Human-Computer Interfaces

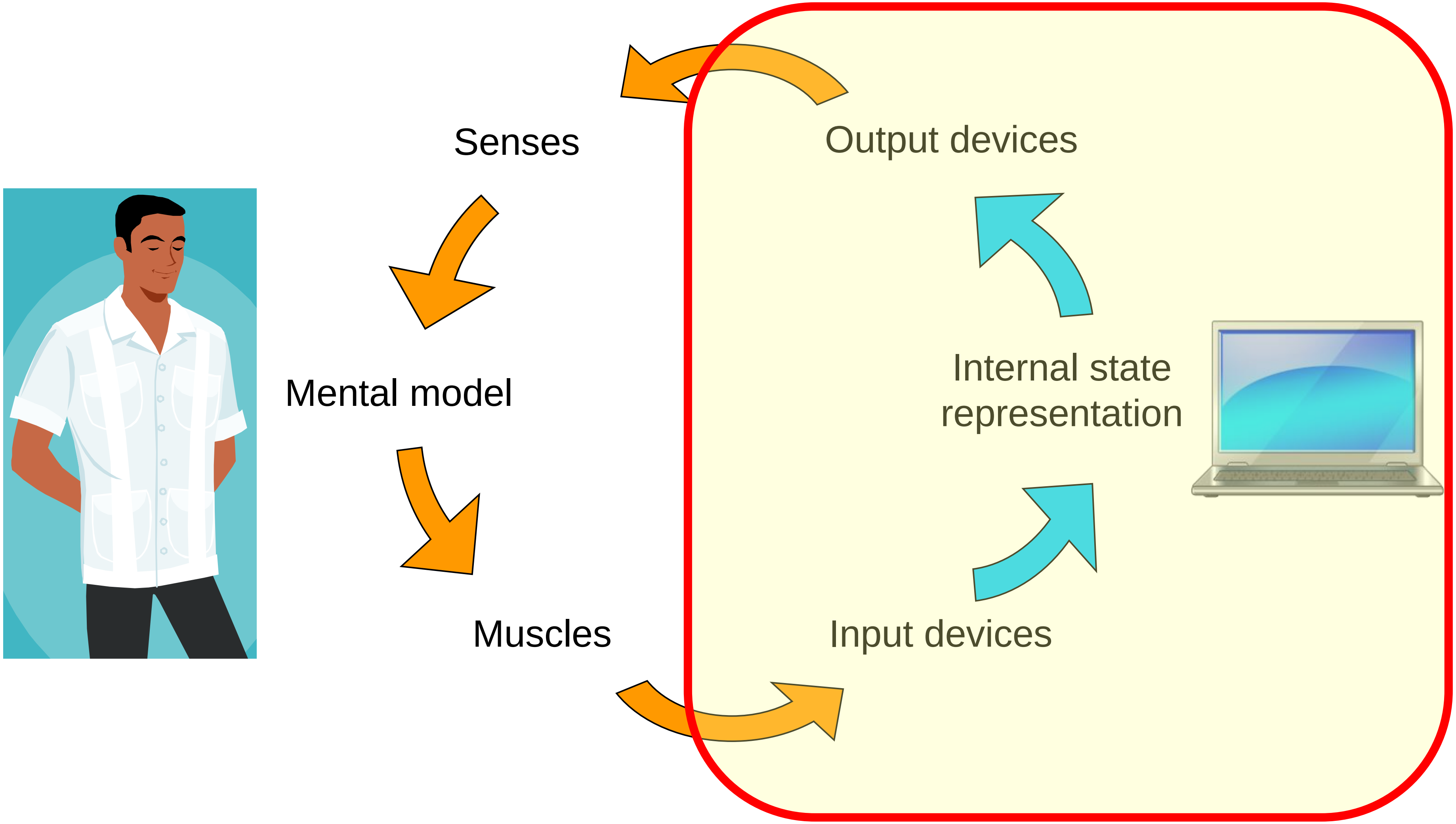
CZ2004 Human-Computer Interaction

Contents

Learning Objectives

- Appreciation of the evolution that human-computer interfaces underwent in the past century
- Knowledge and awareness of different physical input and output mechanisms for human-computer interaction
  - Not just screen / keyboard / mouse / touchscreen, what else?
  - What are the different innovative ways that these interfaces are being used?
  - How do these interfaces relate to and connect with the different human senses?

Interfacing Humans and Computers



Brief History of Computing Interfaces

Not History of Computing, but History of Computing *Interfaces*

- A typical "history of computing" slide would have
  - Machines of different computing capabilities (difference engine, processing speeds, etc.)
  - Internal technology (vacuum tubes, transistors, etc.)

