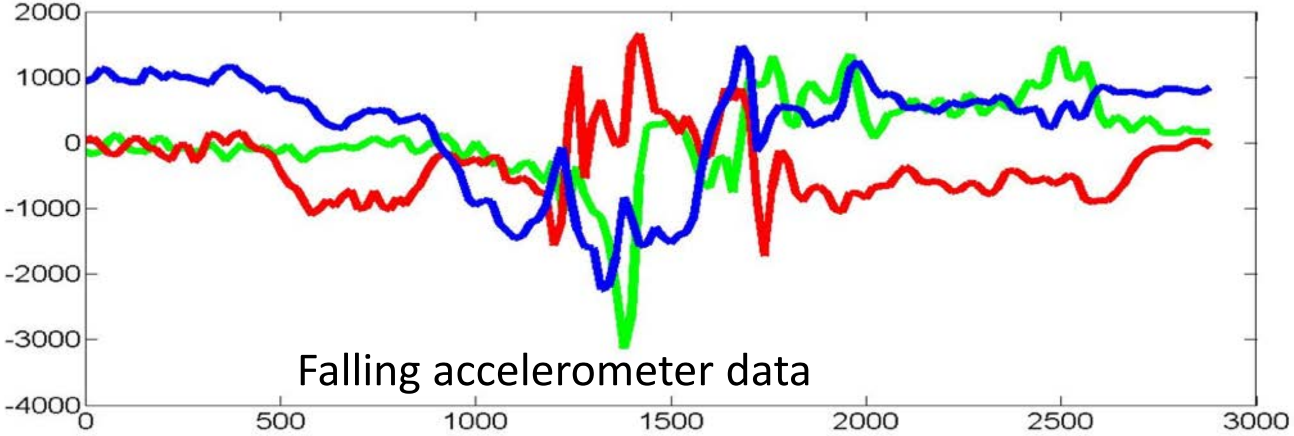
Research objectives

- Can we detect and identify falls using only 3-axis accelerometer time data coming from standard wireless/RFID wrist brands?

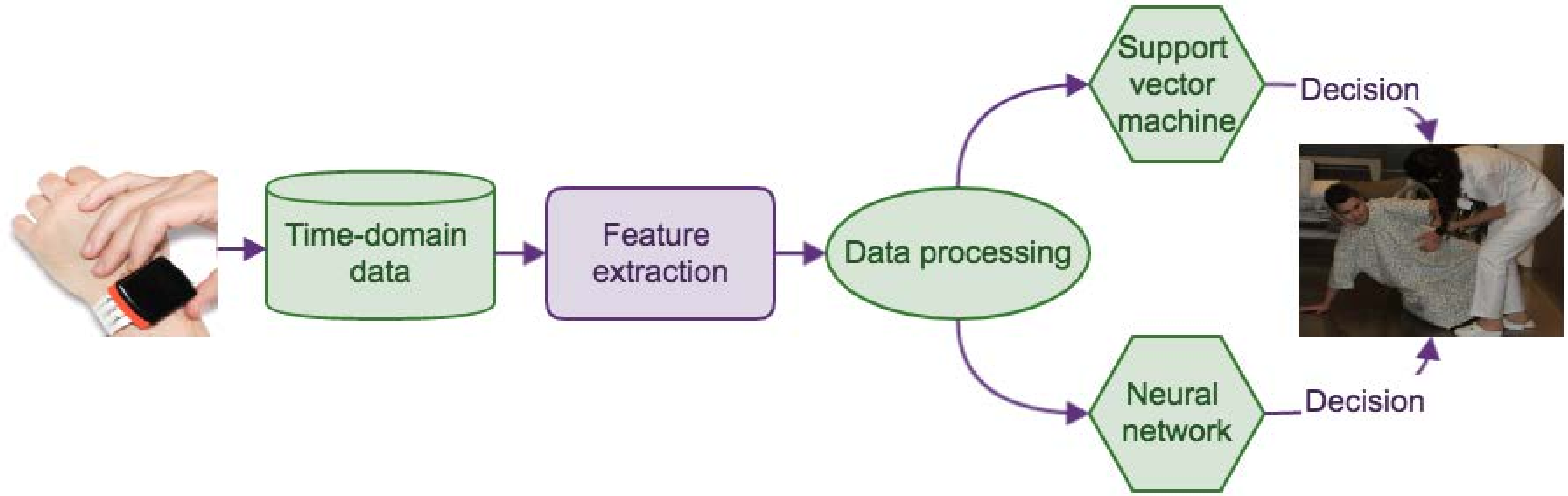
- Can we do more – detect the type of motion based on the same data?

Always begin with the same question: What does the data look like?





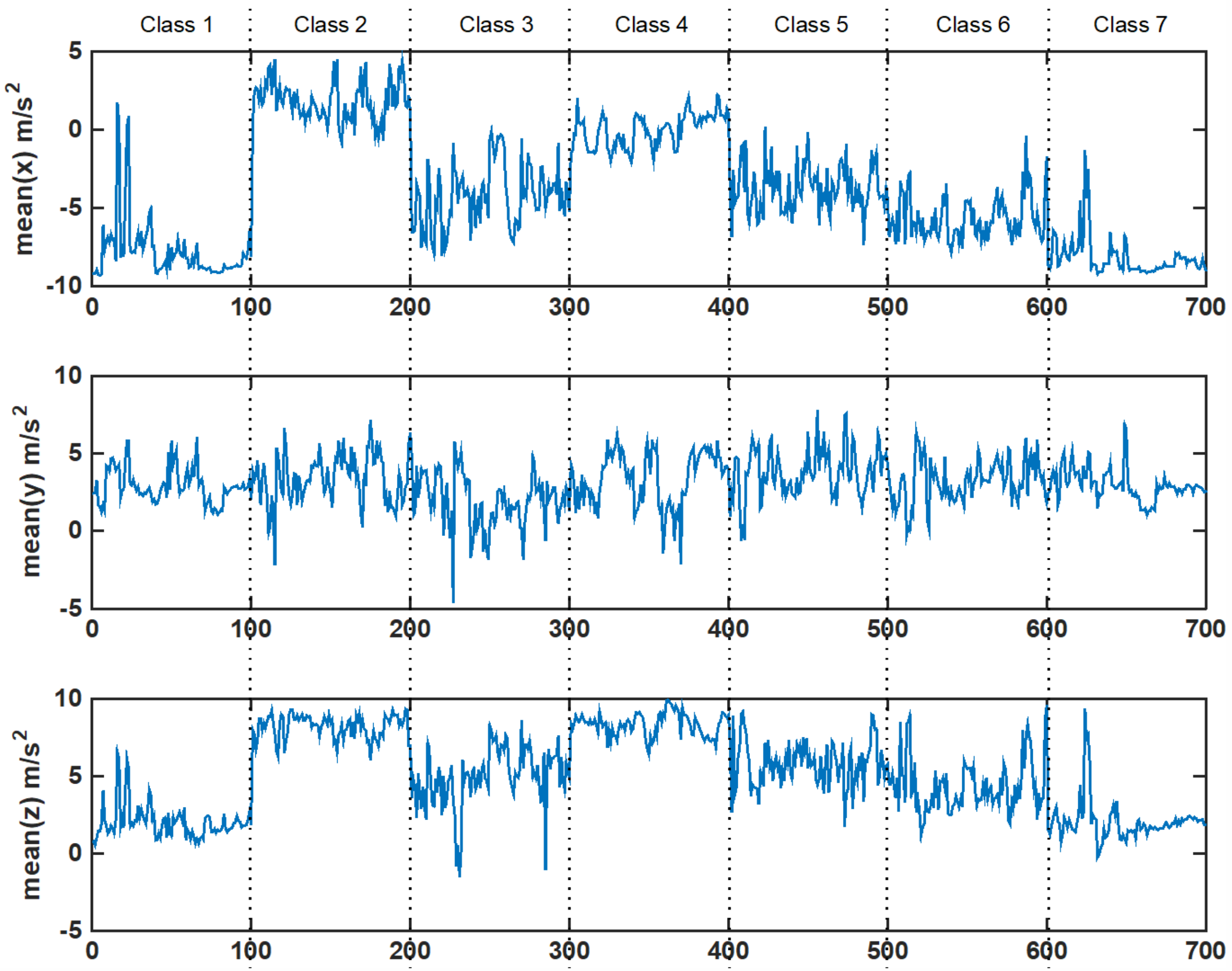
How does the system work?



