AN OUNCE OF PREPROCESSING IS WORTH A POUND OF COMPUTING

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BEFORE WE START

Pedometer, Spencer & Perkins, c. 1780

- A wearable device from 230 years ago
- Used energy harvesting!

USER NEED

"It's really quite simple – all we want to know is are we getting enough exercise to stay healthy?"

THE OUTPUT IS QUITE SIMPLE

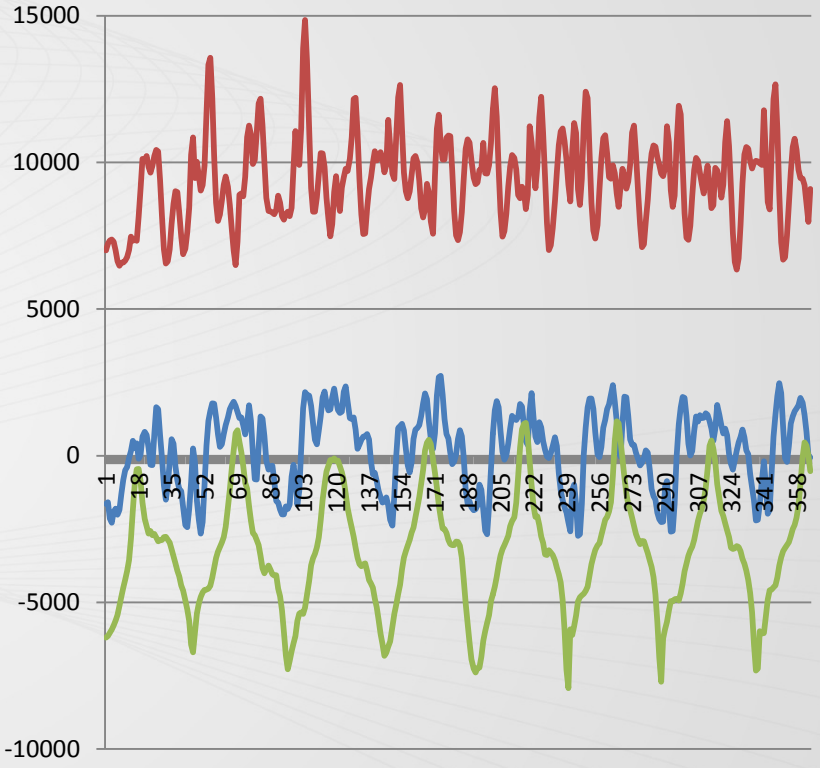
Two bits of data!

Your amount of exercise is:

- ◯ about right
- ◯ too little
- ◯ too much

THE INPUT IS NOT SO SIMPLE

- Typical pedometer records 3 axis of acceleration data 50 times a second
- That is 13 million data points that have to be reduced to approximately 10,000 steps and then ultimately 2 bits of information