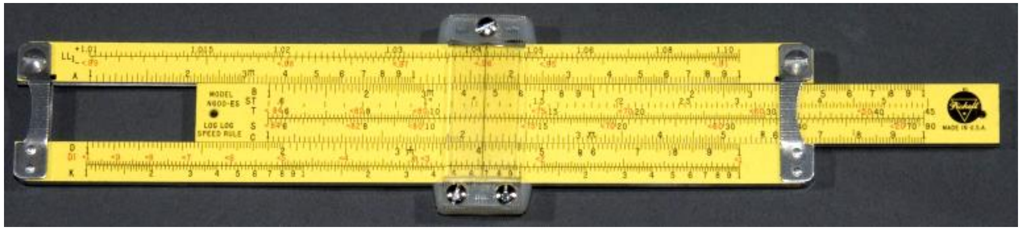
- Here we are more interested in
  - What was the look-and-feel of machines in the past?
  - How have interfaces evolved?

Early Aids: Sliding and Placing

- Abacus
  - First appeared in Sumeria, circa 2000 BCE
  - In China circa 2 BCE

- Counting Rods
  - China, circa 400 BCE

- Slide Rule
  - invented by William Oughtred, circa 1620
  - used as recently as the Apollo lunar missions (circa 1970)



- Tools advanced enough for complex calculation
  - e.g. square/cube roots, computation of π

Mechanical Calculators: Set and Crank

- Arithmometer
  – first commercially successful mechanical calculator
  – Invented by de Colmar, 1820
- Curta Calculator
  – Introduced in 1948
  – Very portable
  – See www.youtube.com/watch?v=A42EUs9QWgg
- Features
  – Multiplication, division, roots, etc.
  – Input: sliders
  – Output: mechanical display
  – Powered by mechanical crank

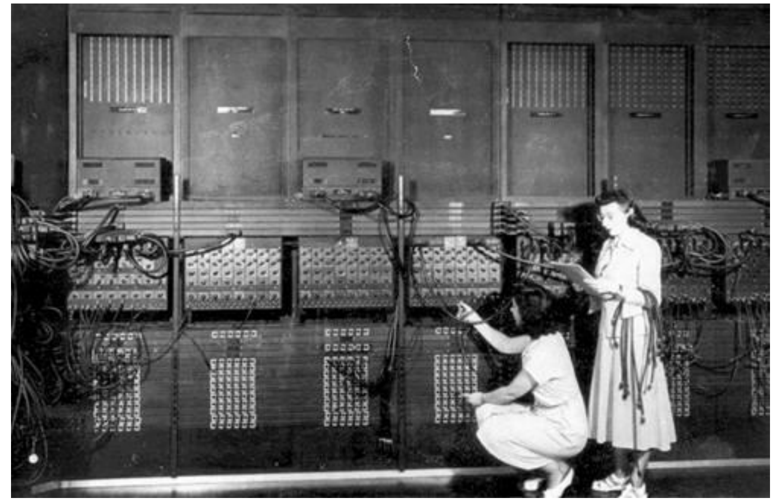
First Electronic Computers: Telephone Operator Style Computing

- Colossus (1944)
- ENIAC (1946)

- Both used for 1940's era military computations

- Programming was by connecting patch cables to/from different components

- See ENIAC video: https://youtu.be/goi6NAHMKog?t=120



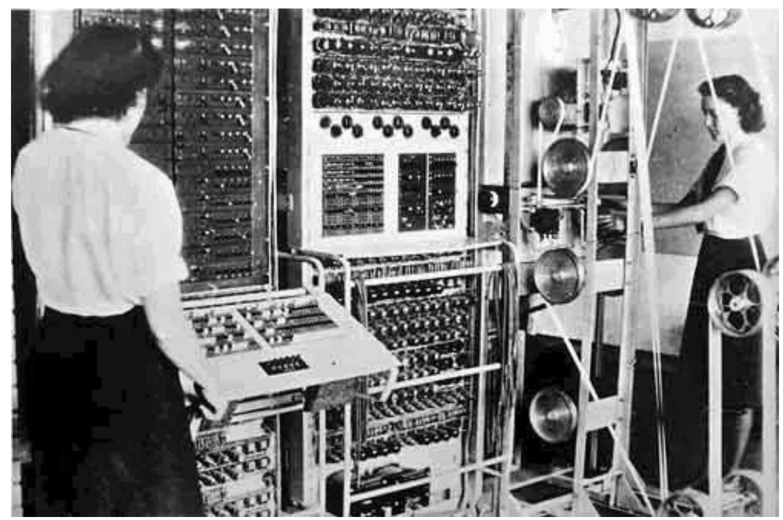
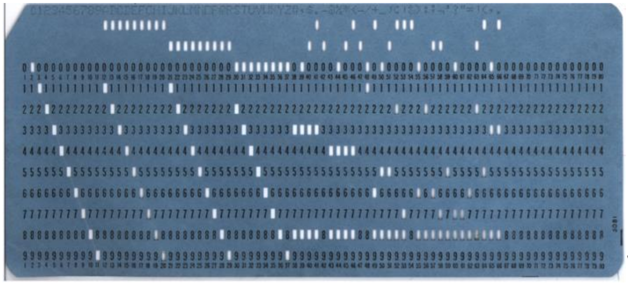