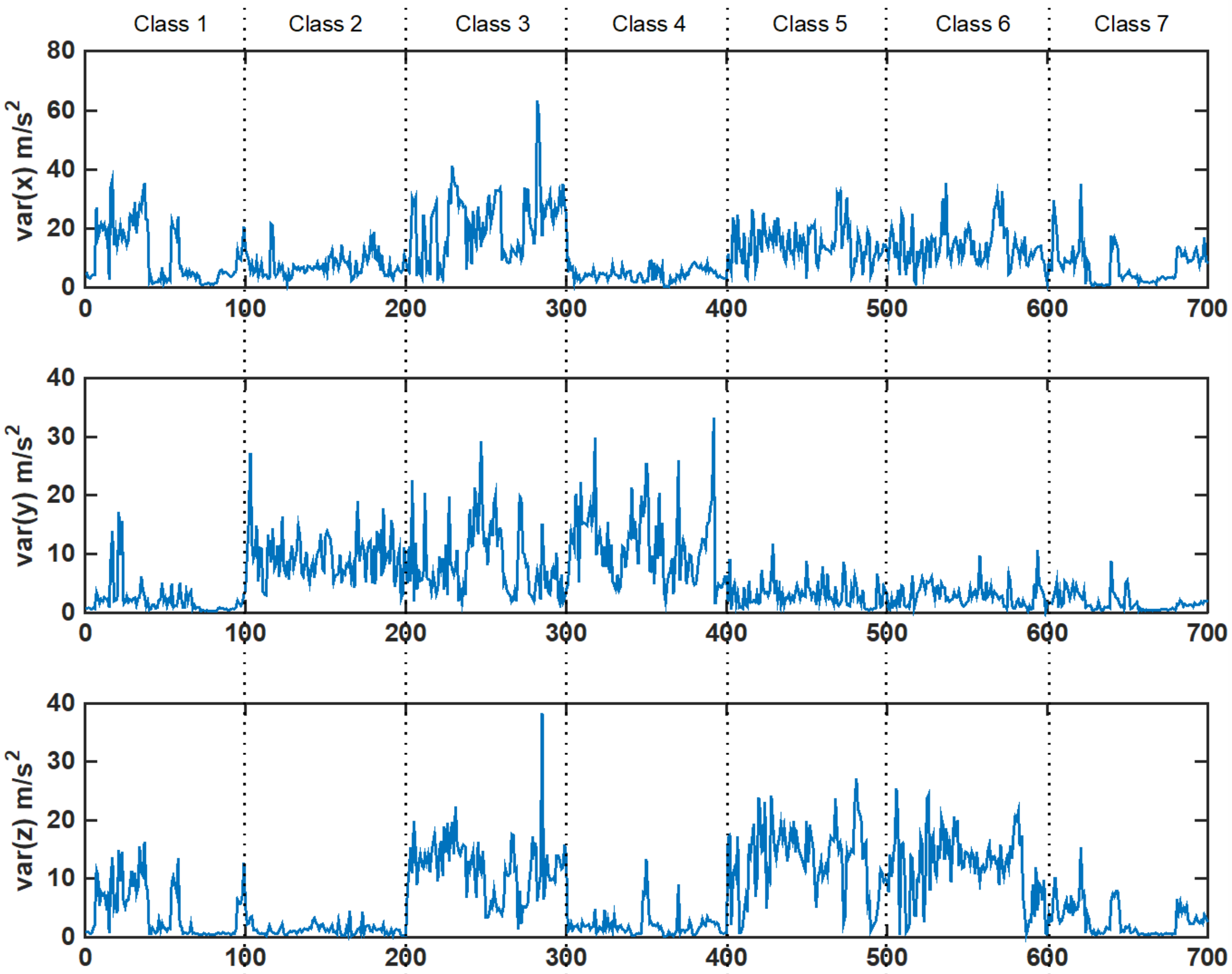
Just looking at the raw data is not very helpful !

- Need to extract meaningful information.
- We call this "feature extraction"
- These features could be simple statistical measures.
- Or more complicated.

