UNIVERSITY OF CRETE
COMPUTER SCIENCE DEPARTMENT

COURSE CS-564 (OPTIONAL)
ADVANCED TOPICS
IN HUMAN – COMPUTER INTERACTION

Course Convenor: Constantine Stephanidis

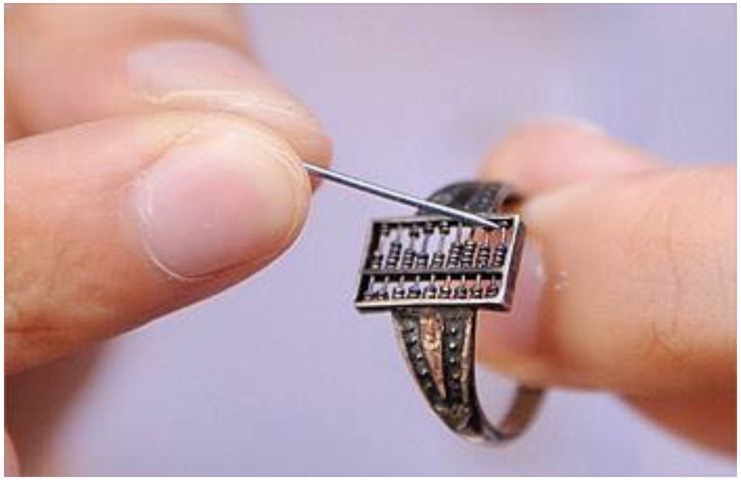
Wearables

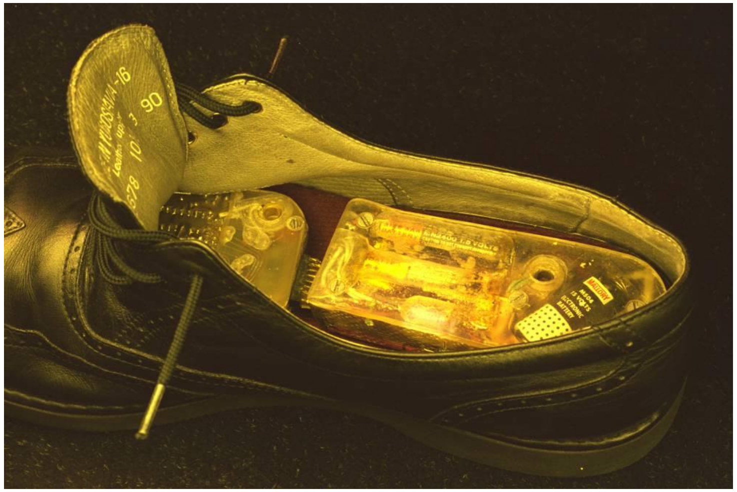
Overview

- History and Definition
- Types of Wearables
  - Activity trackers
  - Smartwatches
  - Smart glasses
- Novel input / output devices
- Application Domains and Expectations
- Challenges and Issues

Introduction

- Depending on how broadly wearable computing is defined, the first wearable computer might have been an abacus hung around the neck on a string for convenience, or worn on the finger
- Or it might have been the pocket watches of the early 1500s, or the wristwatches that replaced them, since a timepiece is a computer of sorts (i.e., a device that computes or keeps time)
- More recently electronic calculators (which could be carried in a pocket or worn on the wrist) emerged, as did electronic timepieces. Other task-specific electronic circuits included a timing device concealed in a shoe to help the wearer cheat at a game of roulette





True computers

- A common understanding of the term "computer" is that a computer is something that is programmable by the user, while it is being used, or that is of a relatively general-purpose nature (e.g., the user can change programs and run various applications)
- Indeed, what made the computer revolution so profound was that the computer is a software re-programmable device capable of being used for a wide variety of complex algorithms and applications

From HUDs to Smart Glasses

- In 1968 Ivan Sutherland described a head-mounted display with half-silvered mirrors that let the wearer see a virtual world superimposed on reality
- His work, as well as subsequent work by others, entailed a serious limitation: because the wearer was tethered to a workstation, generally powered from an ac outlet, the apparatus was confined to a lab or some other fixed location
- In 1980, Mann designed and built a backpack-based general-purpose multimedia wearable computer system with a head-mounted display visible to one eye. The system provided text, graphics, audio, and video capability, and included a handheld chording keyer (for one-handed input)

Steve Mann

- Evolution of Steve Mann’s wearable computer system that led to the EyeTap or DigitalGlass system (1999)
- Steve Mann is considered one of the pioneers of wearable computing and augmented reality