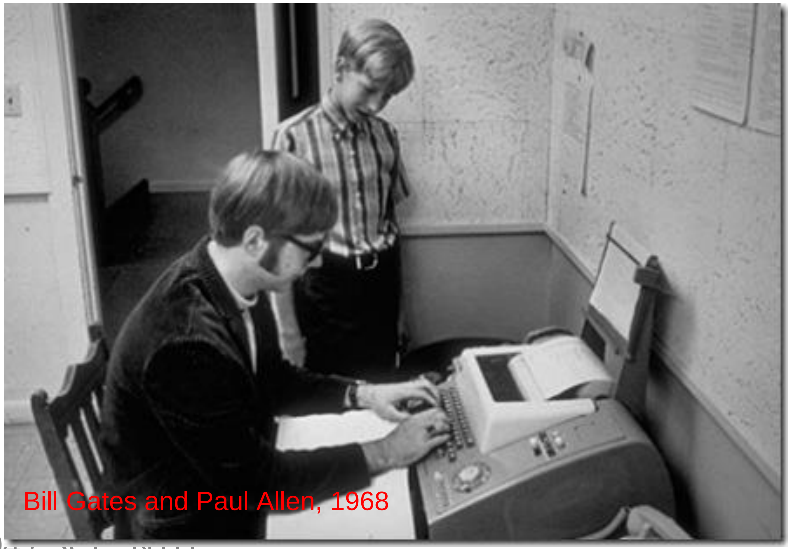
Image courtesy of Computer History Museum

1960's Computing via Paper

- IBM 650
  - First mass-produced mainframe computer, 1953
- IBM S/360 mainframe
  - Introduced 1964
  - Commercially very successful

- Interactive access via *teletypes* (teleprinters) which printed to paper as displays
  - See https://youtu.be/X9ctLFYSDfQ?t=432
- Punched cards were used for offline data entry and programming until 1980's
  - See punched tape 9:04 from previous video





Bill Gates and Paul Allen, 1968

Image courtesy of Computer History Museum

The Advent of Computer Screens

- MIT Whirlwind
  - Created 1951, experimental system
  - First computer to have a video display
    - Oscilloscope technology, but can display text and graphics via vector graphics
  - Also an input light pen (stylus)

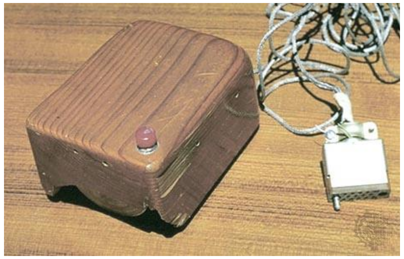
- DEC PDP-1
  - Introduced 1960, descendant of the Whirlwind
  - First commercial mainframe with a video display
  - First computer game SpaceWar!
  - See https://youtu.be/IoqA6fCyIpk?t=23

Image courtesy of Computer History Museum

Engelbart's 1968 Demo

- Douglas Engelbart, at SRI, put together in 1968 a famous public demonstration of a prototype computer system (NLS)
  - Later called "the mother of all demos"
- Publicly introduced many *new* concepts (at that time):
  - Mouse
  - Multiple windows in GUI
  - WYSIWYG word processing
  - Manipulating hierarchical lists
  - Hyperlinks
  - Computer-generated slides
  - Instant messaging
  - Desktop sharing
  - Shared screen Video conferencing

- Video clips at sloan.stanford.edu/MouseSite/1968Demo.html
  - Clip 12 – 1st introduction of "mouse"



Personal Computers: The Beige Box Era

- Early standalone display-based terminals
  - Datapoint 3300, 1969
  - VT-05, 1970

