The Future of Analytical Instrumentation

And the Implications for Environmental Monitoring

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Introduction

- Predicting the future of anything is very challenging
  - It's hard enough to predict the Past (i.e., History)
  - But, predicting the Future is Really Hard!
  - We almost never get it right
- For every insightful prediction

  -There are a thousand lame ones!
- So, why do people keep on doing this?

Better Question: Why Am I Doing This??

- Short answer: Nobody else was foolish enough to volunteer
- The longer answer
  - I've been in the environmental field for a long time
  - I've run both laboratory and instrumentation businesses
  - I've had a life-long fascination with technology
  - I just can't help wondering: What's the next Big Thing?
- So, I agreed to take a shot at it

Today's Modest Scope

- Consider the future of analytical instrumentation, but only in the context of environmental monitoring
- Talk about the whole kit
  - Instrumentation, consumables, software, data crunching, communications, etc.
- My approach
  - Review the history and identify essential trends
  - Extrapolate the trends and consider the impacts
  - Evaluate the synergies
  - Try to extract a deeper meaning
- So, let's take a look at some essential trends……

Three Essential Trends

1. Ever greater power for molecular discrimination
2. Smaller, faster and cheaper instrumentation
3. "Unlimited" capacity for communicating, analyzing and storing digital data

- Individually, these trends are all well known,

but the impact of their confluence

is not well understood

1. Greater Molecular Discrimination

Where Is This Coming From?

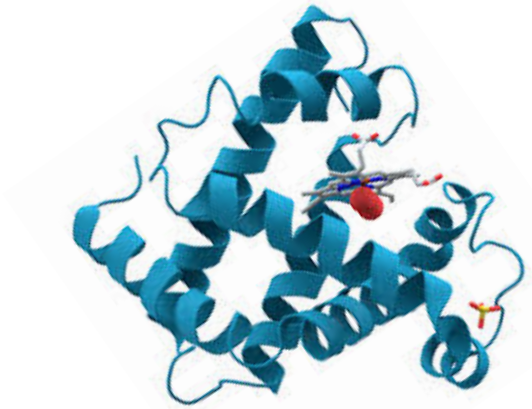
- Improved sample preparation techniques
  - SPE for selective isolation and concentration
  - QuEChERS for matrix removal
  - Advanced instrumental techniques, e.g. MALDI
- Advanced GC and LC chromatography
  - Improved stationary phases and sorbent morphologies
  - Orthogonal separations: (GCxGC), (LCxLC), (LCxGC), etc.
- Spectrometry: Superior resolution and range
  - MS x MS x MS x……
  - NMR, IR, Raman, etc.
- Selective sensors, sensor arrays, etc.

➢ We are living in the Golden Age of analytical chemistry

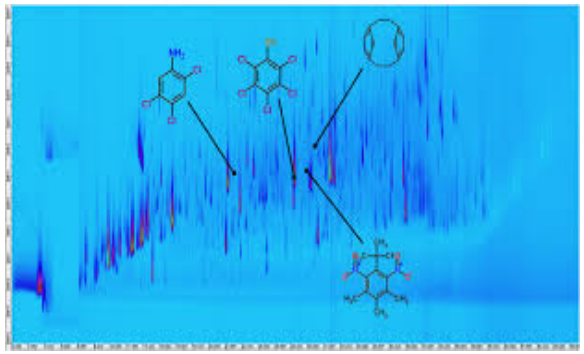
And, it's only going to get better

Why is this Important?