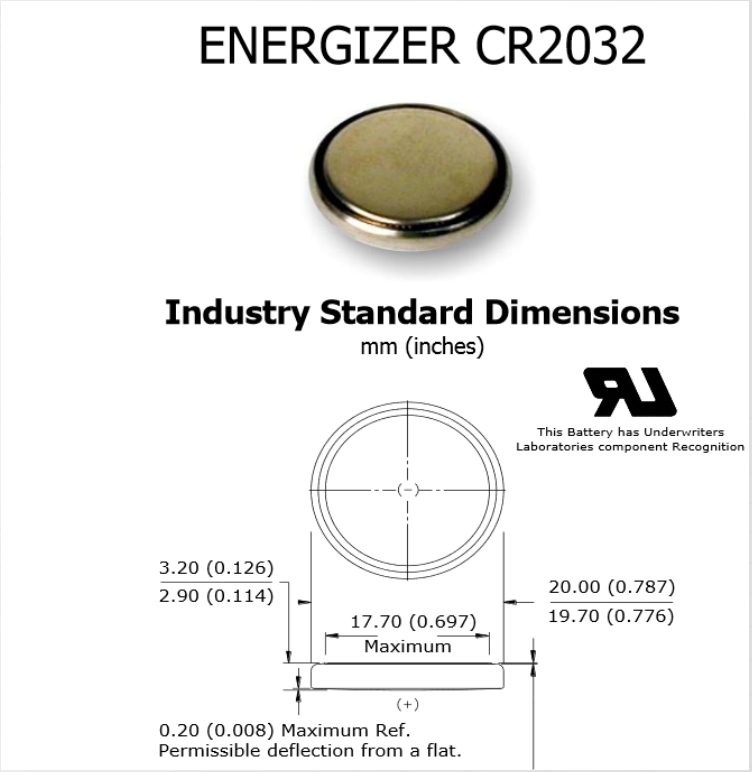


USE THE CLOUD

- 13 million data points is a trivial amount of data by today's standards
- The storage requirement is 26MB/day which easily fits into $1 of flash memory
- So we can easily store the data and communicate it via BLE to a smart phone and then via LTE to the cloud
- What does this do to battery life?

ENERGY TO COMMUNICATE 26MB

- CR2032 typical disposable battery
- Total capacity is “240mAh”
- Which translates into 2,500 Joules (SI unit of energy)
- BLE uses 2J to transmit 1MB of data
  - It takes 52J to transmit 26MB of data
  - About 2.1% of the energy in the battery – looking good!

