Using Computers to Process ECG Recordings

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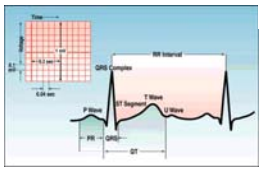
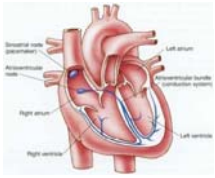
Computers in Cardiology

- One of the earliest uses of computing in medicine!
  - To monitor patients in CCU and ICU
  - To diagnose certain kinds of cardiac illness and to evaluate treatment efficacy: is the treatment preventing the problem?
  - To "pace" the heart, for individuals who have arrhythmias of kinds that can't be treated with drugs (and even to defibrillate if needed).

An example of a single QRS

- A QRS complex is the electrical signature of a heartbeat

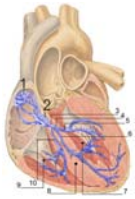




http://members.home.nl/jvdmortel/Het%20ecg%20beoordeling.html

Electrical conduction in the heart

- The heart is controlled by two kinds of pacing
  - The normal nervous pacing involves a network of nerves that control normal heart beats
  - Beat is triggered in the "Sinus Node"
    - Then spreads through the atrium
    - After a delay, spreads down to trigger a ventricular contraction



Terminology

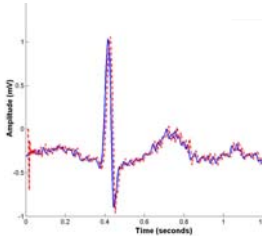
- A "P wave" is the electrical signal from the contraction of the atrium
  - This will be a small wave because the muscle mass involved is small
- The "QRS" wave is the signature of a ventricular contraction, and is large because the ventricles are large and powerful
- The "T" wave represents repolarization (recharging) of the ventricular muscles
  - Very rarely, one can discern a "U" wave as the cardiac nerve network recharges

Our goal?

- Capture ECG data from a patient
- Computer should locate and annotate the QRS complexes and use this data to determine heart rate and to identify abnormalities
- Sometimes, but not always, findings will be reviewed and "edited" to correct errors
- Then used by a provider as basis for care

The actual signal is a time-series of data points, 250/second

- We think of the ECG as a solid curve but the computer sees a series of voltages



What is a Holter Monitor?

- A small recording device that can capture 24 or more hours of electrocardiogram data
  - Size of an ipod or cell phone
  - Five electrical leads connect it to sensors that are taped to the patient's chest
- The data results in a two-channel signal with time advancing from left to right
- This signal reveals data about the patient's cardiac function and rhythms

Concept: an ECG *Holter* Test

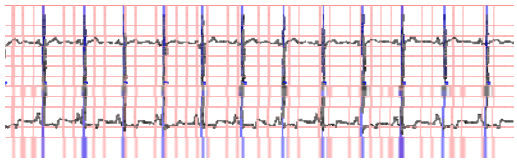
- Some patients complain of faintness or other symptoms that *might* be due to cardiac problems
- But not all cardiac problems are evident in the doctor's office

- So these tests allow the patient to go about his or her normal day.
  - They wear the monitor for the entire day and night
  - Normally also keep a log

- Later the physician can later check for "evidence" of a problem at times the patient felt ill.

A completely normal ECG

- Notice: It has two "channels" showing the same information but from different electrical perspectives
- This patient was healthy



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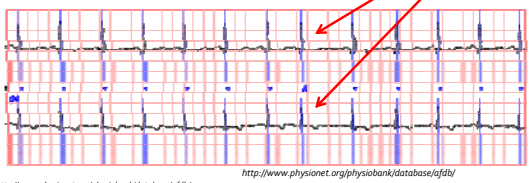
What's normal?

- *Not* the "shape" of the waveform!
  - *In a holter recording, the shape seen depends on where the leads were attached!*
- But a normal rhythm has
  - A regular, fairly steady heart rate between about 40 bpm and about 160 bpm
  - Changes in heart rate usually occur "steadily"
  - Waveform can vary slowly over time, but shouldn't change "abruptly"

A simple arrhythmia: A premature atrial heartbeat or "PAC"

- PAC: "Premature Atrial Contraction".
- An early but otherwise normal heartbeat

Looks normal (but early) in both leads



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What can cause an PAC?