- Apple II, 1977

- IBM PC, 1981

GUI: When the Cat's Away…

… computer mice appear

- Xerox Star, 1979

- Apple Macintosh, 1985

- IBM PS/2, 1987

Portable Computing

- Osborne 1, 1981
- Compaq Portable, 1982

- Apple Powerbook 100s, 1991

- PalmPilot Professional, 1997
  - early PDA

- Compaq TC1000, 2002
  - early tablet

Design Evolution

Apple

Power Mac 5500, 1997

iMac G3, 1998

iMac G4, 2002

iMac G5, 2005

PowerBook G3, 1997

iBook G3, 1999

MacBook G3, 2006

Oracle User Interfaces – https://youtu.be/XPiOCK0JOlU

Input Mechanisms

Keyboards

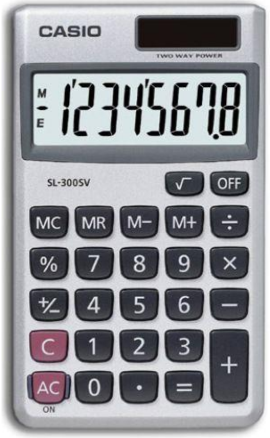
- QWERTY layout
  – Minimize pressing of neighboring keys in succession to prevent jams in typewriters
  – Layout carried over for electronic input
  – 60-100 words/minute (wpm)

- Dvorak layout
  – Alternative, less popular layout
  – Reduces awkward strokes
  – Highest frequency keys in middle row
- Ergonomic keyboards
  – Keep standard layouts, but shaped to reduce stress on wrists and fingers
- Tactile feedback often desired
  – “Click” sensation when pressing a key
    - Originally “buckling springs” by IBM
  – More subtle / missing in modern keyboards

Kinesis, QWERTY layout

Keypads

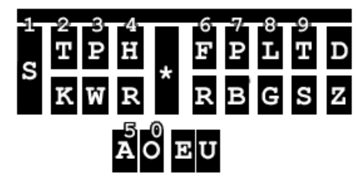
- Numeric keypads very prevalent
  - Phones, ATM's, calculators, cash registers, etc.
- Caution: different layouts!
  - Phones, ATM's ➔ larger numbers at bottom
  - Calculators, keyboard-side keypad ➔ larger numbers at top



- Multi-tap text entry
  - Multiple taps to select letter
- Predictive text, e.g. T9 system
  - Single taps, with selection for ambiguous cases
- Multi-tap ~ 10 wpm, T9 ~ 20 wpm
- Letter mapping on keypads was originally for phonewords as memory aid
  - e.g. 1800-FLOWERS

Chording Devices

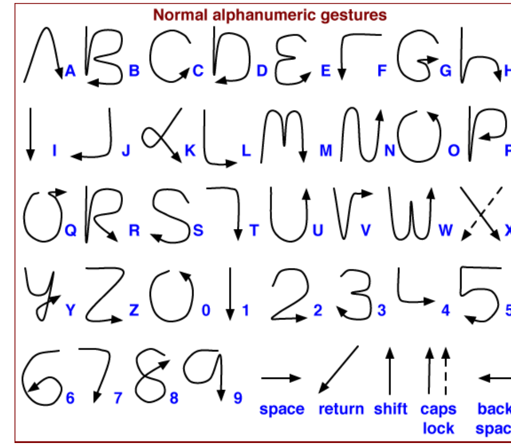
- Chording = pressing multiple keys simultaneously
- Stenotype (user = “Stenographer”)
  - Very fast typing, e.g. for transcription in law courts
    - speed record 375 wpm!
  - Phonetic code (or shorthand system)
    - User writes syllables instead of normal spelling
    - 1 chord = 1 syllable
  - Chording strokes used to record the syllables
  - Processor converts syllable sequences into text
  - See www.youtube.com/watch?v=6t7-IarTESc, www.youtube.com/watch?v=I333oAGSOwk