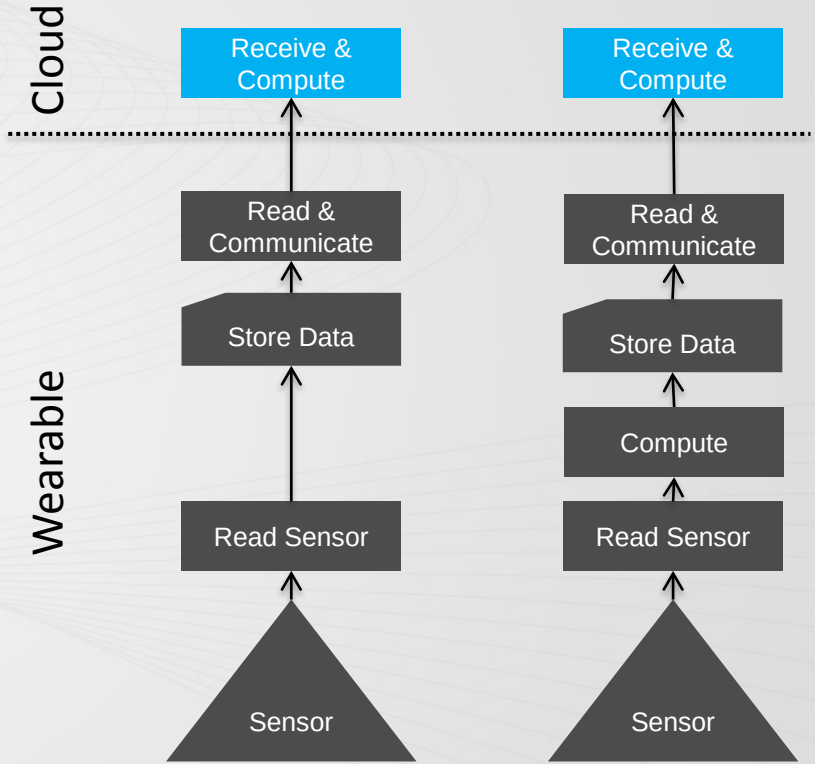


ENERGY TO STORE 26MB

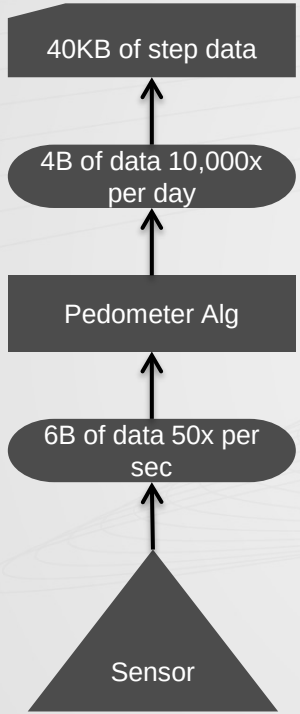
- To store and retrieve data from a flash memory requires 6.3J/MB ➔ 3xBLE
  - It takes 164J to store then retrieve 26MB
  - About 6.6% of the energy in the battery
- BLE alone might get 40 days
- BLE + storage more like 11 days
- Obviously would like to avoid storing all that raw data

PREPROCESSING

- Most people take less than 10,000 steps a day
- Let's look at the energy implications of computing steps and saving them, instead of the raw data



STEPS ARE A LOT CHEAPER THAN RAW DATA



- Pedometer algorithm reduces 26MB of accelerometer data to 40KB of step data – a 500 fold reduction
- Storing and retrieving 40kB of data uses 0.3J
- Communicating 40KB of data over BLE takes 0.1J
  - And takes 4 seconds vs. 40 minutes
- Of course this is only helpful if the pedometer algorithm uses less energy than is saved

- Storing and sending 26MB
  - 164J for storing
  - 52J for sending ➔ 216J total
- Storing and sending 40KB
  - 0.3J for storing
  - 0.1J for sending ➔ 0.4J total
- Net savings: 215J/day
  - This is 10% of the battery capacity
  - This is equivalent to 2.5mW

As long as the pedometer algorithm uses less than 2.5mW, it takes less energy to compute first and then transmit

- Pedometer uses about 5,500 clocks per time sample
  - ➔ 275,000 clocks/second
- M4F + memory uses about 100uW/MHz
  - ➔ 27.5uW to compute pedometer vs.
    2,500uW to store and transmit

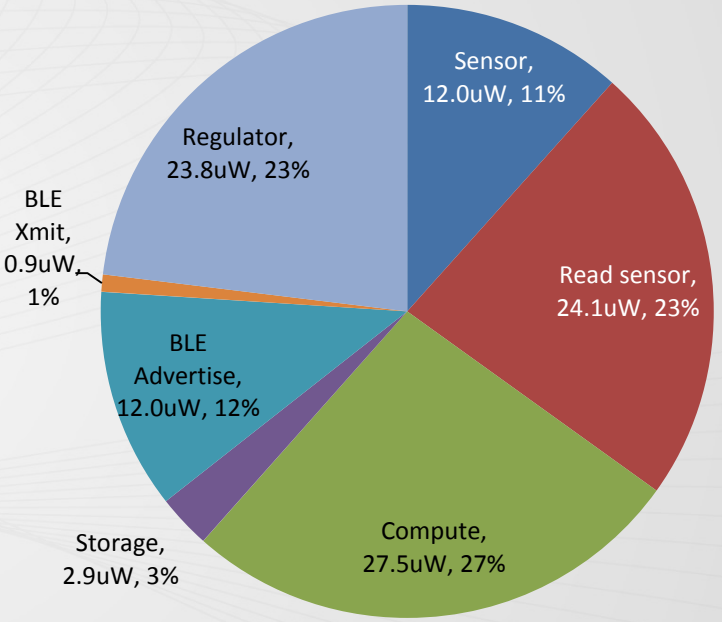
Computing locally is 100x more energy efficient that storing and transmitting raw data