Private Eye, Thad Starner, MIT

- In 1989 Private Eye was released, a "pushbroom" type display using a linear array of 280 red LEDs
- The Private Eye display product brought wearable computing to the mainstream, making it easy for hobbyists to put together a wearable computer from commercial off-the-shelf devices
  - Among them, Thad Starner, who has been wearing his wearable computer since 1993
  - Now a technical lead/manager of the Google Glass project
- In 1993, Mann and Starner co-founded the MIT Wearable Computing Lab along with 4 other colleagues, "the 6 cyborgs"

Definitions (1/2)

- “Wearable computing is the study or practice of inventing, designing, building, or using miniature body-borne computational and sensory devices. Wearable computers may be worn under, over, or in clothing, or may also be themselves clothes”
- Bearable Computing
  - The terms "Body-Borne Computing" or "Bearable Computing" are often used as a substitute for "Wearable Computing" so as to include all manner of technology that is on or in the body, e.g., implantable devices as well as portable devices like smartphones
    - In fact the word "portable" comes from the French word "porter" which means "to wear"

Definitions (2/2)

- Juniper research defines a 'smart wearable device' as an app-enabled computing device (that is a device which accepts input and processes that input) which is worn on, or otherwise attached to, the body while being used. In some cases a wearable device may also be a fashion accessory
- Most wearable devices are always-on and accessible at any time, with constant interaction between the user and the device
- This definition covers a wide range of devices from watches to clothing to displays, any of which can either work independently or in conjunction with an external platform, such as a smartphone or tablet