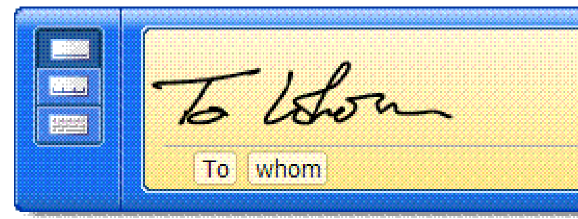


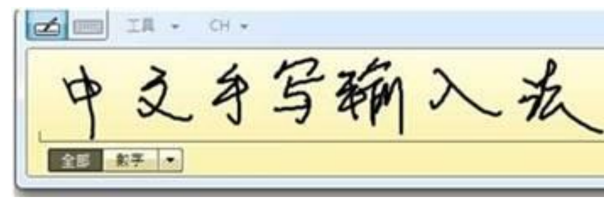
- Chorded Keysets
  - Used for fast single-handed text entry (50 wpm)
  - 1 chord = 1 character
  - Not so popular because of slow learning curve, but used in wearable computing community
    - e.g. Twiddler, EkaPad, FrogPad
      See www.youtube.com/watch?v=RNsrfaHl9kI, http://www.youtube.com/watch?v=FRvuUJR1c5Q#t=86

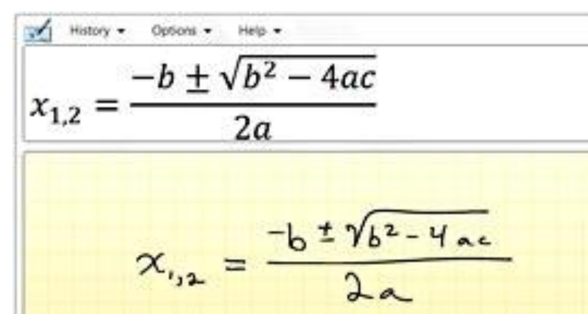
Handwriting

- Single letter recognition
  - May be available on stylus-based PDAs
  - Popularized by Graffiti system on Palm PDAs
    - 1 letter = single stroke (no pen lift)
  - Useful for very limited space for handwriting
- Cursive handwriting recognition now available on tablet PCs with good accuracy
  - Two modes:
    - Writer independent (no training)
    - Writer dependent (training to improve accuracy for specific writer)
- Very useful for “logographic” languages such as Chinese
- Also for math equations





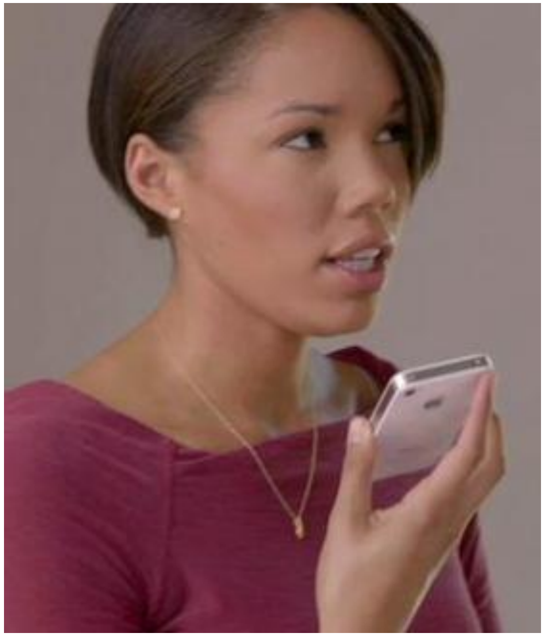




Speech Recognition

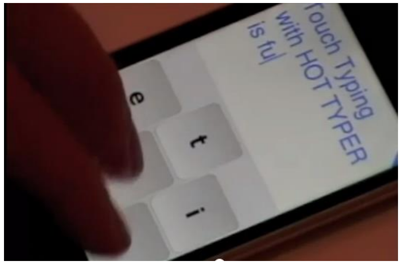
- Continuous Speech Recognition
  - **Speaker dependent**
    - trained for specific speaker for accuracy
    - Dragon NaturallySpeaking ~ 98% dictation accuracy under low-noise conditions
  - **Speaker independent**
    - Multiple speakers without additional training
    - Accuracy still poor, especially when noisy (try YouTube *Transcribe Audio* feature)

- Spoken Command Recognition
  - Recognize command words or command phrases
  - e.g. phone dialog systems, Siri, Windows speech recognition (http://www.youtube.com/watch?v=NFKHAjHrc5A#t=98s), toy robots
  - Usually speaker independent
  - Accuracy high because range of commands very limited, and use of context
    - Robust to noise and speaker variations