Taking simple average



Or looking at standard deviation…



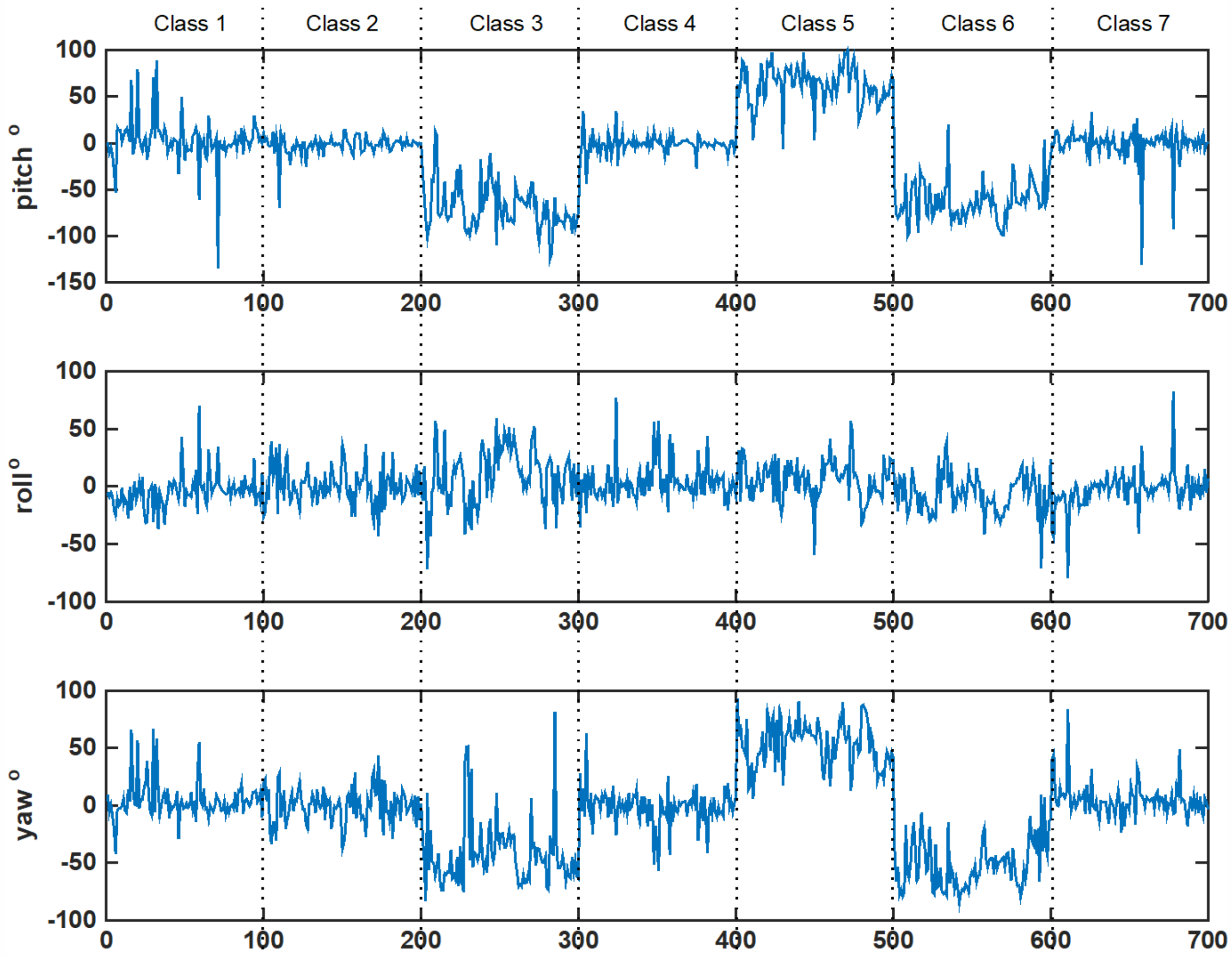
When simple measures are not enough…

$$pitch = \arctan\left(\frac{x_N}{\sqrt{y_N^2 + z_N^2}}\right) - \arctan\left(\frac{x_1}{\sqrt{y_1^2 + z_1^2}}\right)$$

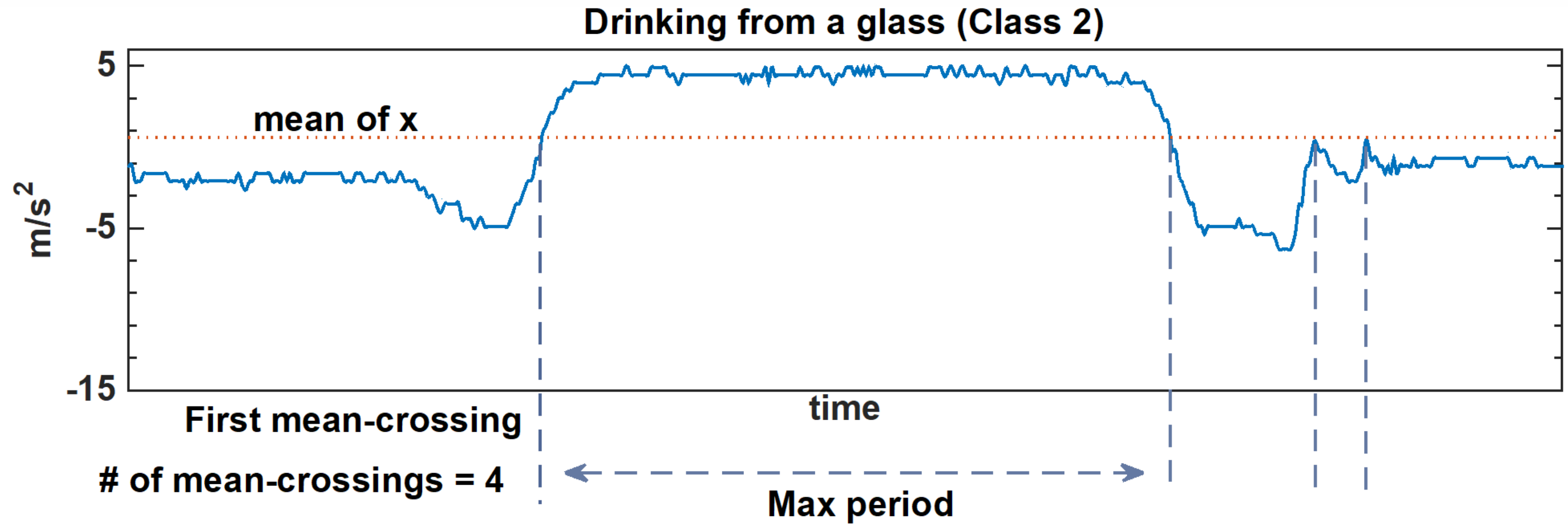
$$roll = \arctan\left(\frac{y_N}{\sqrt{x_N^2 + z_N^2}}\right) - \arctan\left(\frac{y_1}{\sqrt{x_1^2 + z_1^2}}\right)$$

$$yaw = \arctan\left(\frac{z_N}{\sqrt{x_N^2 + y_N^2}}\right) - \arctan\left(\frac{z_1}{\sqrt{x_1^2 + y_1^2}}\right)$$