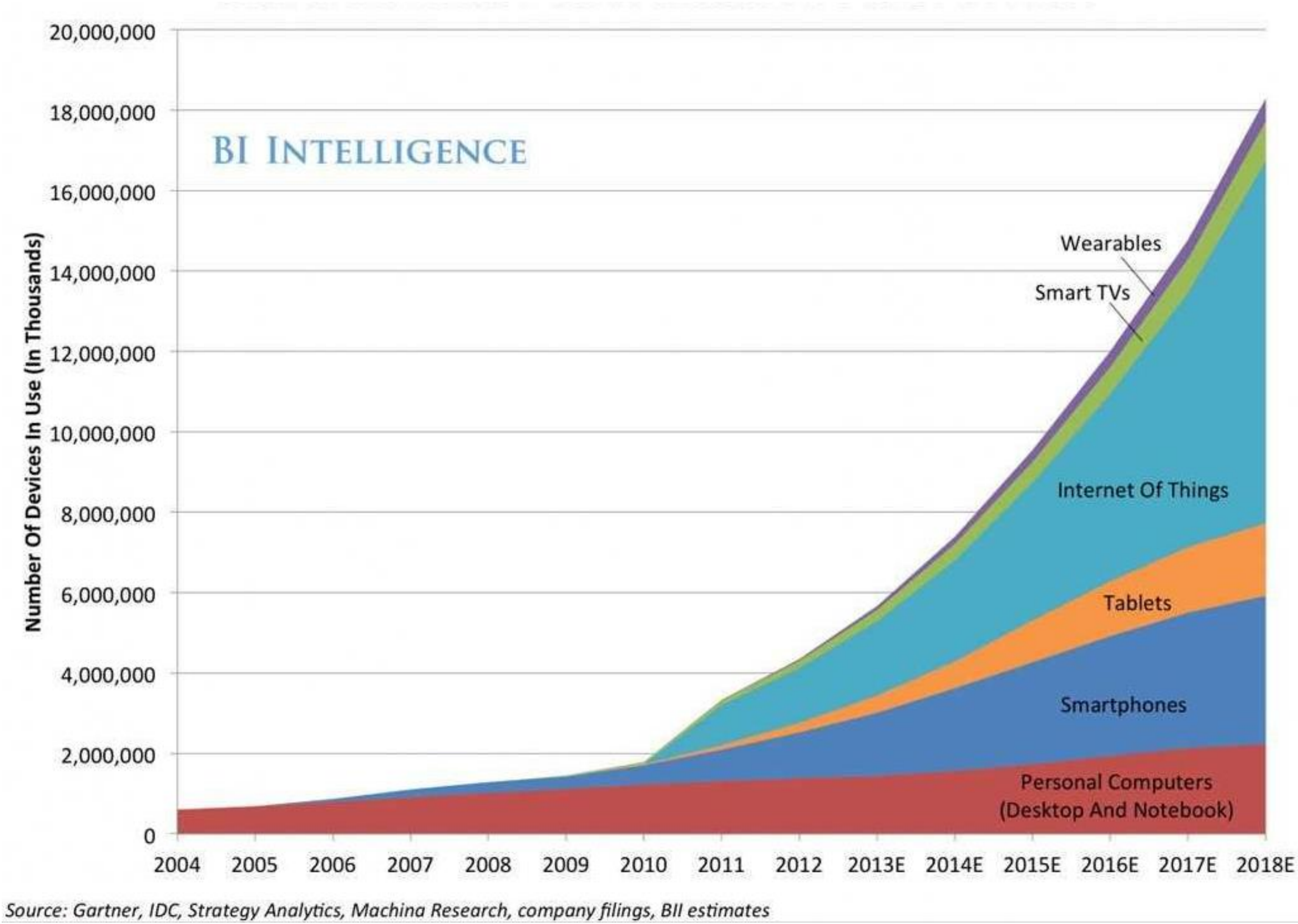
Some examples

- Examples of wearables today range from Bluetooth headsets designed into a pair of earrings with a hidden microphone, a Spy Tie, which includes a color video camera, and USB Heating Gloves which keep hands warm when plugged in
- More recently, wearable technology such as the Jawbone Up or Fitbit have applications in monitoring and real-time feedback for athletes
- The decreasing cost of processing power and other components is encouraging widespread adoption and availability

Market predictions: The wearables era

- While Wearables technology is in its infancy stage, it is expected to become a $1.6 trillion business in the near future, according to research by Morgan-Stanley
- Analysts project sales of wearable devices will grow at a 154% annual compound rate through 2017, where 248 million devices will be sold
- The figure will grow even further after that and sales of wearable technologies are expected to reach one billion by 2020

Global Internet Device Installed Base Forecast



Types of wearables

Categories

- An indication of the various types of wearable devices can be seen in the following table

Activity Tracker	Smart Clothing
Smartwatch	Smart Glasses
Smart Band	Headphones
Wearable Camera	Heart Rate Monitor
Headset (HMDs)	Earpiece
Fashion/Jewelry	

- There is overlap between these categories, for example smartwatches or smart clothing can be activity trackers and smart glasses usually come with a camera
- Activity trackers, smartwatches and smart glasses will be presented in more detail, as they are the most “hot” wearables at the moment

Activity trackers

- An **activity tracker** is a device or application for monitoring and **tracking** fitness-related metrics
- Activity trackers are fundamentally upgraded versions of pedometers
  - In addition to counting steps, they use accelerometers and altimeters to calculate mileage, graph overall physical activity, calorie expenditure, and in some cases also monitor and graph heart rate and quality of sleep
- The concept grew out of written logs that led to spreadsheet-style computer logs in which entries were made manually
- Early examples of this technology include:
  - Wristwatch-sized bicycle computers that monitored speed, duration, distance, etc., available at least by the early 1990s
  - Wearable heart rate monitors for athletes, which were available in 1981
  - Wearable fitness tracking devices, including wireless heart rate monitoring that integrated with commercial-grade fitness equipment found in gyms, which were available in consumer-grade electronics by at least the early 2000s
  - Wearable fitness tracking computers with tightly integrated fitness training and planning software that were available as consumer products by at least 2006

Activity trackers - examples

Nike+iPod (2006)

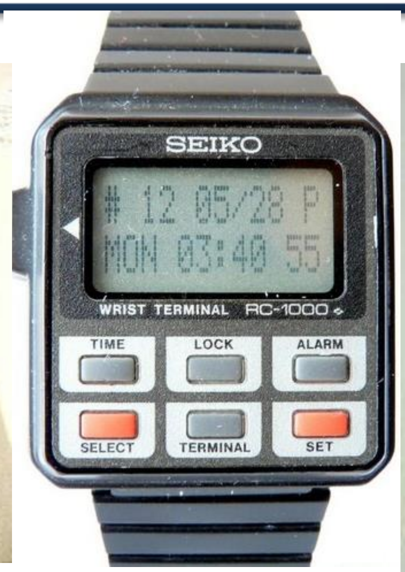
Athos shirt (2014)

Fitbit Charge HR (2015)

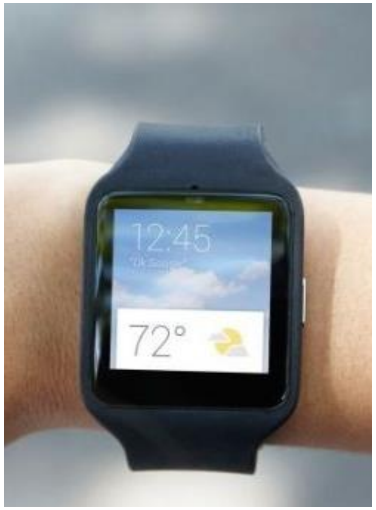
Smartwatches

- In the last century, the wristwatch replaced the pocket watch as a more convenient place to get at time information quickly. More recently, the ubiquity and functionality of mobile phones (which can also display the time) caused many to abandon the wristwatch as redundant jewelry and go back to what is effectively a pocket watch
- Now after more than 40 years of technological improvements, smartwatches seem to be heading in the same direction as mobile phones: multiple functionalities
- Smartwatches are not only a chronograph, but can also be a general-purpose, networked computer with an array of sensors
  - they have followed a familiar pattern in technological trends: the concept has been around for long time, but it took longer for the technology to advance enough for proper implementation