- **Many health & environmental effects are very specificaly related to molecular structure**

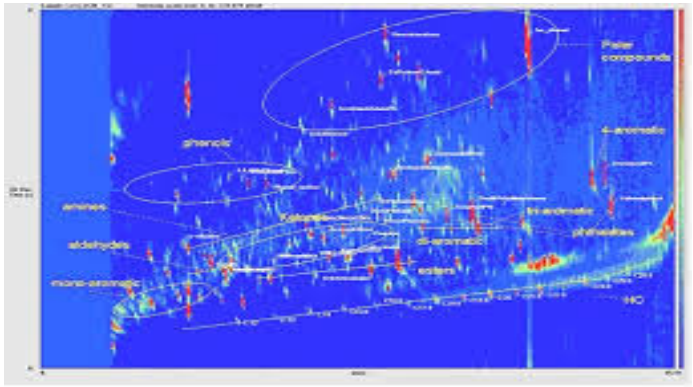


- **Very low levels of biologically active molecules can cause extreme effects (e.g, endochrine disruptors)**



- **The environmental world is <u>extremely</u> complex and messy at the pg/L level**

➢ **The ability to measure extremely low levels of specific molecules in complex matrices will <u>enable</u> us to better understand and mitigate adverse environmental and health effects**

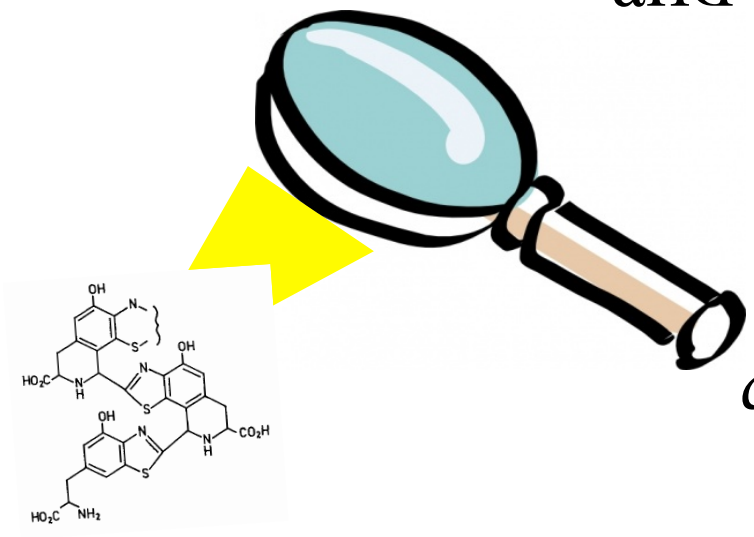


What's the Likely Outcome?

