Final Project

Binary Hypothesis Testing for Real-time Patient Monitoring

ECE 313 – Section F

Fall 2016

Project Objectives

- Hypothesis testing with single and pairs of features
  1. Learn how to use hypothesis testing to learn decision rules based on training data and use the generated rules to predict alarms on testing data
  2. Learn how to create ML and MAP decision rules by:
     - Creating the likelihood matrix based on training data
     - Creating the joint probability matrix from the likelihood matrix
     - Creating the likelihood matrix of joint observations from pairs of features
     - Generating the ML and MAP rules based on training data
  3. Learn how to evaluate decision rules using the conditional probabilities of false alarm and miss detection and probability of error
- Feature selection
  - Evaluate different criteria for selecting features, including:
    - Correlations between features
    - Correlations between features and golden alarms
    - Visualization of decision rules (ML and MAP)

Project Timeline and Grading

- **By Nov. 10, 5.00 PM, email us how you plan to divide the tasks**
- **Progress meeting with individual groups:**
  November 16, 11.00 – 2.00 PM. , each group presents Task 2 results
- **Tasks 0-2: report due on Thursday, November 17, 11.59 PM.**
  Report should address feedback from the progress meeting
- **Final Presentation: Wednesday, December 7, 5.00 – 8.00 PM,**
  - Presentation template will be provided
  - Slides and working Matlab code (for demo) should be submitted by 2pm
- **Final Report, All-Tasks: Friday, December 9, 11:59 PM.**

- **Grading**
  - **Task 1: 40%**
  - **Task 2: 20%**
  - **Task 3: 40%**
  - **Bonus: 5%**

You will be competing with the other groups for designing the best decision rules.

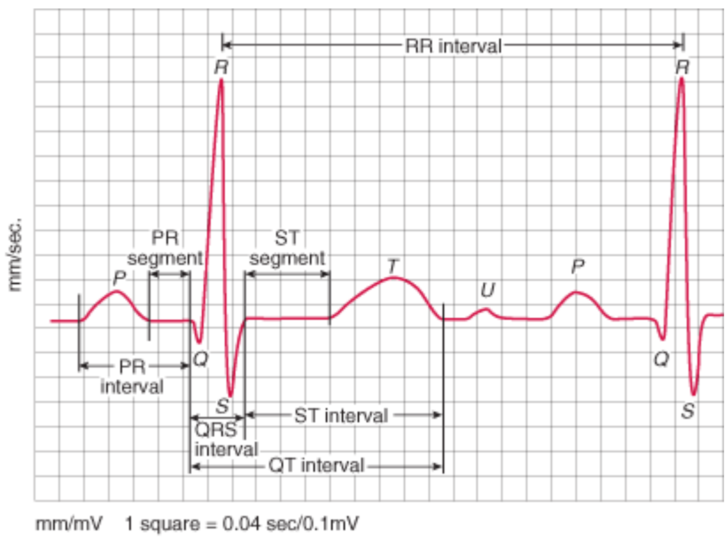
Your results will be compared in terms of **the average probability of error achieved for all the 9 patients.**

The **top three groups** with the lowest error probabilities will get the **bonus.**

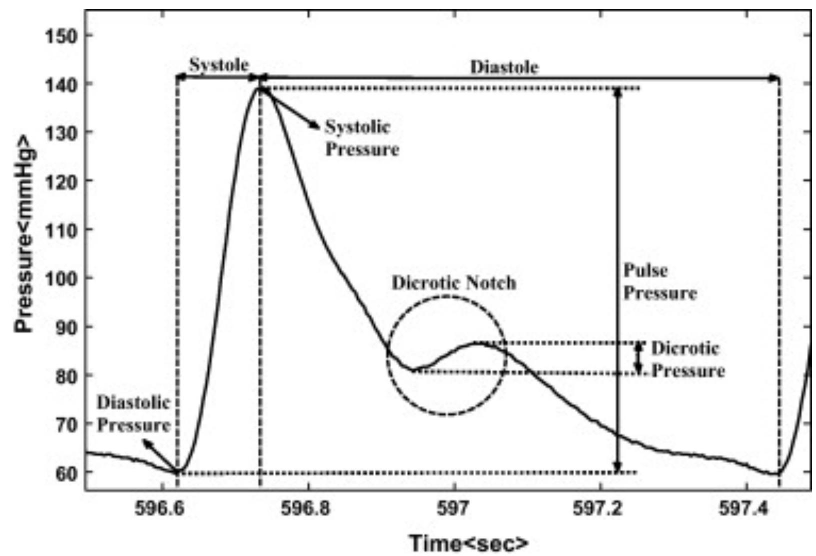
Final Project: Data

- You are given a set of data collected from **9** different patients.
- Each data set includes **7** features calculated from the electrocardiogram (ECG) and blood pressure (ABP) signals collected from a given patient:

ECG Waveform



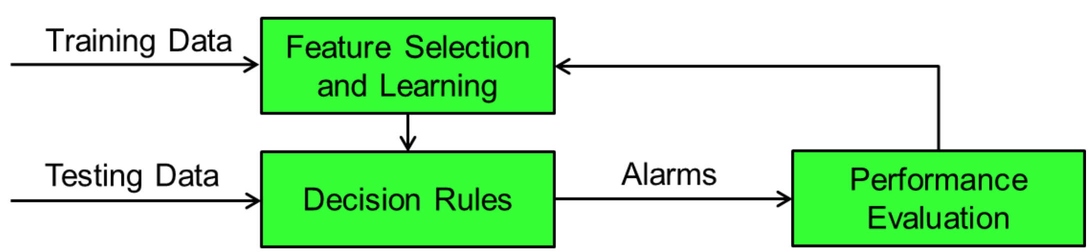
ABP Waveform



1. **Mean Area under the heart beat**
2. **Mean R-to-R peak interval**
3. **Number of beats per minute (Heart Rate)**
4. **Peak to peak interval for Blood pressure**
5. **Systolic Blood Pressure**
6. **Diastolic Blood Pressure**
7. **Pulse Pressure**

Final Project: Task Summary summarized in the figure

- Divide data into training and testing sets
- Learn ML and MAP decision rules based on training data:
  - Single features
  - Pairs of features
- Find the best pair of features for the least error in ML and MAP, using the training data for each patient and using at least two different criteria. Following are some example criteria. State your criteria precisely:
  - Correlations between features
  - Correlations between features and golden alarms
  - Visualization of decision rules (ML and MAP)
  - Weighted sum of pairs of features
- Use the ML and MAP rules using the features selected on testing data



Final Project: Task 0

Repeat all the tasks in the project for each patient data provided to you.

- Load the patient data file into MATLAB, e.g.: *load 1_a41178.mat*
- Each data file consists of two variables: *all_data* and *all_labels*:
- *all_data* is an array of 7 rows:
  - Each row corresponds to the following features, respectively:
    1. Mean Area under the heart beat
    2. Mean R-to-R peak interval
    3. Number of beats per minute (Heart Rate)
    4. Peak to peak interval for Blood pressure
    5. Systolic Blood Pressure
    6. Diastolic Blood Pressure
    7. Pulse Pressure
  - Each column corresponds to a data sample.

    Note: Each patient data file has different number of samples.
- *all_labels* is a binary vector of golden alarms labeled by the physician
  - Each column corresponds to a data sample.

Final Project: Task 0

- Similar to Mini Project 2, Task 1.1, you need to first use ***floor(all_data)*** in order to convert data samples from *double* format into *integer* format. This will enable you in the following, to estimate the probability distributions as probability mass functions (pmf) by calculating the frequencies using ***tabulate*** and other functions (in Matlab).

- Divide *all_data* and *all_labels* vectors to two sets of *training* and *testing* with training set being 2/3 of the data and testing set 1/3 of the data.

  Hint: For example, if we have a dataset with 1500 entries:

  training = all_data(:,1:1000)

  label_training = all_labels(1:1000)

  testing = all_data(:, 1000:1500)

  label_testing = all_labels(1000:1500)

Final Project: Task 1.1

Let: ***H0*** the hypothesis that there is no patient abnormality (no alarm generated).

H1 the hypothesis that there is a patient abnormality (an alarm generated).

For each patient:

Use the *training* data set and its golden alarms (*label_training*), to:

a) Calculate the prior probabilities of P(H1) and P(H0).

b) Construct the likelihood matrices for each of the 7 features.

Hint 2: Calculate the probability mass function for each of the features given hypothesis *H1* is true by calculating the frequency of observations where an alarm was generated (*label_training* indicated “1”), and given hypothesis *H0* is true where no alarm was generated (*label_training* indicated “0”).

Hint 3: You can use *tabulate* function in MATLAB, but remember that ***probability values should be between 0 and 1***.

Hint 4: Remember that in the likelihood matrices, you need to have the same number of columns (possible values of the feature) for both *H1* and *H0.* Find the range of the values that a variable takes by using *min* and *max* commands in MATLAB.