Brief history of smartwatches



Smartwatches today



Smartwatches – constraints (1/4)

- Smartwatches suffer from two major constraints related to keeping them small enough to wear on a wrist:

1. Their small screen size results in restricted I/O
   - Micro projectors are a tantalizing solution, but several years after their announcement they are still too expensive to consider, and thus do not seem to be a realistic prospect in the near future
   - Curved screens increase size but still not enough for keyboard integration
   - Most traditional watch screens are lightweight, waterproof/ resistant and antiscratch. How well curved screens maintain these characteristics remains to be seen
   - The screen restriction will require fresh thinking on user interface (UI) designs and for new interaction techniques such as 3D gesture recognition
   - Google's Android Wear relies heavily on voice input for simple user interaction but this may restrict users to performing more complicated tasks

Smartwatches – constraints (2/4)

- Existing smartwatches have very small touchscreens with no or few buttons on the side, suggesting the need for new interaction techniques such as voice, haptic, gestural interfaces, projection, and near-field communication (NFC)
  - Some brands, such as Android Wear, provide highly reliable voice commands for interaction. Some other brands are working on interaction through the accelerometer as well as haptic feedback
- Therefore, it is likely that new interaction algorithms and also new UI patterns will be introduced, and existing approaches will be optimized toward better precision on a small screen and lower resource usage
- For smartwatches that are smartphone dependent, interaction techniques are distributed between both the devices, for example, supporting keyboard input via the smartphone and voice input via the smartwatch

Smartwatches – constraints (3/4)

2. Their small hardware results in weaker computing capability and especially limited battery capacity in comparison to larger devices

- Small hardware means less computing power, smaller battery capacity, and less-precise sensors
  - These challenges exist in smartphones as well as smartwatches, although to a lesser extent
- Software and hardware providers have been working, slowly but continuously, to address resource-related issues
  - For example, GPS systems typically have a high power requirement. Localization services try to overcome this problem by relying on a combination of sensors such as GSM, Wi-Fi, and GPS—hence reducing the power consumption.

Smartwatches – constraints (4/4)

- Although hardware components get smaller through advances in sensor technologies and electronics, the smaller footprint means smartwatches have fewer ubiquitous computing features compared to smartphones
- Most of the smartphone-dependent smartwatches overcome this by offloading power-consuming sensing and computing operations to the phone and use low-power Bluetooth to communicate
- This enables smartwatches to communicate with the smartphone and to rely on its superior computing capabilities
- This way, power- hungry chips such as GPS can draw on the larger battery of the phone and simply use the watch as a convenient user interface, but the phone still has most of the “smarts”
- The fully independent smartwatches, which incorporate their own 3G or GPS chips, tend to have a much shorter battery life

Smartwatches – advantages (1/4)

- Smartwatches have **two** strong advantages over other devices: their mount location, and (probably more important) the continual connection to the skin

1. Smartwatches are body mounted, with a standard, known location
   - This helps activity recognition research by removing the burden of identifying the location of the device
   - Much research has been done to quantify health information via mobile devices (mHealth). The standard location overcomes challenges associated with smartphones
     - for instance, when measuring users' activities based on accelerometer data, the location of the smartphone (if in a shirt pocket, in a bag, or in a trouser pocket) affects the data

Smartwatches – advantages (2/4)

- A smartwatch is typically in constant contact with its owner, and thus capable of recognizing its owner's physical activities and location
  - In contrast, a limitation associated with smartphones is that, when users are not holding them, they can sense only the users' environment (outward) and not the users' specific condition (inward)
  - When smartphones are carried, they are in various locations in bags and pockets
  - Often, in an indoor environment such as an office or home, a smartphone is not moving and may not be co-located with its owner

Smartwatches – advantages (3/4)

2. The smartwatch's continual connection to the skin could revolutionize mHealth studies
    - Enterprise vendors recognize this and are already including slots for this data in their health kit toolsets, such as Google Fit, Apple HealthBook, Samsung S.A.M.I, and Microsoft Healthvault

- The location also permits easy recording of heart rate, heart rate variability, temperature, blood oxygen, and galvanic skin response (GSR)
    - GSR can be used to identify physiological arousal, especially when combined with heart rate and heart rate variability

Smartwatches – advantages (4/4)