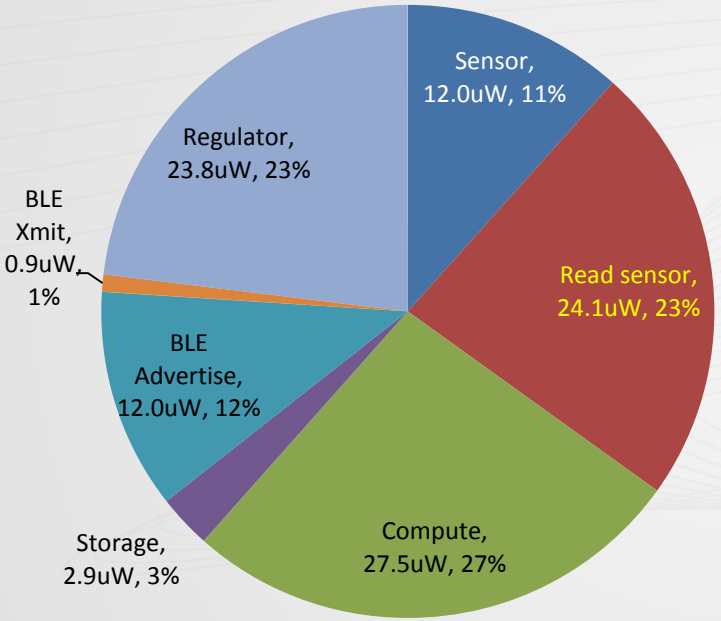
SYSTEM POWER

- Overall device power: 103uW(avg)

Sensor	12.0uW	12%
Read sensor	24.1uW	23%
Compute	27.5uW	27%
Storage	2.9uW	3%
BLE Advertise	12.0uW	12%
BLE Xmit	0.9uW	1%
Regulator	23.8uW	23%

- 8.9J/day which is a lot less than the 52J to transmit the raw data
- Resulting in 280 days from a CR2032 battery
- But we can do better…



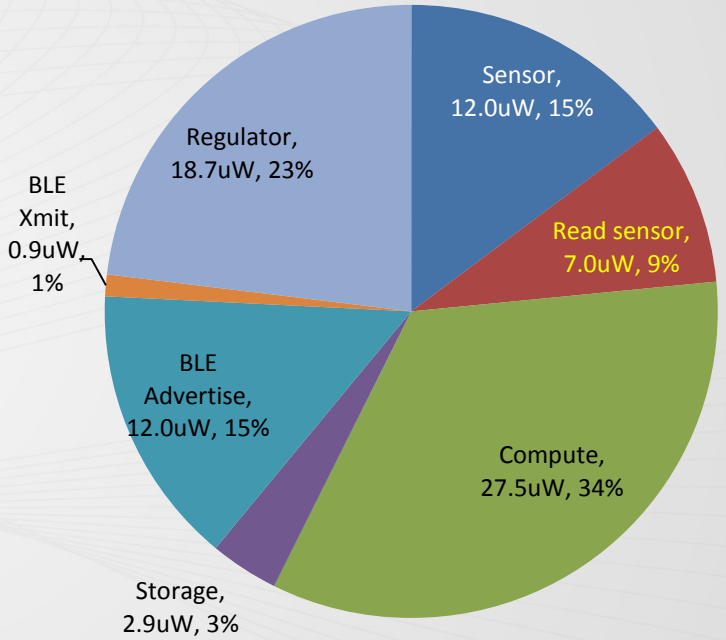


- Reading the sensor uses 23% of the power
- This is because we use a relatively ‘big’ M4 to do a simple I/O task
- Much more power efficient to separate the ‘read sensor’ function off into its own tiny preprocessor
- A small state-machine can read the sensors using only 7uW

- Now Read Sensor is 9% of the total
- Total power is 81uW or 7J/day

- And battery life is 357 days

Now what would a 1 year battery life do for user experience?