Lower

and Lower

and Lower

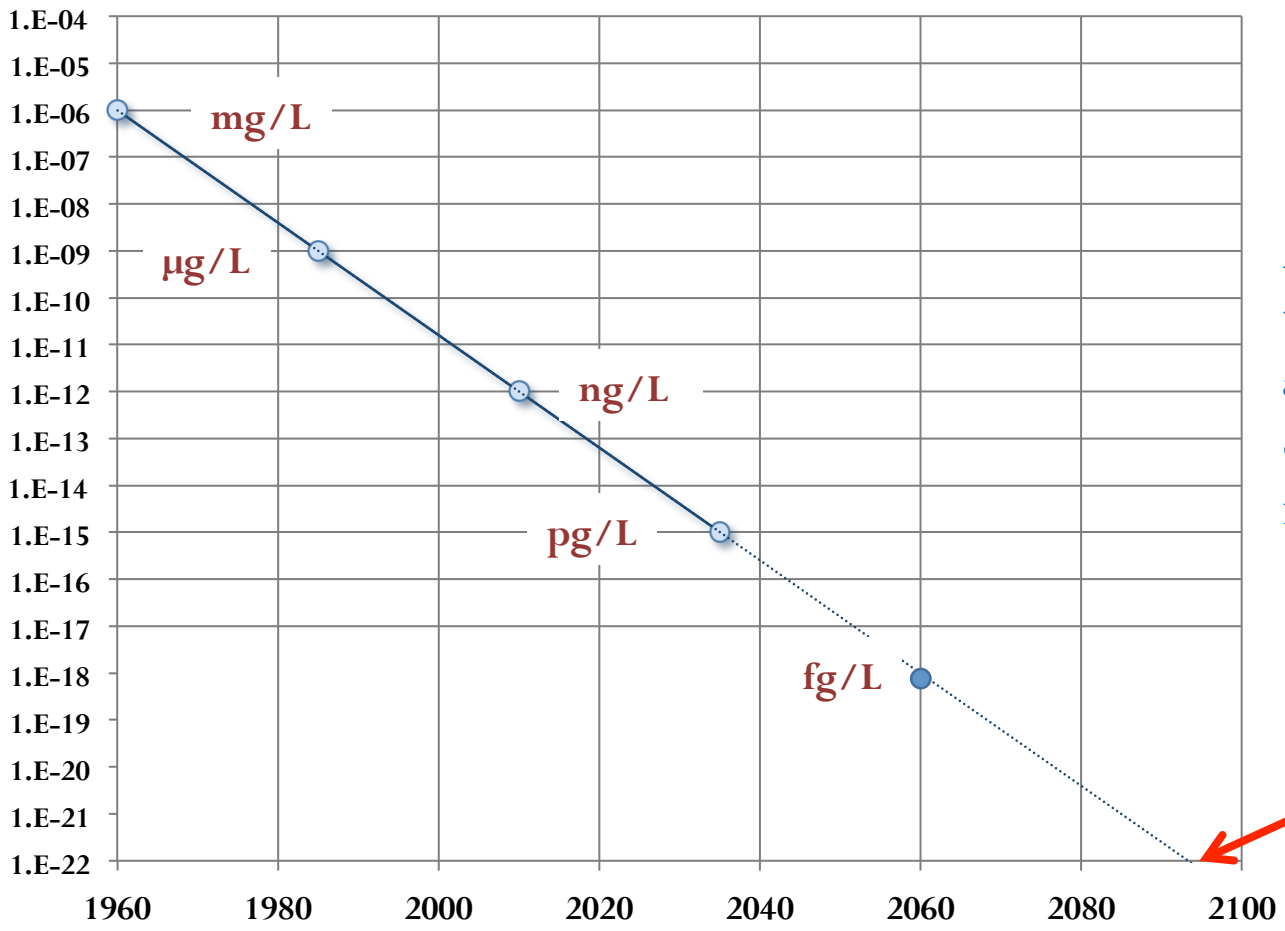


and Even Lower

Detection Limits

A Short History of Detection Limits

(Courtesy of Andy Eaton)



Although it is silly to extrapolate a linear trend over 16 orders of magnitude…….

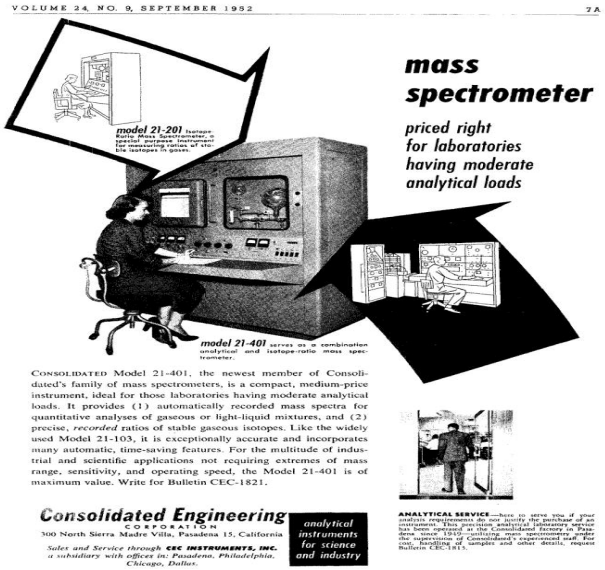
1 Molecule/Liter
(5:43 am, July 9, 2094)

……Does anyone seriously doubt that detection limits will be significantly lower five, ten or twenty years from now?

2. Smaller, Faster, Cheaper

Where is This Coming From?

- Driven largely by continuing advances in microelectronics
  - ➢ Enabled by the demand for consumer electronics
- Smaller and faster are obvious, but cheaper seems counterintuitive
- Today's instrumentation does cost more (in constant dollars)
  - But, the unit cost ($/analyte/day) is dropping exponentially:
    >10X/decade
- Does anyone doubt that this trend will continue?