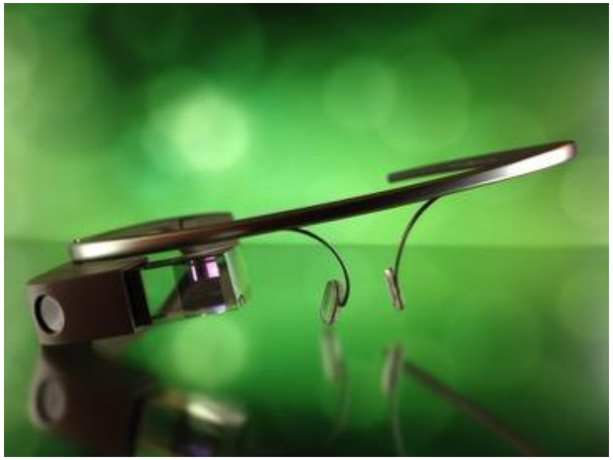
- Emotion has two dimensions: mood valence (positive vs. negative) and arousal (high vs. low)
  - Automatic emotion quantification approaches (except those based on image recognition) are restricted to arousal and not valence
  - Therefore, in order to collect valence, existing affective recognition systems rely either on image recognition or manual user input
  - Because user input is subjective, its accuracy is often questioned. With the advent of smartwatches and effective multisensory data collection, we might develop algorithms (for sensor data fusion) that can identify valence without the need for processing a facial image

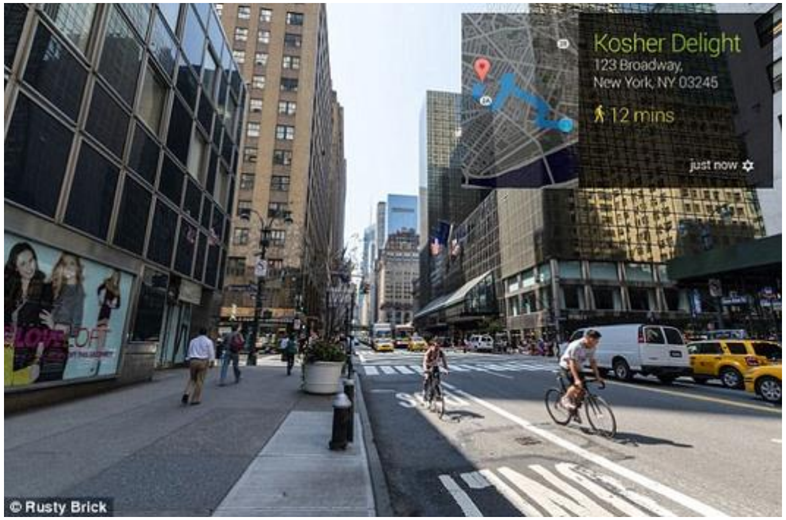
Smart Glasses

- Smart glasses are a wearable computer that adds information to what the wearer sees
- Typically this is achieved through an optical head-mounted display (OHMD) or computerized internet-connected glasses with transparent heads-up display (HUD) or augmented reality (AR) overlay that has the capability of reflecting projected digital images as well as allowing the user to see through it, or see better with it
- Smart glasses are considered to be a defining milestone in the vision of ubiquitous computing and augmented reality

Google Glass

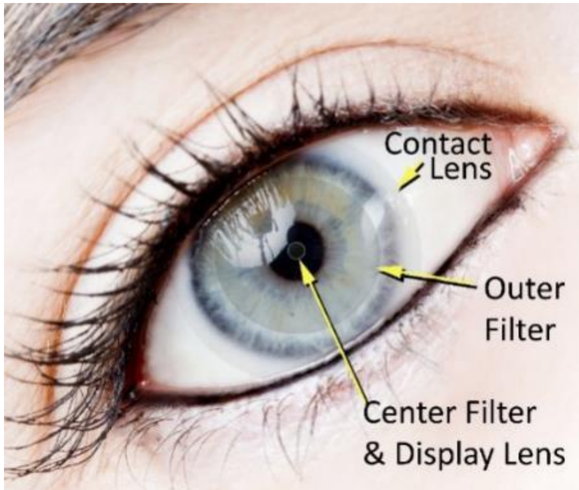
- Google Glass is a type of wearable technology with an optical head mounted display
- Features a camera, a display, various sensors, a touchpad and supports natural language interaction





Innovega iOptik

- Special contact lenses and glasses, powered by a smartphone
- Digital images are projected onto tiny full-color displays that are very near the eye
- These novel contact lenses allow users to focus simultaneously on objects that are close up and far away
- They can act as a glance-able display (like Google Glass, where data is pushed to the periphery) and as a full-screen HUD