Note that the MATLAB indices always start from 1.

Final Project: Task 1.1 (Cont'd)

c) Show your results by generating a separate figure for each patient, consisting of 7 *subplots* corresponding to the 7 features. In each subplot of each figure, plot the conditional pmf under each of the hypotheses *H0* and *H1*. Use *legend* function in MATLAB to distinguish between the two pmf's in the subplot.

Hint: *subplot(7, 1, 1);   plot(H0_pmf(:));   hold on;   plot(H1_pmf(:));*
legend('H0 pmf', 'H1 pmf');

d) Calculate the ML and MAP decision rule vectors.

Hint: To be definite, break ties in favor of *H1*. For example:

If *H1_pmf(i)* $\geq$ *H0_pmf(i)* then *ML_vector(i) = 1*.

e) **Save the results of Task 1.1** in the form of a 9-by-7 cell array, **called HT_table_array**, with each cell representing a two-dimensional array in the following format: **Hint:** *HT_table_array = cell(9, 7);*
HT_table_array(patient1, feature1) = HT_table(feature1);

The range of values that feature X takes.

X = i	P(X=i | H1)	P(X=i | H0)	ML Predicted Label	MAP Predicted Label

Final Project: Task 1.2

a) Use the *HT_table_array* calculated in Task 1.1 part e, to generate alarms based on each of the ML and MAP decision rules for the *testing* data set.

b) Use *label_testing* golden alarms to evaluate each of the ML and MAP decision rules, by calculating:

1. The conditional probability of false alarm
2. The conditional probability of missed detection
3. The probability of error

Hint: Remember:

P(False Alarm) = P(Decision rule declares an alarm | Physician indicates no abnormality)

P(Miss Detection) = P(Decision rule declares no alarm | Physician indicates an abnormality)

P(Error) = P(Decision rule declares an alarm AND Physician indicates no abnormality)+
P(Decision rule declares no alarm AND Physician indicates an abnormality)

Save the results of Task 1.2 in the form of a 9-by-7 cell array, **called Error_table_array**, with each cell representing a 2-by-3 array in the following format:

	P(False Alarm)	P(Miss Detection)	P(Error)
ML Rule			
MAP Rule			

Final Project: Task 2

In the rest of the project you will perform ML and MAP hypothesis testing using a **pair of features**.

Use the *training* data set and its golden alarms (*label_training*), to:

- Find the **best pair of features** that would achieve the lowest probability of error for each of the ML and MAP rules for **3 patients of your choice** that you think are best. i.e., remember you will be choosing one pair per patient

- Justify how each of your criteria relates to the expected performance in the hypothesis testing by showing the plots and results from your analysis above.

- Choose a set of possible pairs of features to be used for hypothesis testing based on pairs of features in the next task.

Final Project: Task 2 (Cont'd)

- Use **two or more** of the following techniques or other techniques **to find the best pair of features** to be used with ML and MAP decision rules:

  1. Find the top two features with the lowest ML and/or MAP errors from Task 1.
     Example: if feature f1 and f2 had the lowest ML error and f3 and f4 had the lowest MAP error, you can pair (f1, f2) or (f1, f3) or (f3, f4), … etc.

  2. Analyze the correlation between each of the 7 features and golden alarms (from Task 1.2) to prioritize the features
     Hint: Plot the features and ML and MAP alarms generated based on each feature in Task 1.2, along with *label_testing* golden alarms provided. Plot in one figure to visualize the correlation.

  3. Analyze the correlation between different pairs of features to eliminate redundant features with overlapping information. i.e., if two features are highly correlated, having them in a pair won't provide more information for decision making.
     Hint: *corr1 = corrcoef(training(f1, :), training(f2,:))* and then *corr1(1,2)* returns the correlation between f1 and f2

  4. Use the weighted sum of pairs of the feature values to generate new candidate features (e.g., $f_1' = \sum_{i=1}^{n} w_i f_i$, where $\sum_{i=1}^{n} w_i = 1$). Might be useful for combining multiple features into two.

Present the results of Task 2 in the **progress meeting** and submit a **formal report** with the results and answers to the questions for Task 0~2

Final Project: Task 3.1

In Task 3 you will perform ML and MAP hypothesis testing using a selected pair of features. **Write a function** that performs the following subtasks in Task 3:

a) Takes the likelihood matrices for the selected pair of features in Task 2.1 (saved in the *HT_table_array* from Task 1.1, part e), to generate the likelihood matrices for joint observations from the pair of features.