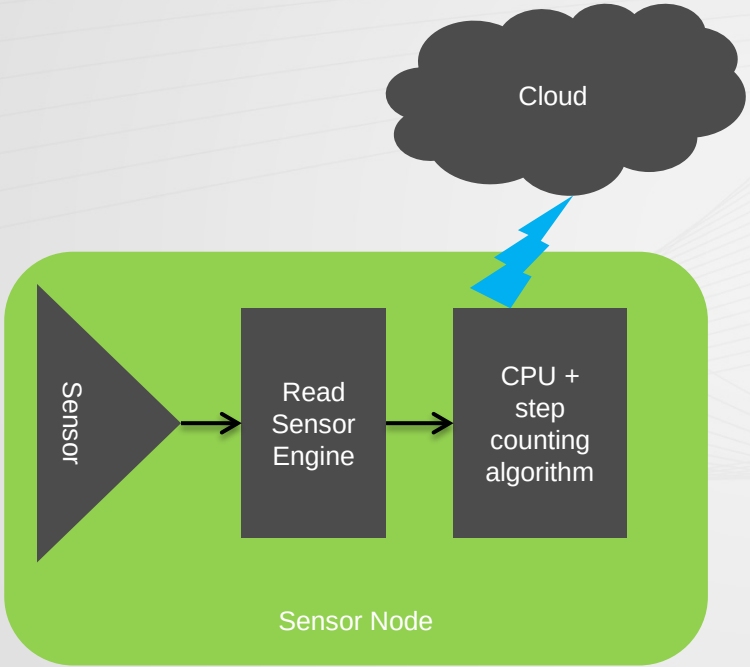


RECAP

- Store and forward raw sensor data requires 261J/day of energy, resulting in less that 10 day battery life
- Using the wearable to preprocess accelerometer data into steps reduced daily energy to 9J/day
- Adding a state-machine to pre process the serial data-stream from the sensor into a parallel form for a MCU further reduced the energy consumption to 7J/day