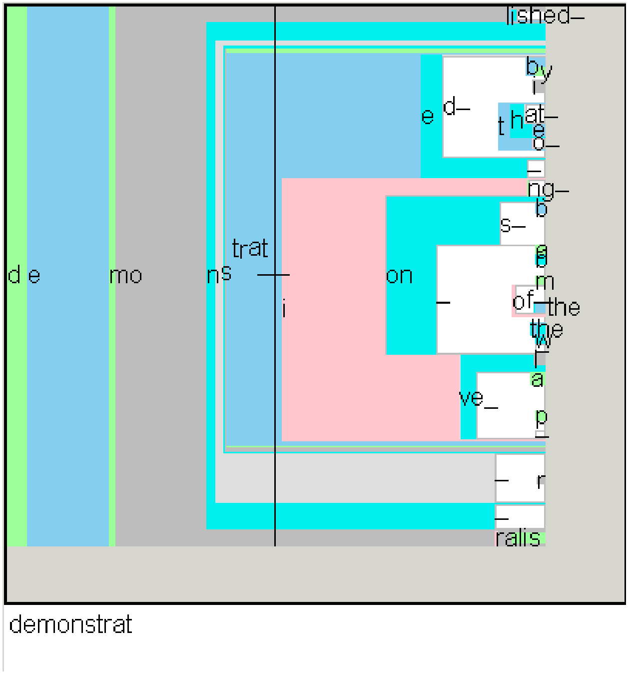


Other Text Entry Methods

- Chording on Multi-Touch Devices (iPhone, etc.)
  - GKOS, HotTyper (www.hottyper.com)



- Dasher software
  - Fast text entry by navigating
    - steering a pointer
  - Particularly useful for users with special needs
  - Has been tailored for different input
    - E.g. mouse, joystick, gaze tracking
  - Video demo www.youtube.com/watch?v=0d6ylquOKQ0
  - Main website: www.inference.phy.cam.ac.uk/dasher/DasherSummary2.html



Word Input Speeds

- Words per minute (WPM)
- Standardized word = 5 symbols
- Keyboard speed tests online, e.g. at http://speedtest.aoeu.nl/

Type	Experienced User WPM	Professional WPM
Stenotype	180	230
Speech	100-150	(250 for auctioneers, but software cannot yet process at this rate)
QWERTY keyboard	60	100
Twiddler	50	
Dasher	40	
Handwriting	30	
T9	20	
Graffiti	15	
Multi-tap keypad	10	

Relative Pointing

- Most map *velocity* of device ➔ digital *velocity* on screen
  - Nonlinear: scale factor increases with speed

- Mouse
  - Pointing, plus clicking (scrolling from 1997)
  - One vs multi-button debate
    - Apple: multiple buttons from 2005

- Trackball
  - “Inverted ball mouse”
  - No space issue, used in some laptops

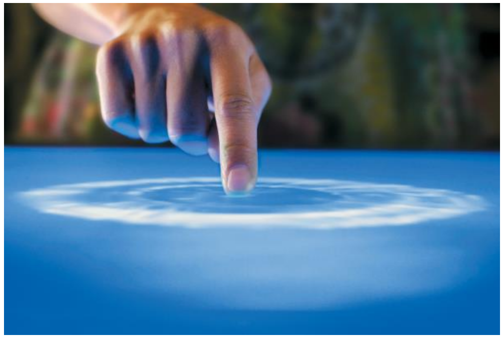
- Touchpad
  - Finger replaces mouse, clicks by taps
  - Interaction modes more ambiguous
    - Moving vs clicking

Absolute Pointing

- Direct pointing to actual position on screen

- Stylus-based Displays
  - Great accuracy, but require stylus

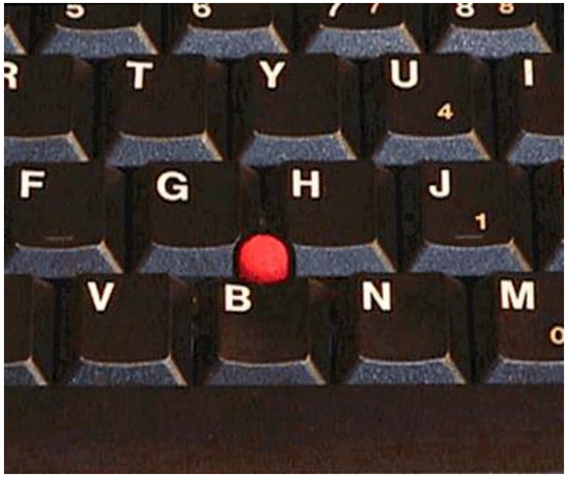
- Touch-based Displays
  - More intuitive, but less accuracy
  - Cannot rest arm on display



- Aimed Pointing
  - Large displays: interaction at a distance
  - Lower accuracy / less steady
  - Device-based (e.g. Wii pointing)
  - Natural pointing with arm/finger
    - Direction is line from eyes to finger tip, not line of whole arm
  - Tiring!!