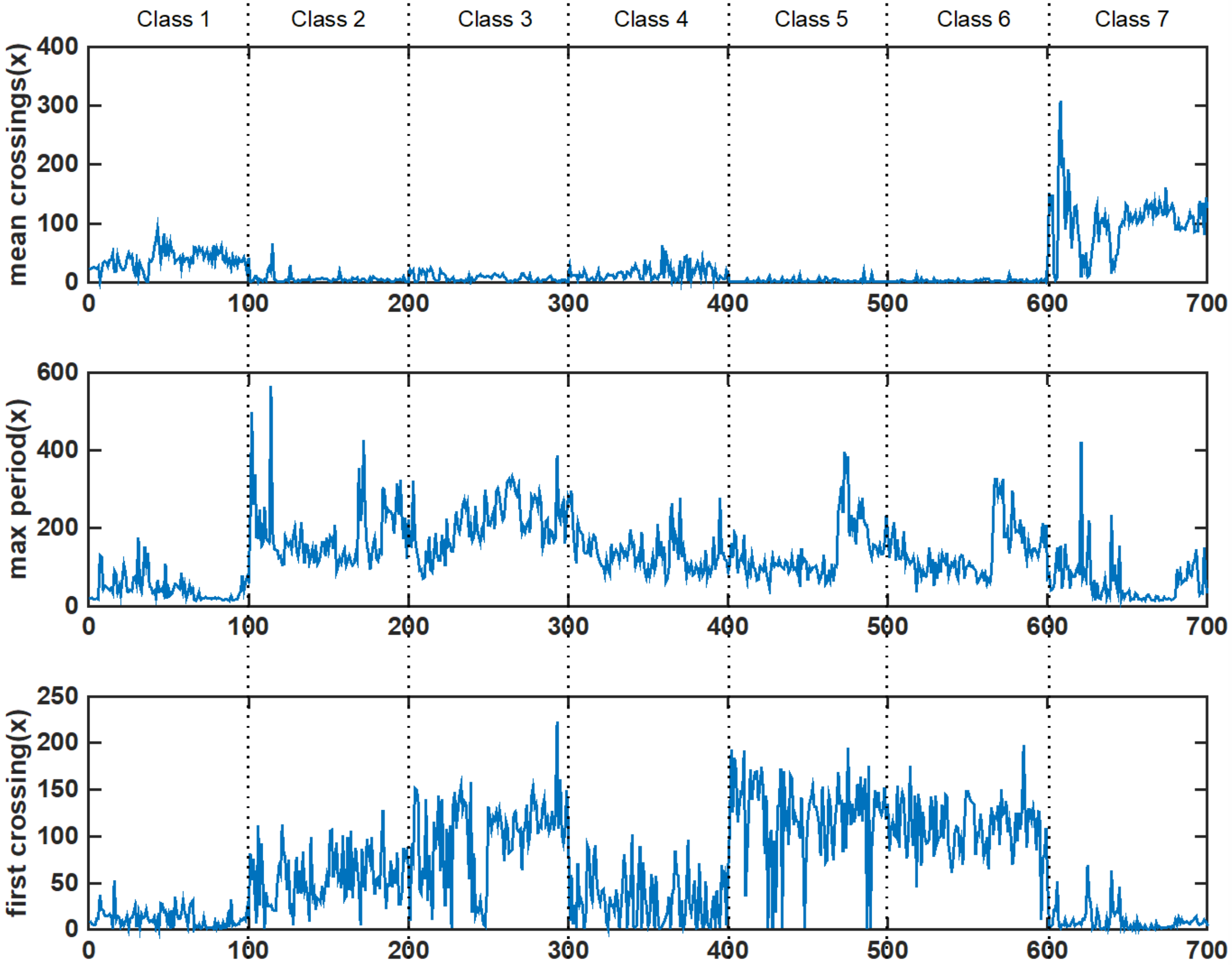
Do they make a difference?



“Intuitive” features



Do they help?



Class 1
Class 2
Class 3
Class 4
Class 5
Class 6
Class 7
mean crossings(x)
max period(x)
first crossing(x)
0
100
200
300
400
500
600
700

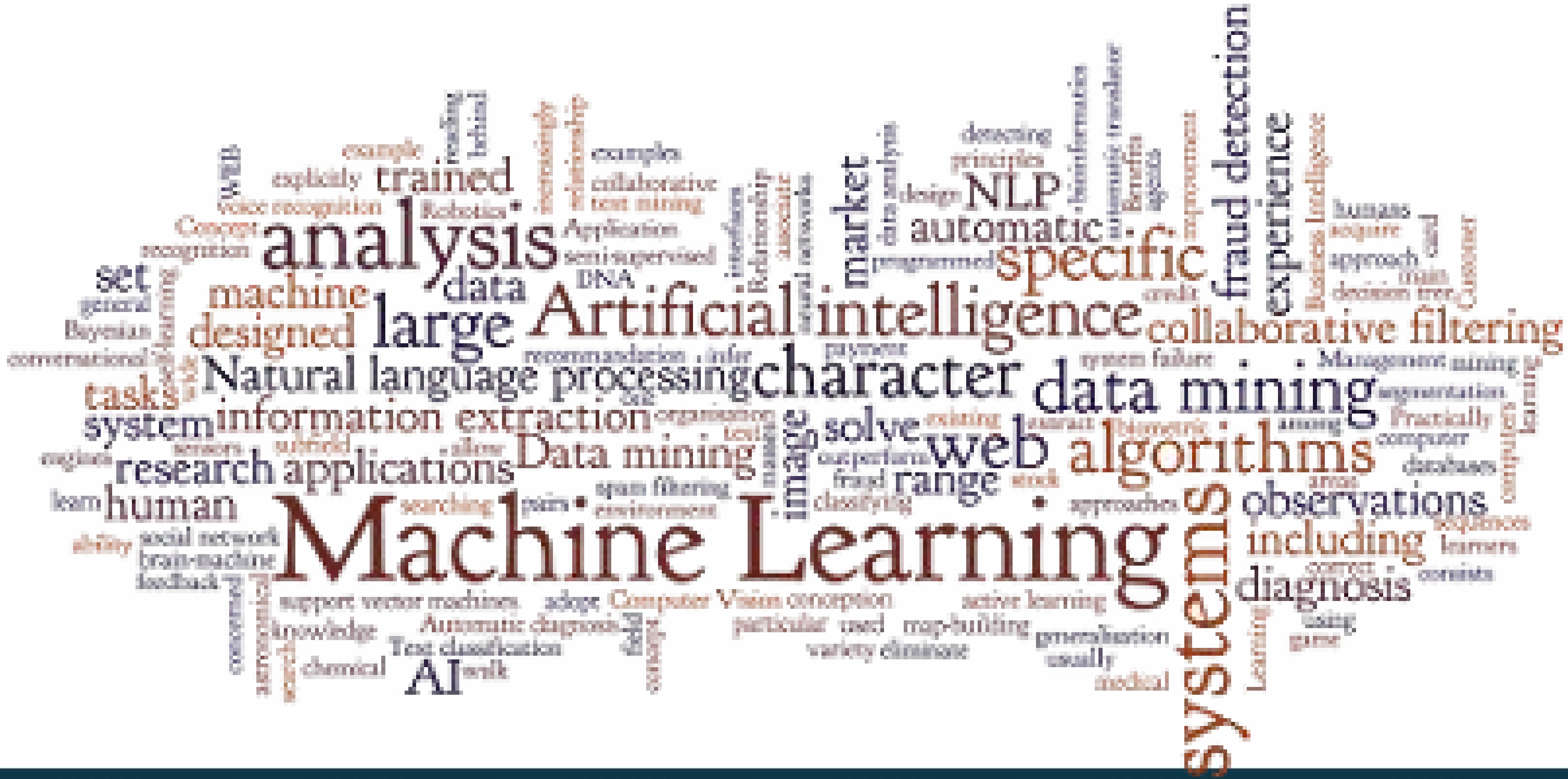
Our early research looked found that using these features together is better !