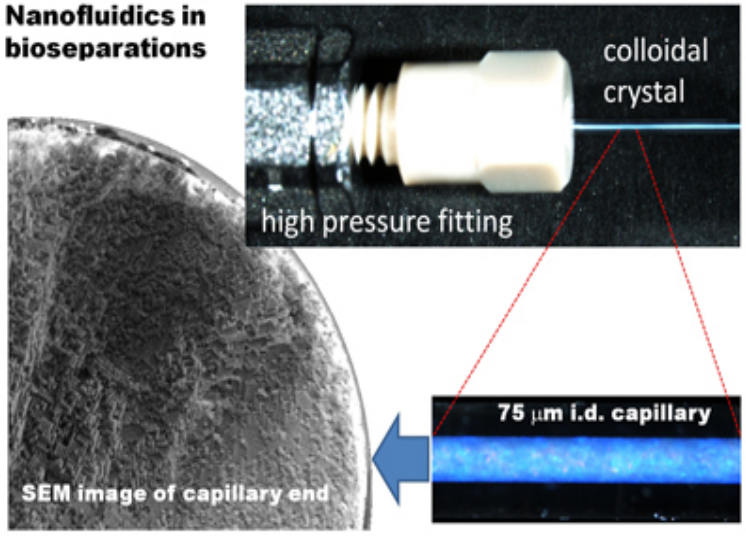
Why is this Important?
(Is this a Trick Question?)

- No trade-offs between small, fast and cheap
  - You don't have to choose 2-out-of-3
- More analytical power more widely available
  - In the Lab > In the Field > In your Hand > In a Cell
- Less waiting around for something to happen
  - Faster equals greater productivity
- Huge economic leverage is created
  - Cost scales very favorably with information growth
    (i.e., the slope of the cost/information curve is less than 1.0)
- So, getting more - costs less

What's the Likely Outcome?

- MORE: Smaller - Faster - Cheaper!
- Milli > Micro > Nano > ?
- Allow more analytical devices to be deployed in unusual places
- Fewer measurements in the lab and more at the "point of use"
- Increasing ability to generate lots and lots of Environmental Data:
  - Inexpensive
  - Widespread
  - Real-time
  - In-situ

➢ ***What are we going to do with all that data?***



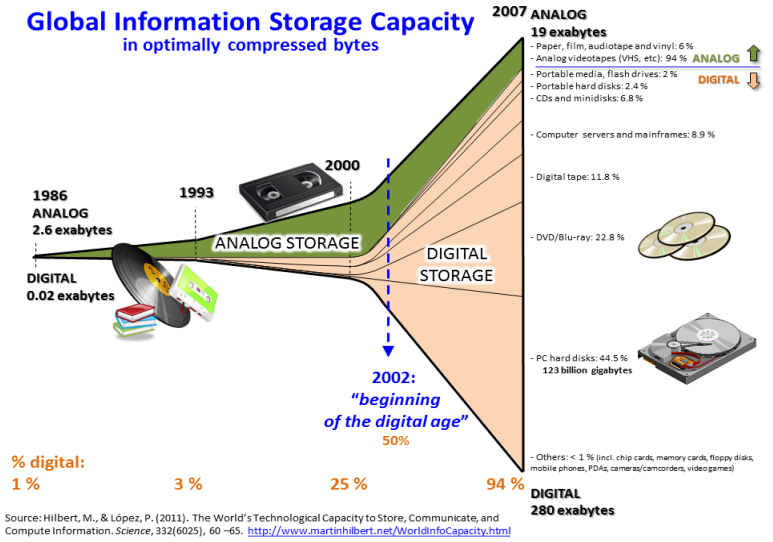
HETP = 32 nano meters

3.The Digital Information Revolution

There's an App for That

Where is This Coming From?