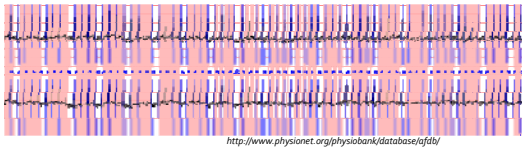
- Typically associated with
  - Common: Stimulants (e.g. caffeine or cocaine), heavy drinking, dehydration and exhaustion….
  - Certain kinds of nerve damage that makes the atrial network "twitchy"
  - Can't always pin down the cause and in fact, many healthy people get them – now and then

What can cause an PAC?

- Can you feel them?
  - Sometimes patient will feel a "flutter" or believe that they sometimes "skip" a heartbeat
- How are they treated?
  - Problem often resolves if the patient changes their behavior.
  - Medications can also be used for severe cases

PAC events can be quite rare

- Important issue: by what percentage must a contraction be early to qualify as an PAC?
  - Rhythm always changes a little, need to track heart rate to know what "normal" actually is
  - Usually 20% early qualifies as abnormal



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But can also occur in "runs"

- A short run isn't much different from a single isolated PAC. A long sequence is termed "Atrial Fibrillation" and can be serious
  - AFIB is associated with heart attacks.

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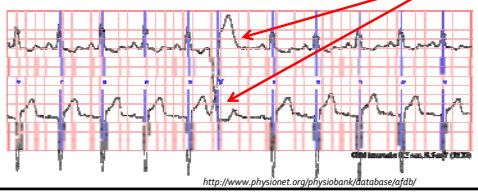
How can you recognize noise?

- You usually know it when you see it!
  - Basically, no *explanation* for what you are looking at.
  - But computers can have trouble doing what humans easily are able to do…. Humans see patterns; computers need to be programmed to find them
- Noise could fool a computer!
  - A big noise spike in between two normal QRS complexes…. Could "mimic" an PAC
  - But unlikely to show up in both channels…

PVC: Premature Ventricular Contraction

- The normal "sequence" for a heartbeat is disrupted: the ventricle contracts without atrial pacing, like a twitchy muscle
- No "P" wave, or a very distorted one

Looks abnormal in at least one lead



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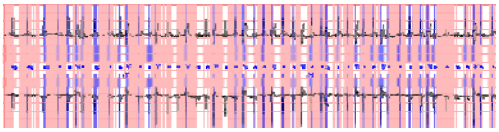
What causes them?

- A PVC is *potentially* a sign of damage to heart muscle tissue or to the nerve paths
  - Surprisingly many people experience them, including some healthy people. Many causes
  - Feels like a skipped beat…. Or goes unnoticed
- When caused by damage to the heart…
  - Could be a left-over from a prior heart attack, and may not be a sign of trouble to come
  - But may also be a warning of a serious problem

Frequent PVCs are more serious

- A patient experiencing frequent PVCs will have poor blood flow as a result, may feel out of breath, tired, dizzy
- Can also be prone to blood clotting disorders and may be at risk of a heart attack



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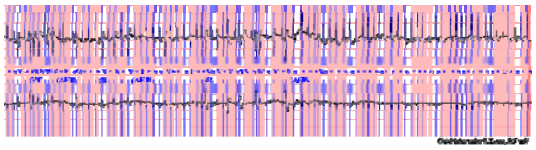
Frequent PVCs are more serious

- Is it noise? Or frequent PVCs?



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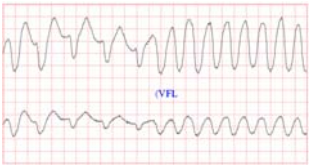
Ventricular "Fibrillation"

- A very irregular, inefficient, cardiac rhythm
- Blood flow largely stops. Classic heart attack



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So how do computers analyze a Holter ECG?

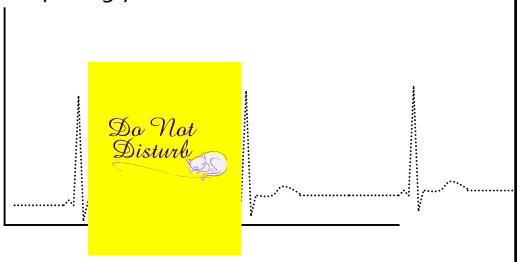
- Step one: Digitizing the signal
  - The machine needs to capture the signal, normally at 250 samples per second (an agreed standard that dates to around 1982).
  - Done directly on the collection device itself
  - Samples are integers representing amplitude
- Thus there will be 24 hours x 250 samples per second, or 22 million data points, per channel
  - This data will be stored into a file

Need for a "real time" operating system

- Systems like Windows and Linux sometimes pause for brief periods to do very important stuff
  - Like scratching their, um, network interfaces
  - And while doing this important stuff, might neglect to capture data
- What will it look like if ¼ second of data is "clipped out" of a normal signal?