Steering

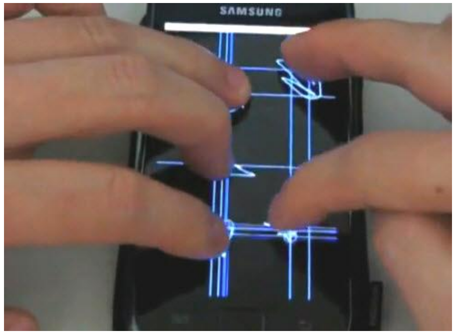
- Steering-based devices map *displacement* of device ➔ digital *velocity*



- Pointing Stick (IBM TrackPoint)
  - Mini joystick

- Gaming input devices
  - Joysticks
  - Gamepads

Multi-Touch / Surface Computing



- Multi-touch devices allow more complex interactions beyond normal pointing or dragging
  - Rotation, scaling
  - Igarashi's shape manipulation demo
    - www.youtube.com/watch?v=1M_oyUEOHK8

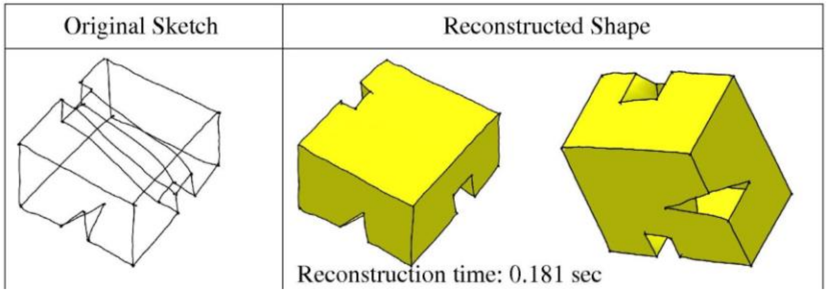
- Smartphones

- Tablets
- Surface computers
  - Multiple users per display
  - May also interact with tagged physical objects
    - NTU SCE – tangibles on surface
    - Also see http://www.youtube.com/watch?v=hMW7pd41Cz0#t=133s

Sketching as Input

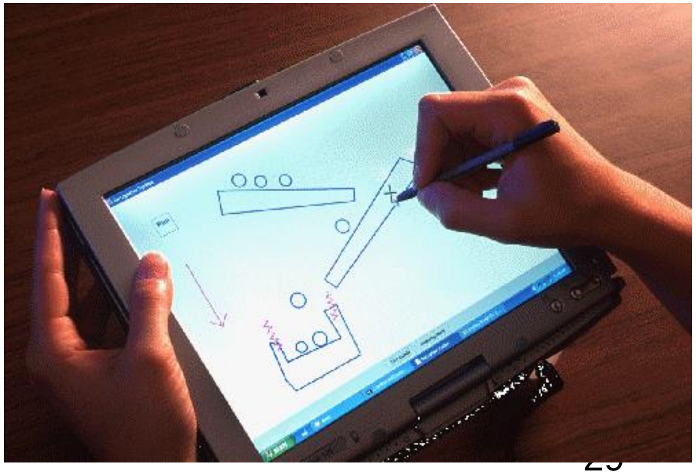
- Sketch input can be used beyond handwriting and digital art
- Intelligent systems can interpret sketches into higher level concepts

- 3D models from 2D sketches
  - Cornell University CCSL: 3D Journal
    creativemachines.cornell.edu/research/sketch/index.html
    (software available)
  - Takeo Igarashi (U. Tokyo): Teddy
    www-ui.is.s.u-tokyo.ac.jp/~takeo/teddy/teddy.html
    (software + browser version available)



- Physics simulation
  - MIT / Microsoft Physics Illustrator (freeware)
    - Old video at www.youtube.com/watch?v=1l2tDiyRWvw
  - Physion

- GUI lo-fi sketch interpretation
  - James Landay's SILK / DENIM projects
  - Able to recognize sketched widgets and simulate them working!
  - See video (www.open-video.org/details.php?videoid=5018)