Contact lenses can be tailored to the individual's prescription

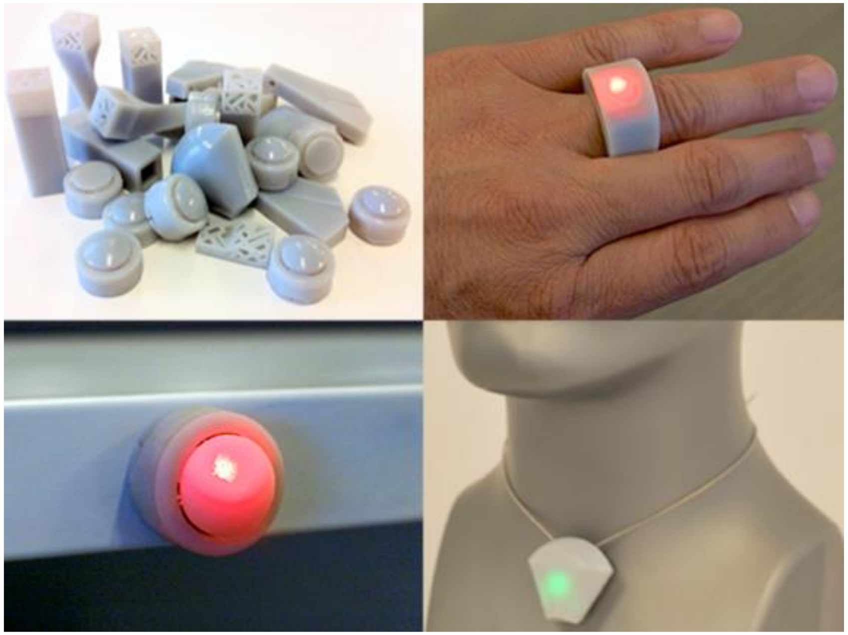
The glasses feature micro-projectors that project the images onto the lenses

Novel input wearable devices (1/2)

- Researchers have actively looked into novel input wearable devices
- For example, Nenya consists of a magnetic finger ring that provides an always-available input mechanism
- It allows for simple input actions such as twist to select and slide along the finger to click. A wrist-worn sensor tracks this small and socially acceptable ring
- Facet is a multi-display bracelet consisting of multiple independent touch-sensitive segments. It supports multi-segment touch, yielding a rich set of touch input techniques

Novel input wearable devices (2/2)

- BitWear is a prototyping platform for small, wireless, interactive devices
- BitWear incorporates hardware, wireless connectivity, and a cloud component to enable collections of connected devices
- NotifEye uses a rub pad placed on people's index finger to provide input to interactive glasses by means of small, subtle finger movements
- A natural first step for this line of research has been to look into individual use of these wearable devices



BitWear: a variety of 3D printed physical forms including rings, buttons, and pendants

Application Domains and Expectations

Consumer/Jewelry (inc. Watches)

- These types of wearables fall under the “lifestyle” category, epitomized by wearables that are worn to perform a specific function that enhances an aspect of the user’s lifestyle, generally without having more detailed or customizable functionality
- Such devices include notification jewelry and smart clothing that uses location-based or other contextual information to change its appearance

Apparel

- Wearables will accelerate an already strong retail trend by imbuing apparel with sensors so that clothing will be able to provide real-time feedback on comfort, fit, style etc.
- In addition, virtual and augmented reality devices that are based on the availability of content to be consumed while the device is worn are now emerging for a wide variety of use-cases ranging from video eye wear (smart goggles and wearable cameras) that enable users to “consume” a retail product in their own homes before they actually purchase it, to augmented or virtual reality headsets (such as the Oculus Rift and the Microsoft HoloLens) that enable them to engage with stores in a completely new way

Payments

- Apple's ApplePay payment system, as adopted in the Apple Watch, makes mobile electronic payments even easier to use, generating intense competition for others to follow suit
- Other "wearable" payment systems include Google Wallet, Samsung Pay, and the CurrentC standard supported by Walmart, CVS, Rite-Aid and others
- These devices perform a variety of different computational functions generally (but not necessarily) relayed through a tethered smartphone
- Due to the variety of different wearable form-factors that have evolved to service specific purposes, multi-functional devices are generally limited to smart phones or smart watches, into which payments functionality can be easily integrated using NFC, Bluetooth, or other low-energy radios

Retail

- Enormous “e-tailers” such as Alibaba Group Holding Ltd, Amazon Corp, Baidu Inc and eBay are working with suppliers of mobile “beacon” technology (including iBeacon from Apple) to equip stores and malls with technology that improve the customer experience by interacting with wearable and mobile devices and provide rich real-time data analytics that personalize offers to consumers
- One of the “holy grails” in retail marketing is the “Omnichannel Experience”, the capability whereby, regardless of channel or device, consumers can engage with a company in a physical store, on an online website or mobile app, through a catalog, or through social media with a seamless experience
- Wearable devices that can communicate a user’s personal information to a store go a long way to having the store “respond” to the customer in a highly personalized, targeted manner