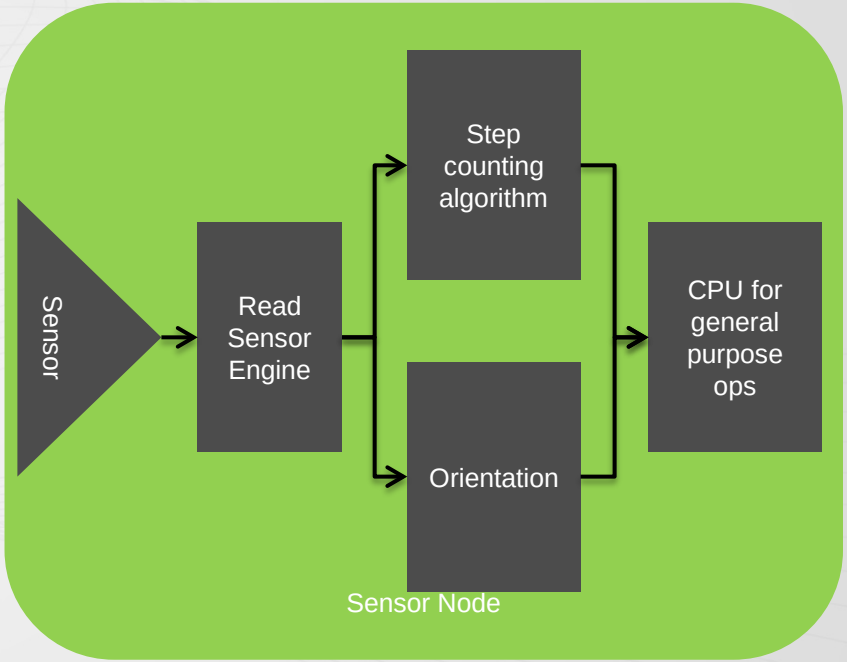
Going deeper…

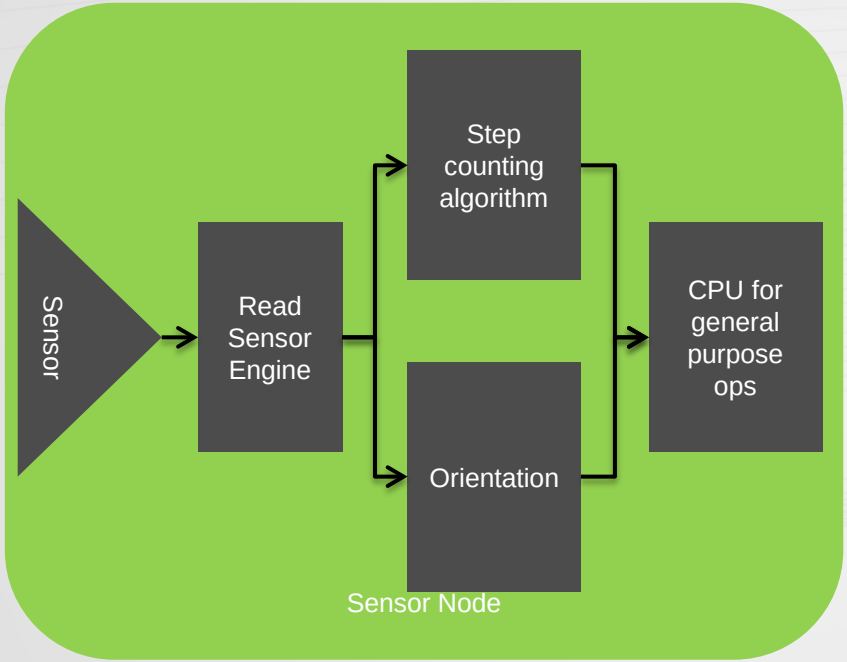
GENERALIZING THE CONCEPT



- We have shown how moving calculation *before* communication can save energy
- We also showed that using a specialized CPU to manage reading the sensors can further save power
- The latter example works because dedicated hardware is lower power than generalized hardware – but it also requires specialized design

- CPU designers have been doing this for a long time:
  - UART
  - SPI controller
  - USB controller
  - Ethernet controller
- What will be the equivalent functions in the wearable space?
  - Step counting?
  - FFT
  - Rotations





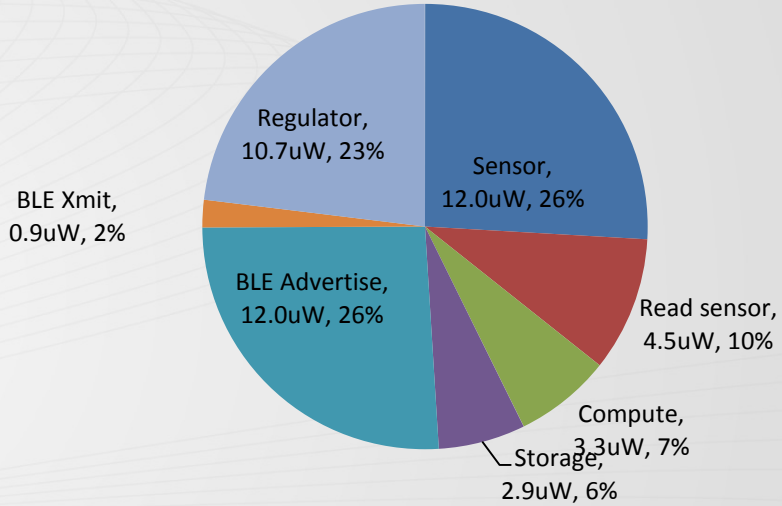
- Our studies show that custom blocks can operate at ½ the energy per clock cycle *and* implement basic algorithms in ¼ the clock cycles

- For example, the M4 in our EOS product uses 100uW/MHz and the step count algorithm takes 5,500 clock cycles
- The Flexible Fusion Engine in our EOS product uses 50uW/MHz and takes only 1,300 clock cycles

SYSTEM POWER USING FFE

- Overall device power: 43uW(avg)

	FFE	M4
Sensor	12.0uW	12.0uW
Read sensor	4.5uW	24.1uW
Compute	3.3uW	27.5uW
Storage	2.9uW	2.9uW
BLE Advertise	12.0uW	12.0uW
BLE Xmit	0.9uW	0.9uW
Regulator	10.7uW	23.8uW
	46.3uW	103.2uW