- The same origins as B-F-C
  - Driven by consumer electronics; science is just along for the ride
- Digital information storage capacity is doubling every three years (28% CAGR)
  - Currently > 600 billion gigabytes = 600 exabytes
  - One exabyte = 10(exp)18 bytes
- Broadband growth CAGRs
  - Global population: 1.1%
  - Global subscribers: 4.2%
  - Mobile broadband growth: 26%
  - Mobile data transmissions: 61%
- The digital party ain't over yet!



Source: Hilbert, M., & López, P. (2011). The World's Technological Capacity to Store, Communicate, and Compute Information. *Science*, 332(6025), 60 –65. http://www.martinhilbert.net/WorldInfoCapacity.html

Percentages refer to device or connections share.
Source: Cisco VNI Mobile, 2014

Why is this Important?

- Rapid proliferation of small, fast, sophisticated analytical devices will generate vast amounts of data
- Unless we can transmit, process and store these data, the "Smaller – Faster - Cheaper Revolution" could choke on itself.
- After all, we do have a ***lot*** of competition out there for bandwidth…….

Server Farm

What's the Likely Outcome?

- The insatiable demand for consumer electronics will continue to drive digital infrastructure growth
- The capacity to transmit and store digital information will grow much faster than our ability to generate analytical data.
- That's a good thing, because we're going to need a lot of bandwidth for environmental monitoring!
- ***So, a big thanks to all you Gamers, Tweeters and Surfers out there!!***

Digital footprint on Wikipedia

Put All Three Trends Together

What Do You Get?

Future Environmental Monitoring Devices Will be…

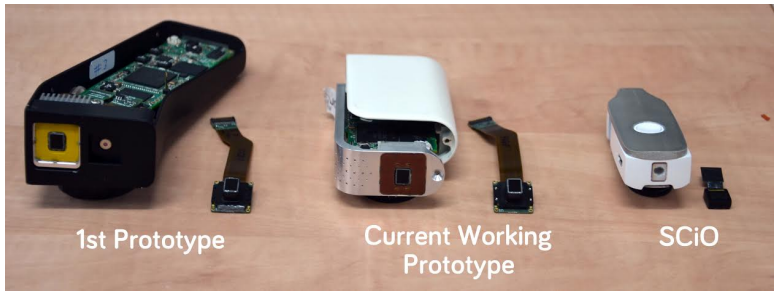
- Small, light and portable
- Cheap and abundant
- Very low levels of detection
- High molecular discrimination ability
- Allow real time measurements at point of use
- Based upon cellular/WiFi communication
- Cloud-based applications and data storage
- Enable the rapid growth of mobile monitoring devices for personal use (as well as for professional use)

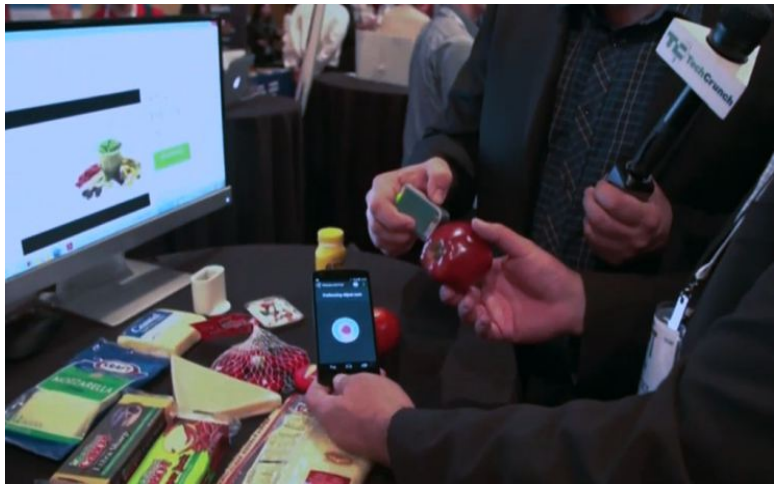
➢ **This is already beginning to happen……**