Healthcare (1/2)

- Wearable devices will have a profound impact on healthcare by monitoring patient passively, actively suggesting wellness strategies, and providing patient diaries and other continuously monitored information that can improve clinical studies and other activities
- In addition, system inefficiencies in the delivery of medical care will be addressed by tracking patient and provider workflow, follow-up, and reminders
- Wearables may be used by consumers to monitor medical conditions, to aid in the administration of medical aid (by either the consumer themselves e.g., self-administered insulin for diabetics), or by a healthcare professional (such as a wearable ECG monitor)

Healthcare (2/2)

- They may also include smart clothing to smart sheets (in hospitals) that could monitor vital signs at night-time in a non-invasive manner
- One category of intense interest is non-invasive (no blood-stick) continuous glucose monitoring for diabetics and others
- Examples of health and wellness wearables include those that are worn to enable quantification of user's routine or fitness activities, such as pedometers, mobility and heart-rate trackers
- These include clip-on or wristband activity trackers, as well as clothing that monitors biometric data, such as the Samsung Gear Fit, Razer Nabu, Jawbone Up, FitBit and Acer Liquid Leap that also offer notification services, but are still primarily considered fitness devices

Industrial

- Wearables will be a catalyst offering consumers a gateway into the Internet of Things (IoT) – for instance allowing unique products to emerge for the smart home, smart community, and smart workplace
- Wearable devices will also enable seamless interaction between consumers and their “built” environment, optimizing for factors such as transportation, weather, work or leisure activities, and the like
- Lastly, wearables can be extremely effective on the factory floor or the stock-room, ensuring workers follow appropriate Standard Operating Procedures (SOPs), manufacturing processes, on-the-spot training, as well as certification and licensing for Occupational Safety and Health Administration (OSHA)

Military

- The military are at the cutting edge of wearable technology, with many developments in the way of object and facial recognition hardware
- In addition, the military is pioneering in the use of technologies such as exoskeletons (augmented wearables), robotics and the intersection between individual and group (team) wearable technology
- Other augmenting wearable tools (for instance, infrared “night-vision” goggles are already standard operating practice in many militaries) will find use and be made robust under battlefield conditions before being transferred to broader consumer use

Enterprise Wearables

- Enterprise wearables are app-enabled smart devices that perform tasks in a business context
- Exactly what that task is will vary depending on the industry in question, but many have shown a preference for smart glasses, from industries as diverse as logistics and warehousing to healthcare and surgery
- Other examples of enterprise wearables include high-capacity strap-on tablets (e.g., for airline pilots or others who need to access manuals and other documents), or for those in the energy or construction industries
- Another application is performing real-time quality audits in manufacturing processes, based on feedback from wearable devices and sensors

Challenges and Issues

Challenges

- All these devices have similar challenges: power and heat, on and off-body networking, mobile input, and the display
- **Heat**: as devices become smaller and have less surface area, they dissipate less heat
  - Thus, a smartphone with the same processor as a tablet can reach uncomfortable temperatures quickly and have to throttle its performance, whereas the tablet can continue running at full speed
  - Thus, industrial designers need to consider heat dissipation issues when designing devices

Energy (1/2)

- **Power** is the scarcest of resources for most mobile electronics
- Although disk storage density increased by a factor of 1,200 during the 90s, battery energy density increased only by a factor of three
- Aggressive reduction in size imposes serious limits on battery capacity. Wearables are equipped with a range of sensors, such as accelerometers and gyroscopes
- Most economical sensors were developed for mobile phones, with energy consumptions more appropriate for phones than for ultra-compact wearables

Energy (2/2)

- Battery life and cost are probably the most important success factors for smartwatch acceptance in the market.
  - The failure of Microsoft's SPOT (Smart Personal Object Technology), because of cost and battery limitations, and the delays in Apple's Watch release show the importance of considering these two factors
- The challenge of optimizing resources, especially power, is an ongoing research topic and a multidisciplinary challenge
- End-user applications, internal hardware (lightweight battery, hardware miniaturization) and external hardware (wireless inductive charging or substituting lithium-ion with other materials such as solid electrolytes) could be investigated further
- Research on harvesting kinetic motion and body heat for electricity generation could also have an impact
- However, device makers continue to focus on reinventing the battery and its charging process, such as charging wirelessly with magnetic induction
- We have yet to see any revolutionary improvements

Networking (1/2)

- Today's cellular networks are fast, but only in the past few years has the latency been reduced to where computing in the cloud can be used effectively in user interfaces
  - For example, when sending a message, a Google Glass user might say "OK Glass, send a message to Thad Starner. Remember to pick up the instruction manual"
- The speech commands are processed locally, but the message "Remember ... manual" is processed in the cloud, where more resources can be exploited. With an LTE cellular connection, the experience is fairly seamless. However, with a GPRS, EDGE or sometimes even a 3G+ connection, the wait is intolerable