Data "clipped out"

- A surprisingly common issue....



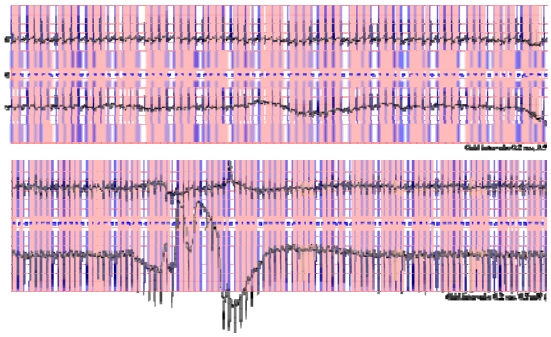
Result?

- A "computer generated" arrhythmia
  - Could mimic a PVC or a PAC
  - Or could look like noise
- Can actually be almost impossible to "understand" by visual inspection
- Hence must use a "real time" operating system on the device collecting the data

What does this show us?

- We're dealing with very sensitive data
  - It might be critical to a patient's life
- And yet minor issues such as whether the computer is continuously *instantly* available for 24 hours can cause us to make mistakes!

What are these?



If you guessed "noise"...

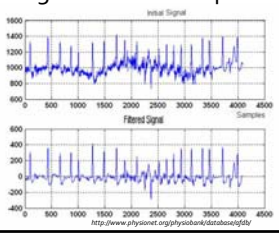
- Correct!
  - Many holter recordings have noise on them
- What causes noise?
  - Thick, loose skin
  - Sweat can detach electrodes
  - Patient might scratch the electrode, or hit a tennis ball, or cough, or take a shower

Noise

- The computer needs to
  - Flatten the "baseline" to remove those huge swings
  - Normalize the signal so that the peaks are of a pretty steady amplitude

Filtering to Reduce Noise

- 50/60Hz noise is common (electrical machines like blenders, vacuum cleaners)
- Often must "filter" the signal to clean it up
  - Worry: When filtering we average data to smooth the noise
  - But did filtering cause *other* changes too?



Filtering

- Filtering makes data easier to look at but also distorts what we measured.
  - Some systems display the raw data but process filtered data.
  - Other systems display the filtered data and only show raw data if you "turn off" filtering.
- Thought questions:
  - What issues can filtering create?
  - Is there a best story? What would you do?

But we're far from done…

- OK, we've cleaned up the signal
- Now how does the computer analyze it?

Finding the QRS itself

- Look for a sharp spike?
  - But noise can have sharp spikes
  - And some QRS shapes on normal ECGs are pretty "round" looking
- Use the rhythm as a hint for where to look for the QRS complex itself?
  - But a normal sinus rhythm could be as low as 30bpm and a very fast heart rate can reach 180 bpm
- Many systems make small mistakes (and sometimes they make big mistakes!)

Then what?

- Next classify the "shape" of the waveform
  - Learn what a normal QRS looks like
  - Early but looks normal => PAC
  - Early, looks weird? Call it a PVC and learn the shape of the PVC
- Why not use a "frequency domain analysis"?
  - Turns out that the mathematics underlying FFT analysis and "wavelets" don't really apply cleanly in our setting (ECG isn't "stationary")
- But even a so-so job of shape analysis helps us resist confusion due to noise

Last stage? Look for patterns

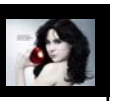
- Run of PACs? AFIB
- Two PVCs in a row? A "pair"
- Alternation of normals, PVCs?
  - Bigeminy, Trigeminy…
- Long run of PVCs? VFIB
- (And there are others: sleep apnea, for example, is sometimes associated with serious sinus bradycardia: the heart rate drops drastically)

So what's the take-away?

- ECG analysis isn't really "science"
- We use sophisticated artificial intelligence…
  … which means, a grab-bag of tricks, heuristics and rules invented by people like us
- This feels wrong, but it usually works

- Bottom line: *A rigorously correct ECG analysis can't really be done by machines. Even people make mistakes in some cases.*

Machines can't think (yet)



- A physician has a mental model of cardiac behavior and illnesses

- She can use that knowledge to make sense of the data

- A computer just applies a grab-bag of rules. It doesn't "think" at all.

Discussion topics

- ***The computer can't "understand" an ECG. Yet it is practicing medicine. Is this ethical?***

- ***Suppose a medical center uses a computerized ECG monitor for two years. It works flawlessly and they begin to rely on it. Then one day, an "unusual" ECG waveform triggers a latent bug. The patient dies. Who was at fault?***