- 4J/day which is significantly improved
- Theoretically this results in 600 days of battery life from a CR2032

- In practice, leakage currents become non-negligible and noticeably reduce battery life

SUMMARY

I hope this convinces you that adding small amounts of specialized preprocessing can dramatically improve battery life

Some thoughts on where this might lead…

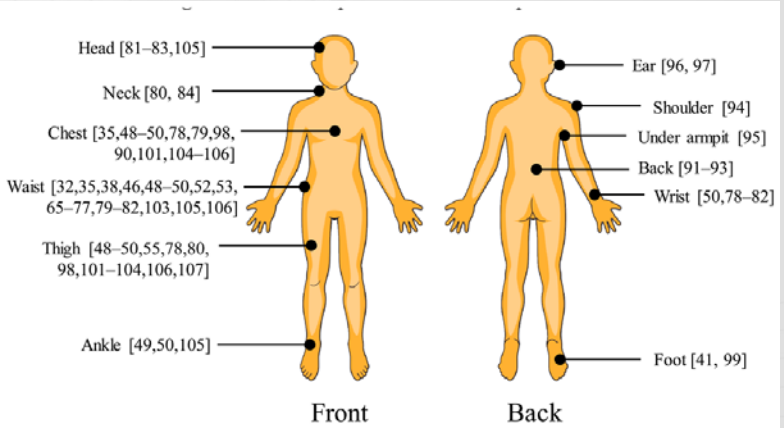
GOING FORWARD: LET'S RETHINK WEARABLE

"It's really quite simple – all we want to know is are we getting enough exercise to stay healthy?"

Notice the user never asked for a band, or watch – they asked for information

A COLLECTION OF SENSORS

- The wrist is *not* a good place for a pedometer – especially for people who talk with their hands
- If sensor nodes preprocess then they won't overwhelm the communication bandwidth, and with long battery life they become low maintenance
- Imagine sensor nodes in shoes, in belt buckles, in pendants, in gloves, in smart watches



Source: mdpi.com

BODY AREA SENSOR FUSION

- If we use preprocessing at the sensor node, shoes + buckle + smart watch sensors will compress 100MB of accelerometer data into 160KB of step count data

- The cloud can fuse the data to provide a significantly more accurate and low-touch user experience:
  - Getting strong watch motion but weak buckle motion – probably waving arms
  - Buckle and shoes dead still, but watch showing steps: changed into gym clothes and gone walking/running
  - Buckle and watch showing walking and shoes dead still – changed into a different pair of shoes, use buckle data

GOING FORWARD: PROCESS TECHNOLOGY

- For the past 4 decades process development has all been about bigger, better, faster
  - We love our multi Gigahertz smart phones
  - We rely on multi Gigahertz servers
  - But power has taken a backseat to performance
- Recently companies have started paying attention to power
  - But when your baseline is a 60W chip, 1W sounds like low power
  - We are seeing a second generation of low power processes, and more attention placed on design techniques such as subthreshold logic

GOING FORWARD: PRINTED CIRCUITS

- Perhaps the most exciting trend is towards printed ICs
  - Printing allows small volume production
  - Printing allows mass customization
  - Printing allows cost reductions
- Printed transistors are not as fast as conventional transistors
  - You cannot crank the clock up to get more compute power
  - With this technology, low clock cycle count becomes critical and hardware preprocessors can deliver

GOING FORWARD: SENSORS

- The people who build sensors are really good at improving them:
  - Cost declines with time
  - Size declines with time
  - Power declines with time – big improvements every generation
- The people who develop new sensors are also incredibly creative:
  - Gas sensors are typically heated oxide structures
    - Making them smaller saves power
  - But then there is the company that uses the gases to *produce* power! The higher the concentration, the higher the power (its still too little to be useful, but hey)

Thanks