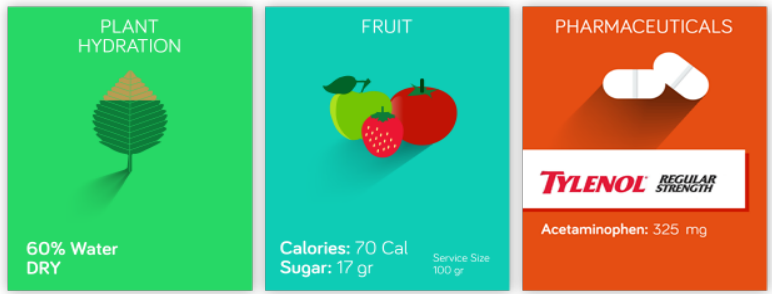
A Glimpse into the Future?

- **Meet SCiO (consumerphysics.com)**
  - Thumb-sized, wide-band, near IR spectrometer
  - Tethered to your smart phone
  - Linked to cloud-based analytical applications
  - Marketed as a "personal, molecular food scanner"
  - Financed with $2M from Kickstarter
- Provides real-time information on calories, alcohol content, sugar content, hydration, etc.
- Over 600 developers have already signed on to build apps!

➢ ***When you extrapolate this business model to it's logical conclusion: what do you get ?***







The Star Trek Tricorder, of Course!

- The mythical **TRICORDER**…….
  - The device that measures anything in everything
  - Anywhere
  - At any concentration

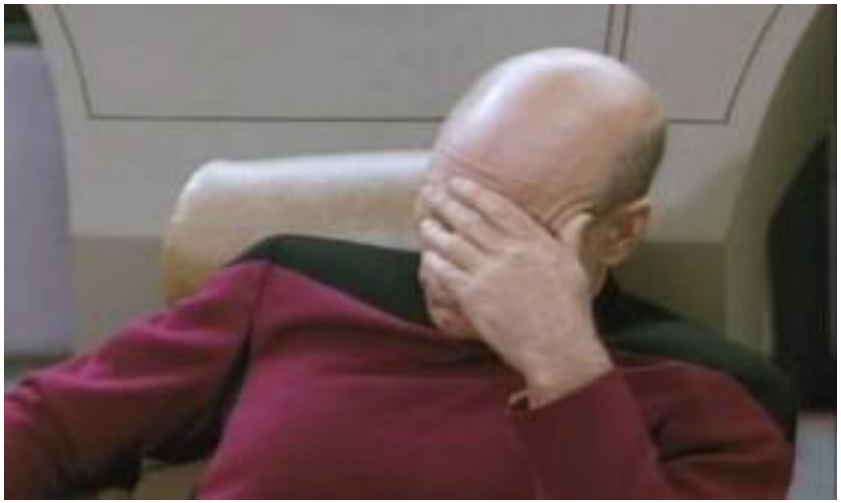
➢ Then it tells you exactly what you need to know

- But, this begs the logical question:
  - How do you even know what you need to know, when you just don't know it?

- Massive proliferation of analytical data won't necessarily tell you what you need to know

➢ *When everybody is measuring everything, everywhere at the picogram/liter level the more likely result will be…….*

Total Information Overload!!



More Data

≠ More Information

≠ Greater Understanding

As we peer more deeply, Nature becomes more complex, not simpler

So, how do we get to:

“What does this mean?”

- *Something is missing!*

The Fourth Essential Trend

“Environomics”