Used Features	***Accuracy %***
Mean(x,y,z), Variance(x,y,z)	60.5
Mean(x,y,z), Variance(x,y,z), PRY	66.9
Mean(x,y,z), Variance(x,y,z), PRY, MCR	81
Mean(x,y,z), Variance(x,y,z), PRY, MCR, FCR	82.6

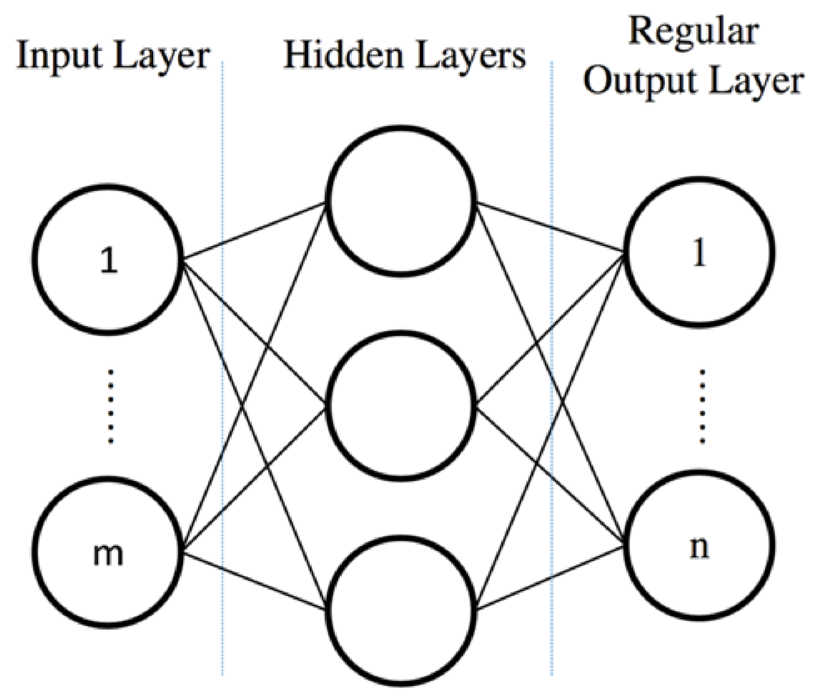
Question is – how do we use them together?

- Artificial intelligence !
- We are doing pattern recognition.
- To recognize means to classify a sample based on its class label.
- Two classifiers:
  - Support vector machines
  - Artificial neural networks

Machine Learning



It started with linear regression, but morphed into something more…



Where are we at now?

A baseball game in progress.

A person holding a cell phone in their hand.

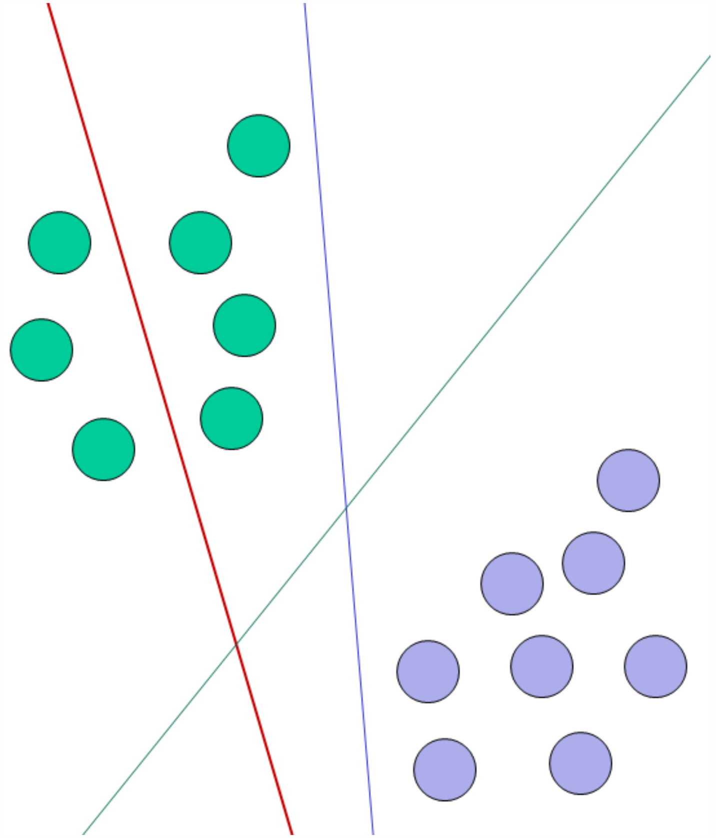
A brown bear standing on top of a lush green field.