Networking (2/2)

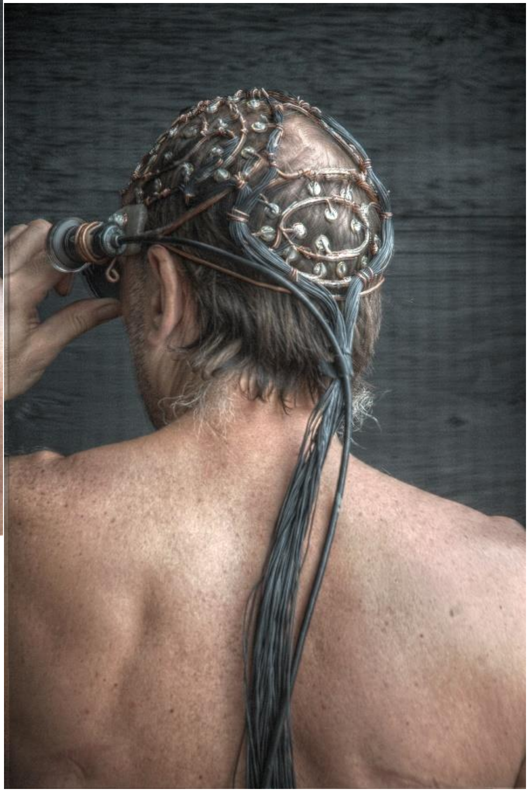
- Although **Bluetooth** (802.15) has existed for many years, it was originally intended as a wireless alternative for connecting mice and keyboards to desktop PCs
  - Bluetooth connections weren't reliable until 2001, and the standard wasn't designed with power as a foremost concern
  - Only now, with the widespread adoption of Bluetooth Low Energy by the major mobile phone manufacturers, have wearable devices really had an appropriate body-centered wireless network
- **GPS** can also be considered a network
  - Before 2000, GPS accuracy was 100 meters, because the US military intentionally degraded the signal
  - With that accuracy, turn-by-turn directions would be impossible
  - Today, by integrating cues from several different sensors and networks, accuracy is 20 meters or better. Modern units can even maintain connection and tracking through wooden roofs

Privacy

- Most activity tracking wearables can easily sense and record most private information such as sensitive medical information, and knowledge of the owner’s fundamental weaknesses
- Given the potential of wearables to sense and record individuals’ behavior and physiological responses, maintaining the privacy of this information is another research challenge
- Other way around: how do we know that people with wearables use them ethically?
  - Recording private conversations
  - Cheating

Privacy, security and ethics: The Steve Mann case

- Steve Mann is not only a pioneer of wearable computing but also a living embodiment of various issues raised by wearable technology
- Cyborg / Transhumanism
  - He considers himself to be a real cyborg
  - The EyeTap device needs special tools to be removed from his skull
  - Wears his device 16/24, 7 days a week



Sousveillance

- Sousveillance
  - Sousveillance is the recording of an activity by a participant in the activity, typically by way of small wearable or portable personal technologies. The term "sousveillance", coined by Steve Mann, stems from the contrasting French words sur, meaning "above", and sous, meaning "below", i.e. "surveillance" denotes the "eye-in-the-sky" watching from above, whereas "sousveillance" denotes bringing the camera or other means of observation down to human level, either physically (mounting cameras on people rather than on buildings), or hierarchically (ordinary people doing the watching, rather than higher authorities or architectures doing the watching)
- The 2012 McDonald's incident
  - Steve Mann was attacked in a McDonald's store in Paris by employees for not taking off his EyeTap device (no photo policy)
  - 2732 comments on reddit
    - "I still don't understand what he was attacked for"
  - Cyborgs / transhumanism
    - "Pretty creepy. Cool...but creepy."
    - "Am I the only one fazed by "digitally augmediated glass" that is ATTACHED TO THIS GUY'S SKULL?"
  - Is it ethical?
  - What about other people's privacy?

Epilogue / Augmented Reality

- Wearable technology first originated from the field of ubiquitous computing and the history and development of wearable computers (see M. Weiser, The Computer for the 21st Century – 1991)
- With ubiquitous computing, wearable technologies shares the vision of interweaving technology into everyday life by making technology pervasive and lessening the friction of interaction between human and machine
- The field of wearable technology is part of the larger ecology in Human - Computer Interaction that includes the Internet of Things (connected sensors and smart devices) and Augmented Reality
- The work of Steve Mann for example or the research conducted by Google in Project Glass is as much about wearables as it is about augmented or mediated reality
- Augmented Reality will be the subject of the next lecture

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