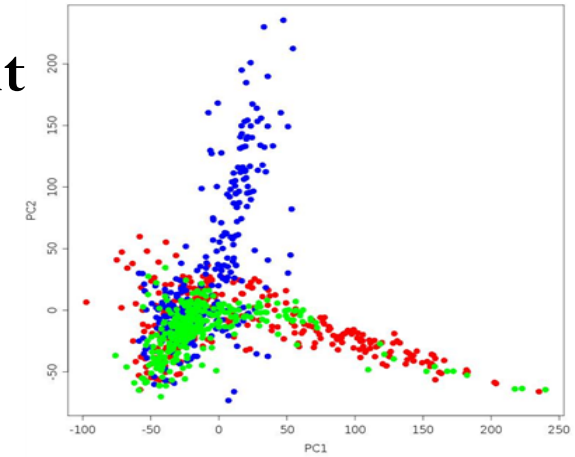
4. The Fourth Essential Trend

- Premise: Our ability to generate detailed analytical information will quickly outstrip our ability to extract useful meaning from it
- The data generated by 100,000 individual mobile devices doing real time measurements at the pg/l level would be enormous
  - But, who could make any sense of it? What value would it have?
    - ➢ The Missing Piece: **"Environomics"**
- Needed: Massive, parallel advances in Informatics that make usable sense of the vast quantity of information generated by large numbers of advanced analytical devices
  - Need to apply "Big Data Analysis" to this tsunami of analytical data
  - Without it, you don't have useful environmental monitoring
  - Just a massive amount of noise
- Fortunately, the field of Big Data Analysis is also advancing rapidly

(Thanks, NSA)

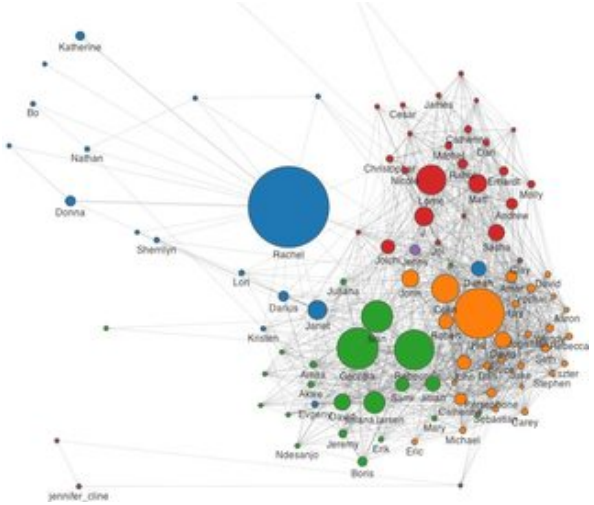
Components of Environomics

- **Principle Component Analysis (PCA)**



- **Pattern Recognition**

- **Big Data Analytics**



- **Meta Data**

Powerful techniques that can extract information from chaos

Why the Environomics Challenge is Important

- Probable advances in analytical instrumentation will enable both of these monitoring scenarios:
  1. 500,000 people running around with their smart "Enviro-Phones" making random analytical measurements for their personal benefit
  2. The same people, but part of an environmental monitoring network with 500,000 mobile measurement nodes providing real-time environmental awareness
- Smart, mobile analytical devices are going to happen anyway
  - But, alone they will provide useful information only to individual users
- However, if these devices can be linked, networked and collectively analyzed:
  - Could create a much more comprehensive and useful environmental picture that is currently possible

Environomics could change the Environmental Monitoring Paradigm

Environmental Monitoring Paradigm Shift

Current Paradigm	New Paradigm
• Expensive data	• Cheap data
• Centralized	• Distributed
• Independent	• Networked
• Generalized	• Personalized
• Few measurement nodes	• Mega measurement nodes
• Historical	• Real time
• Averaged	• Integral
• Remote measurements	• Point of use measurements
• Limited information	• Abundant information

What Might the New Paradigm Look like?

- Every "smart phone" a node on an environmental monitoring network
- Wearable devices that monitor, log and assess personal environmental exposure, then compile, analyze and predict the regional impact
- Instantaneous water quality measurements at the tap, rainfall event or watershed that feed into dynamic water quality models
- Widespread food quality monitoring at the point of purchase or consumption to quickly identify and isolate health hazards
- Crowd-sourced environmental monitoring
- Global environmental trending
- "Instant" epidemiology
- Etc., etc., etc.