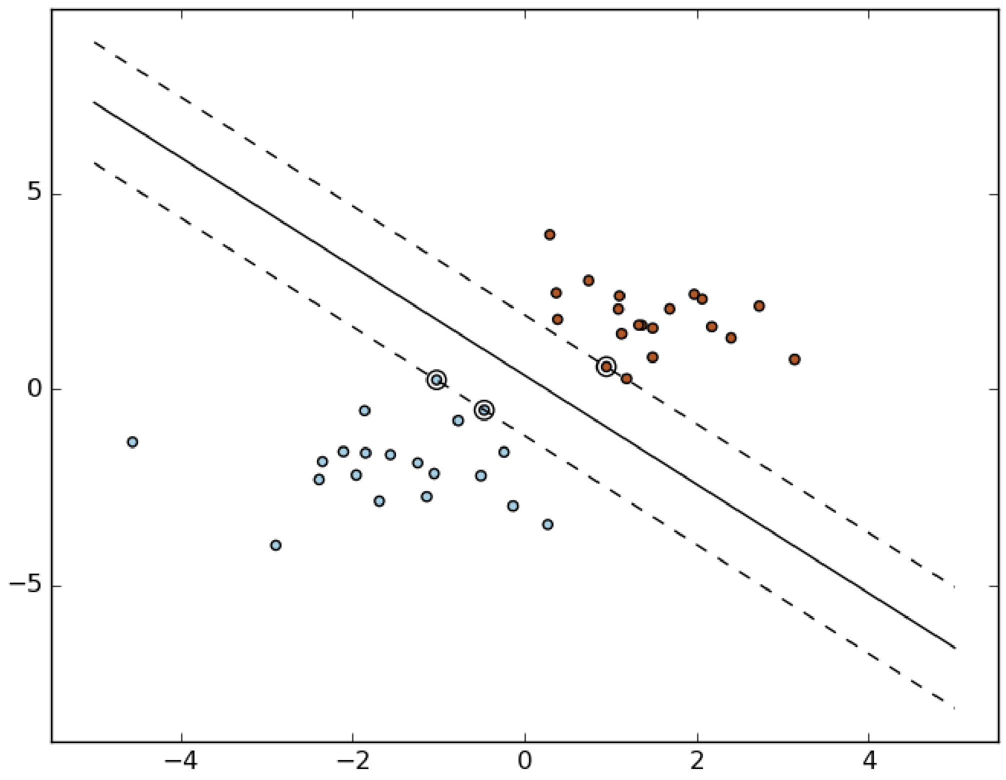
A close up of a person brushing his teeth.

Can we use these advances for fall/activity recognition?

- We will use support vector machines.
- Why?
  - SVMs are very powerful binary classifiers.
  - Binary – as in, 1 or 0.
  - Has the patient fallen? Or not?
- How do they work?

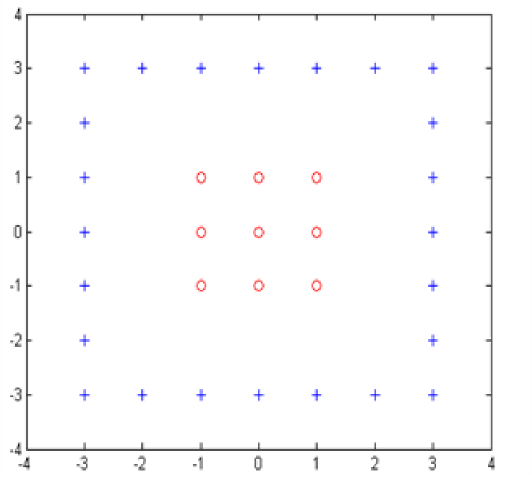
Support Vector Machines

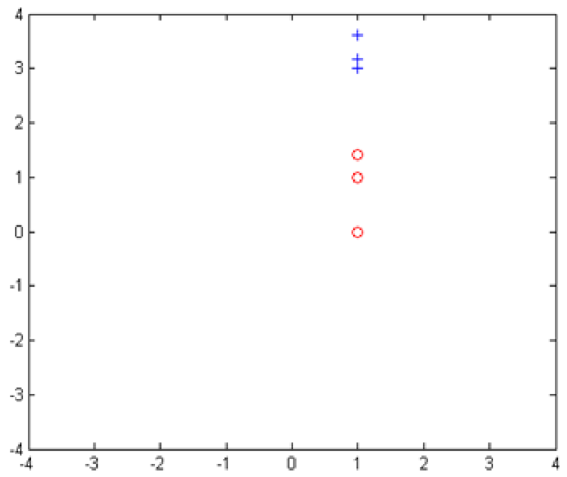


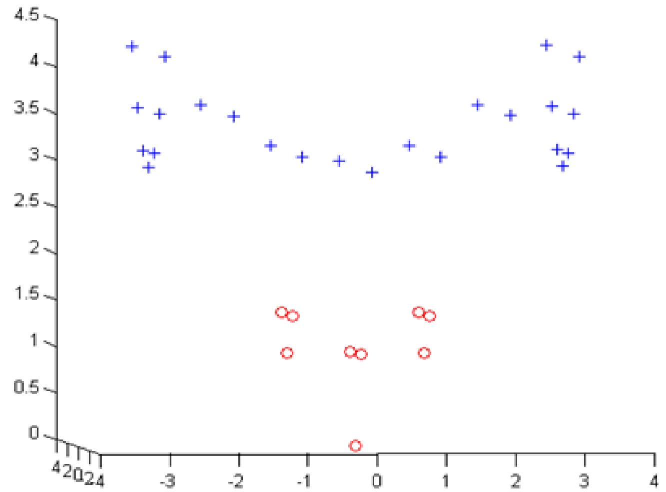


What if my samples are not linearly separable?

Can we see beyond the two dimensions ? How about adding a third dimension in the form of “distance from the center” ?







Early results on fall detection

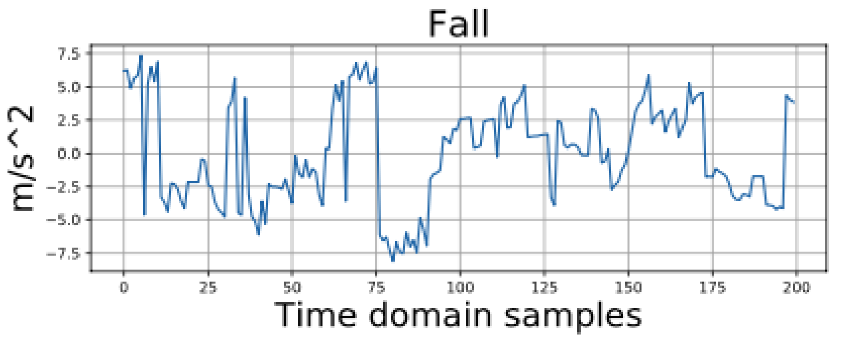
- Publicly available datasets are not readily available on patient falls using accelerometers.
- Limited dataset – obtained using real wireless wristbands in an actual hospital.
- 100% accuracy with <u>no false positives </u>(identify a fall when there is none) or <u>false negatives</u> (miss a fall when someone did).

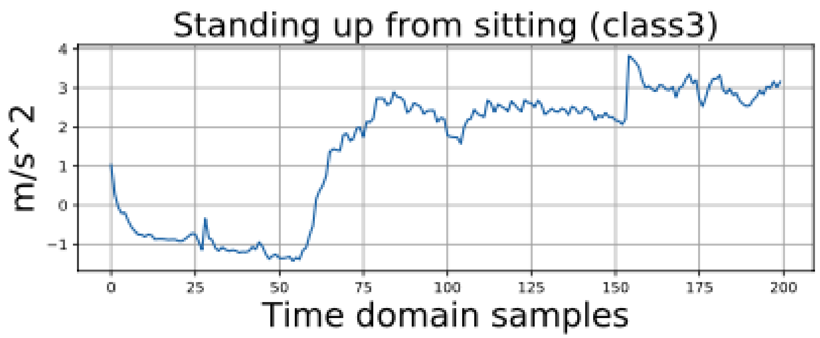
New data !