   Hint: Assume that the features are independent from each other.

b) Calculates the ML and MAP decision rule vectors, based on the likelihood matrix of the joint observations from the selected pair. To be definite, break ties in favor of H1.

c) **Saves the results of Task 3.1** in the form of a two-dimensional array, **called Joint_HT_table**, in the following format:

The range of values that the pair (X,Y) takes.

X = i	Y = j	P(X=i, Y=j | H1)	P(X=i, Y=j| H0)	ML Predicted Label	MAP Predicted Label

Final Project: Task 3.1 (Cont'd)

For the 3 patients that you chose in Task 2:

d) Show your results by plotting the conditional joint pmfs under each of the hypotheses *H1* and *H0* (based on the likelihood matrix calculated in for Task 3.1 part a) in two separate subplots in a figure.

Hint: Use the *mesh* function to draw 3-dimensional plots of joint pmfs for each of the hypotheses. See the help for *mesh* function in MATLAB: http://www.mathworks.com/help/matlab/ref/mesh.html

Note that the *mesh(X, Y, Z)* takes two vectors of *X* (with length *n*) and *Y* (with length *m*), and a *n-by-m* matrix of *Z,* representing the values corresponding to each pair of (X, Y). So in order to use the *mesh* function, you will need to reformat your *Joint_HT_table* created in part c, into a two *n-by-m* matrices corresponding to the conditional pmfs under each of the hypotheses *H1* and *H0*:

n = range of values that feature f1 take

m = range of values that feature f2 takes

and each element of matrix, representing P(*X, Y* | *H1*) or P(*X, Y* | *H0*)

Final Project: Task 3.2

a) Uses the *Joint_HT_table* calculated in Task 3.1 part c, to generate alarms based on each of the ML and MAP decision rules for the *testing* data set.

Hint: For the given pair of features (f1, f2) and a data sample *i* in the *testing* data set, you need to look up the row related to the joint observation (*testing(f1, i), testing(f2, i)*), in the *Joint_HT_table* to generate a "0" or "1", corresponding to the hypotheses *H0* or *H1* declared by the decision rule for the data sample *i*.

b) Use *label_testing* golden alarms to evaluate each of the ML and MAP decision rules, by calculating:

1. The conditional probability of false alarm
2. The conditional probability of missed detection
3. The probability of error

Your function for Task 3 should return a 2-by-3 array, in the following format:

	P(False Alarm)	P(Miss Detection)	P(Error)
ML Rule			
MAP Rule			

Final Project: Task 3.2 (Cont'd)

Your function for Task 3 should plot alarms generated based on *testing* data set for a given pair of features along with the *label_testing* golden alarms in one figure.

> **Hint:** Use the *bar* function in MATLAB. Each bar will represent an alarm ("1"). Use *subplot* function to plot ML, MAP, and golden alarms in three subplots.

Final Project: Task 3.3

For the 3 patients that you chose in Task 2:

a) Use the function implemented in Task 3.2 to generate alarms based on ML and MAP decision rules and evaluate their performance based on your selected pair of features.

b) You may need to repeat Task 2 by adjusting your criteria to get the best results for every patient.

c) Calculate **the average probability of error for each of the ML and MAP achieved for the selected 3 patients.**

Your report and your final presentation should include your insights on:

– Comparing the results generated by the ML and MAP decision rules based on:
  - Different features (Task 1)
  - Different selected pairs of features
  - Different criteria for choosing the pairs (Task 2)
  - Different error metrics (false alarms, miss detection, and error)

Your insights should be justified using figures and tables and observations from data.

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Project Timeline and Grading

- **Checkout the class website for description of system, tasks, and data sets, as well as your group assignments**:
http://courses.engr.illinois.edu/ece313/SectionF/projects.html

- **Contact your group members to start the project as soon as possible.**

Project Submission

- A **report** describing your work and results **and your Matlab code** must be submitted to Compass by the due date.

- **Matlab code Instructions:**
  - We will not provide you with a skeleton code for this project.
  - But you need to report and plot the results as instructed in each task.
  - TAs will execute your code & check the results.
  - Kindly comment your code to describe your logic / design
  - **Non-executable code will not be graded.**

- **Report Instructions:**
  - Format your report to separate different tasks in separate sections.
  - Copy the results and plots for each task into corresponding sections in the report. **Any plots or results missing from your report will not get a credit.**
  - Explain all your work and assumptions made for deriving your results.
  - Incorrect final answers without any explanations or comments receive zero credit.
  - Non-readable reports will be returned without a grade.
  - **Include your names and group name on the report.**