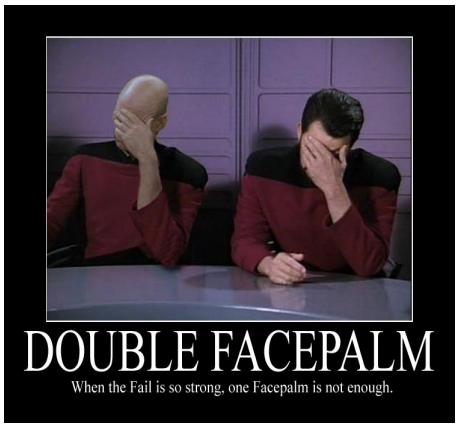
➢ You can imagine the applications just as well as I can……

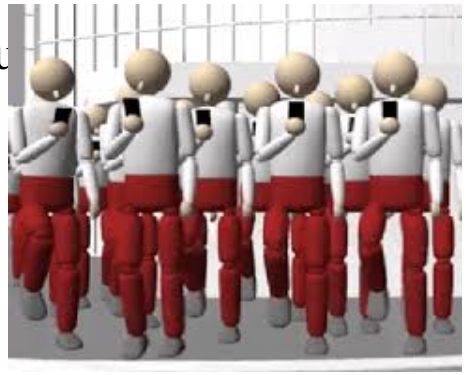
All This Could Happen, but Will it?

- Everything I've talked about is well within the bounds of likely technology growth over next 10-20 years
- Smart "Enviro-Phones" are definitely going to happen
  - Driven by individual concerns for personal health and safety
  - Demand for personal environmental info will create a mass market
- But, will the Environmental Monitoring Paradigm also change?
  - i.e., Can we actually harness this huge future stream of environmental data for the greater benefit of society?
- That's a much more difficult proposition
  - Government (EPA, FDA, etc.) would have to make major changes
  - Overcome inertia, achieve political consensus, find the money, etc.
- However, I believe that the paradigm has to change
  - Otherwise a very unpleasant future could await us……

Our Brave New World?

- Widespread, personal, environmental monitoring – if left unregulated - could create some sort of Hot Mess
  - Imagine 10 million "Enviro-Twitter" followers!
  - Short term focus, no long term perspective
  - The environmental crisis of the day (or the hour)
  - Misinformation, chaos and potential panic
- So, at some point Government would have to step in
- But what should the role of Government be?
  - To suppress personal environmental monitoring and stifle technology?
  - Or, to harness and guide the personal monitoring revolution for the greater good of society?
- My second Straw Man seems more appealing





The New Monitoring Paradigm?

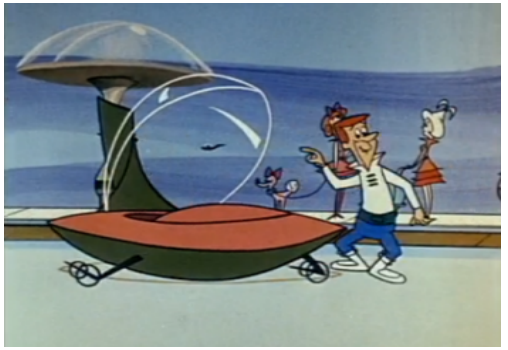
- In this paradigm, the environmental regulatory agencies would:
  - Write the Rules of the Road
  - Establish the Big Data structure
  - Manage, guide and regulate personal environmental monitoring
  - Bring order and beneficial direction out of potential chaos.

- In the end, it would be more productive for Government to guide the revolution than to drive it
  - Perhaps, like the FCC regulates the electromagnetic spectrum
- However, this is only one of many possible futures

➢ But, whatever happens, you can be sure that we are in for quite an adventure!

In Conclusion

- That's my vision of the future of analytical instrumentation
- Whether my predictions are insightful - or just plain silly - remains to be seen
- I'm no Leonardo Da Vinci; so your guess is as probably as good as mine
- But, I going to very confidently make one final prediction …….



Two Newspaper Headlines That You Will Never See

Psychic Wins $500 Million Powerball Lottery!

Some Guy *Actually* Predicted the Future of Analytical Instrumentation!

Although both these events are possible, they are highly unlikely ……

However, Hell really did freeze over last winter……..