- Publicly available UniMiB-SHAR dataset
  - 11771 samples for fall data **(Labeled as AF-2, Action vs Fall Binary)**
  - 30 different users
  - Three-axis acceleration data from simple sensors
- Like before when we use the algorithm we previously developed with SVM and the same 9 features we get:
  - **96.85% accuracy**
  - **Better than state-of-the-art reported on this dataset**
  - But not necessarily error-free

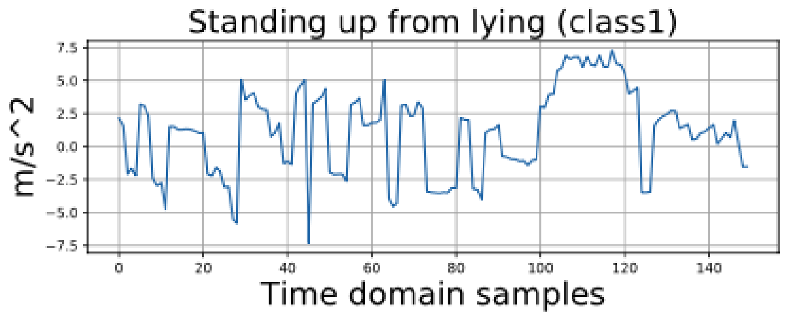
Shall we try something else?
Did someone say Deep Learning?

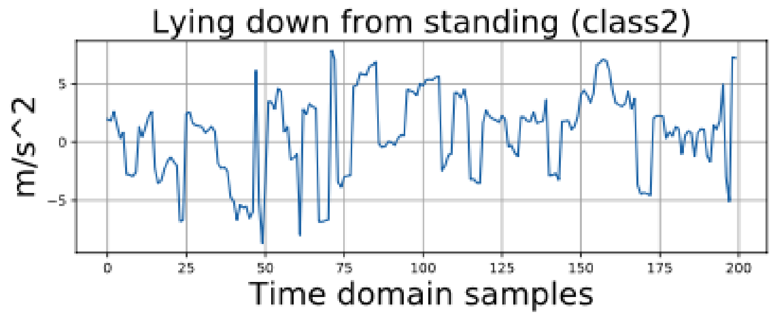
- What is so special about Deep Learning for this application?
- No complicated feature extractions – let the algorithm learn everything from raw, unfiltered data



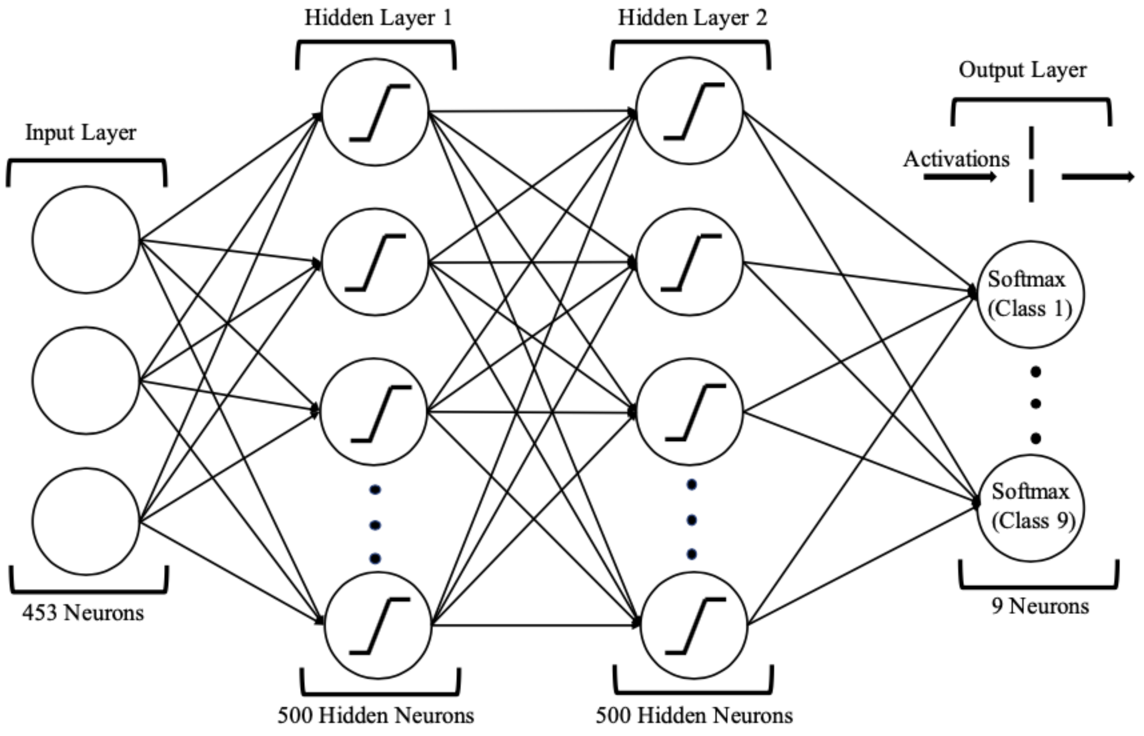


- Easy right?
- Perhaps not…





To learn this we need something more powerful…



Just like a human being, you train a neural network by showing examples and telling it which class they belong to.

Through iterative learning process, the neural network learns over time to identify different data samples.

And then you test it on samples it has never seen before !

How do they learn?

If this is a dog…

And this is a cat…

What is this?

Does complexity help?

Yes – as long as you keep in mind that is is not an **exact science to choose the best settings.**

Does that remind you of another technology? ☺

99.01% - best results reported so far on this fall detection dataset

Data	HL1	HL2	HL3	HL4	HL5	Mean Acc raw data (%)
	500	—	—	—	—	98.76
AF-2	500	500	—	—	—	98.64
11771	250	250	50	—	—	98.89
observa	250	250	50	20	—	99.01
-tions	250	250	50	50	20	98.51

Can it be used for more than simply detecting patient falls?

We anticipate…if we can scale beyond binary detections of fall versus no-fall, there are tremendous applications in healthcare !

- Recognize daily activities
- Assist in physical therapy of elderly patients
- Welfare checks and automated reporting
- Preemptive diagnosis and detection of falls or movement issues.

Our previous study on a different, smaller scale dataset…

B. Bruno, F. Mastrogiovanni, A. Sgorbissa, T. Vernazza, and R. Zaccaria, "Analysis of human behavior recognition algorithms based on acceleration data," *2013 IEEE Int. Conf. Robot. Autom.*, pp. 1602–1607, 2013.

- 54% true-positive-rate
- 81% true-negative-rate

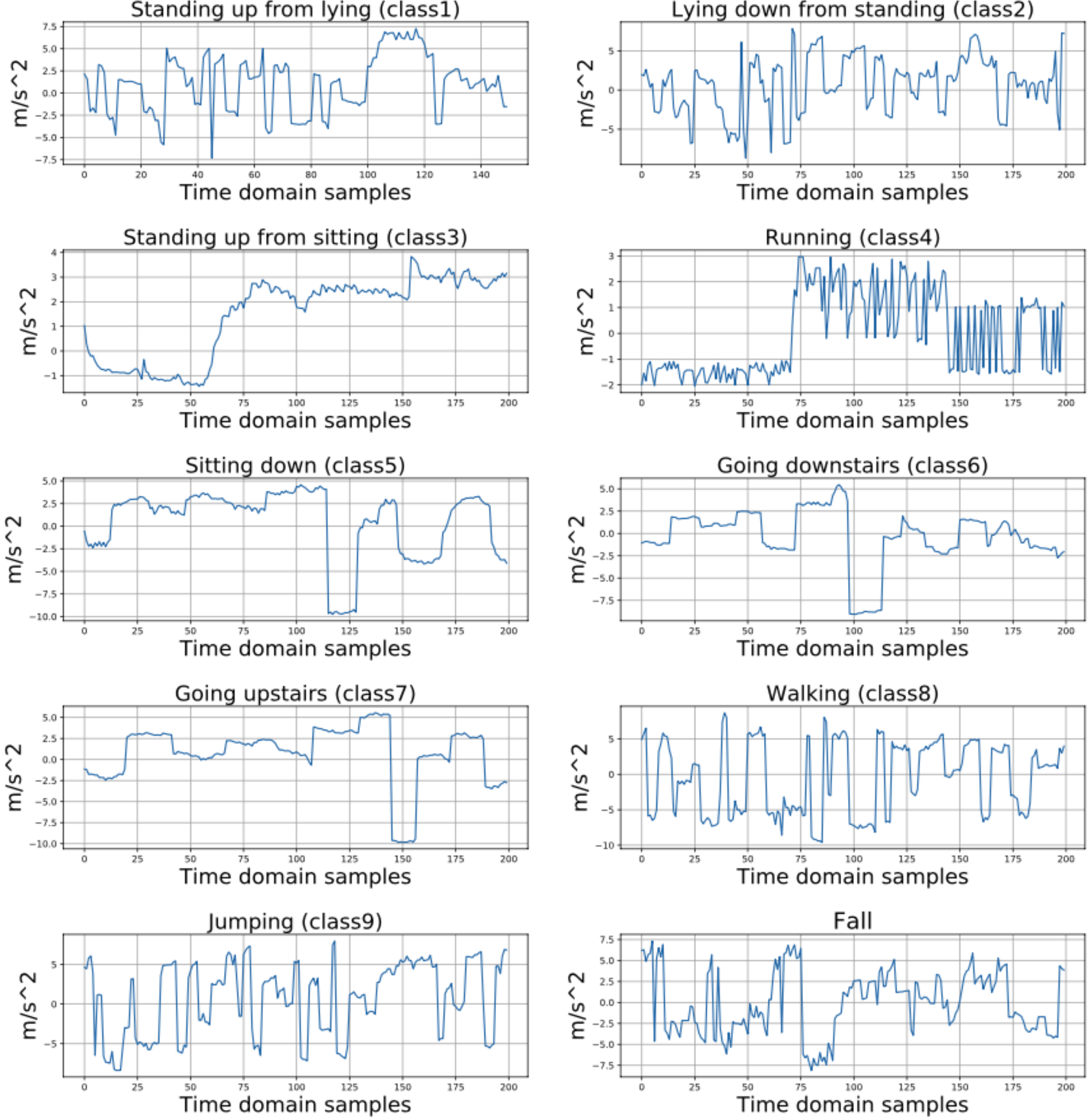
vs.

- 91.15% true-positive-rate with AI
- 98.5% true-negative-rate with AI

with real-time operational speed !

New Data !

- UniMiB-SHAR Dataset
- 9 different activity classes
- 7579 observations from 30 different subjects
- **Labeled as A-9 (9 different action classes)**



Is new technology better?

Data	HL1	HL2	HL3	HL4	HL5	Mean Acc raw data (%)	Mean Acc fea-tures (%)
	500	—	—	—	—	87.79	91.61
A-9	500	500	—	—	—	87.86	92.07
7579	250	250	50	—	—	88.20	93.79
observa	250	250	50	20	—	85.75	91.87
-tions	250	250	50	50	20	84.83	92.05

- Highest reported accuracy in the literature is 88.41%
- Highest accuracy we could obtain is 88.20%
- Shall we go back to features?

What’s an excellent example for deep learning?

- Speech recognition…
- How do they do it ?
- Google, Apple, Facebook, Microsoft, etc. all use the same underlying technology called…
- LONG-SHORT-TERM-MEMORY (LSTM) recurrent neural networks
- LSTM has feedback connections which can learn the short-term and long-term dependencies in temporal (time-based) data
- Data format for fall detection/activity recognition?
- You guessed it: **time based !**

Again – does it help?

Mean accuracy of RNN-LSTM model on UniMiB-SHAR dataset

Data	HL1	HL2	HL3	HL4	HL5	Mean Acc raw data (%)	Mean Acc features (%)
	500	—	—	—	—	94.13	95.78
	500	500	—	—	—	97.89	95.84
A-9	250	250	50	—	—	97.96	96.35
	250	250	50	20	—	98.02	95.84
	250	250	50	50	20	97.11	95.75

As a quick reminder: state-of-the-art on this dataset was 88.41%

Our best performance was 88.20%

Best performance we got using LSTM on raw, unfiltered time-domain acceleration data is **98.02%**

Best results ever reported in the literature for human activity recognition on this dataset !

Conclusions

- We are finally there !
  - RF/wireless technology is easy to implement and generate lots of data.
  - Data science (AI, machine learning, analytics, etc.) has come a long way within the past decade.
  - Together they unlock applications from healthcare to supply chain we never thought possible before.
- We can now detect patient falls up to 99-100% accuracy.
- We can detect common human activities up to 98% accuracy.
- We can run these algorithms in near real time to improve patient outcomes and quality of life related to falling incidents.

Thank you for listening ☺

- Questions? Comments?
- If you'd like to learn more about our research on using artificial intelligence/machine learning on wireless sensor and RFID applications:
  - iuysal@usf.edu
  - 813-974-8823

THANK YOU

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