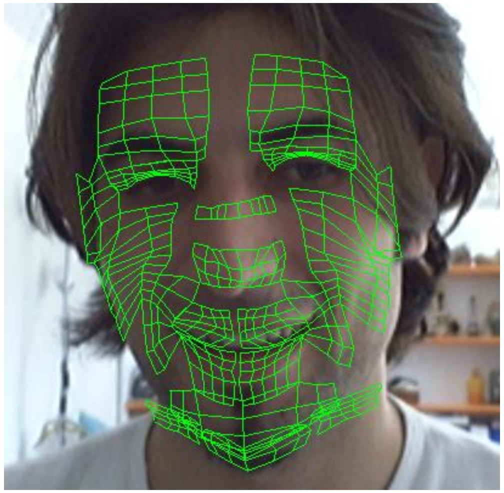
Natural 3D Motion

- Device Direction Sensing
  - Tilt sensors and electronic compasses
    - Found in various phones, cameras, etc.
  - Get vertical inclination and/or horizontal bearing
    - e.g. detect orientation modes, align maps

- Device Motion Sensing
  - More accelerometers and gyroscopes to sense full motion
    - e.g. Nintendo Wii, higher end phones
  - Partial motion from cameras (optic flow)
    - e.g augmented reality phone games

- Body Posture and Motion Sensing
  - Microsoft Kinect
    - Based on structured light 3D sensing
    - Can sense posture of all limbs
    - See www.youtube.com/watch?v=nr8vgCnb9_0

Affective Computing



Valenti et al., 2007

- Still fairly immature technology
  - Parts overlap with lie detectors (polygraph)
- Goal is to recognize user's affective states of mind
  - Facial expressions (see www.youtube.com/watch?v=uw5weBOZ6vU)
  - Body postures
  - Vocal indicators
  - Physiological indicators (e.g. blood pressure, breathing rates)
- Monitoring channels
  - Video, audio and physiological sensors (more intrusive, e.g. skin conductance)
- Commercial Product
  - Affectiva Affdex
    https://youtu.be/mFrSFMnskI4
  - Microsoft Cognitive Services (Emotions API)
    https://youtu.be/R2mC-NUAmMk?t=1m8s

© Affectiva

Brain-Computer Interface

Emotiv

- Ongoing area of research
- Current most popular approach: EEG
  - Measure electroencephalography (EEG) signals from the brain
  - Dry electrodes (i.e. no gels) interfaces are least intrusive
- Low-cost consumer-level products (but still mainly used for research)
  - Emotiv
  - Neurosky
- Current capabilities
  - Spelling (slow, 5-10 char/min)
    - intendiX, see www.youtube.com/watch?v=kXY50Ig773M
  - Navigation (e.g. for wheelchairs)

- Challenging because EEG signals are extremely noisy and difficult to find systematic patterns to mental imagery, even after extensive machine training

Output Mechanisms

Displays

- Displays transfer visual information to the user

- Different technologies with different characteristics
  - CRT
  - front & back-lit LCD
  - Plasma
  - full LED, OLED
  - electronic paper (e-ink)
  - LCD & DLP projectors
  - retinal projectors

Amazon Kindle

Samsung OLED

- Different desired display characteristics depending on use scenarios:
  - Mobility
  - Office work
  - Entertainment
  - Immersion

Brother Industries retinal projector

IMAX

Spatial Characteristics of Displays

- Display Physical Sizes
  - typically defined by **diagonal length**
    - e.g. 20” monitor, 47” LCD TV
- Aspect Ratios
  - Ratio of width to height
  - Typical: 4:3 or 1.33 (CRT, older LCD, iPad, business projectors), 1.5 (photoframes), 1.6 (LCD monitors), 16:9 or 1.78 (TV’s, entertainment projectors), 2.39 (widescreen cinema)
- Display Pixel Resolution
  - Various standards, e.g. XGA (1024x768), UXGA (1600x1200)
    - examples: iPad 1 = XGA, many 20” monitors roughly 1600x1000
  - HDTV: 1080p / 1080i (1920x1080)
- Viewing Angle / Viewing Cone
  - Max off-center viewing angle where display “quality” is acceptable
  - Greater ➔ better for sharing, smaller ➔ better for privacy
  - Examples: 140° for desktop LCD, 175° for LCD HDTV

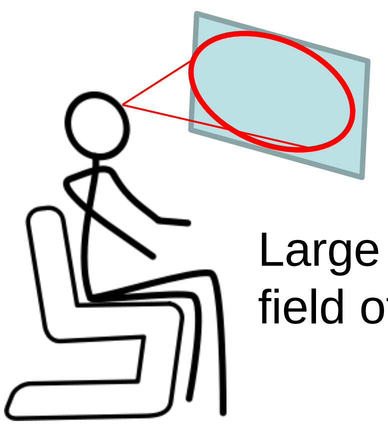
Display Field of View

- Visual angle the display takes up from the viewer's position
  - Depends on display size, aspect ratio, and also viewer position

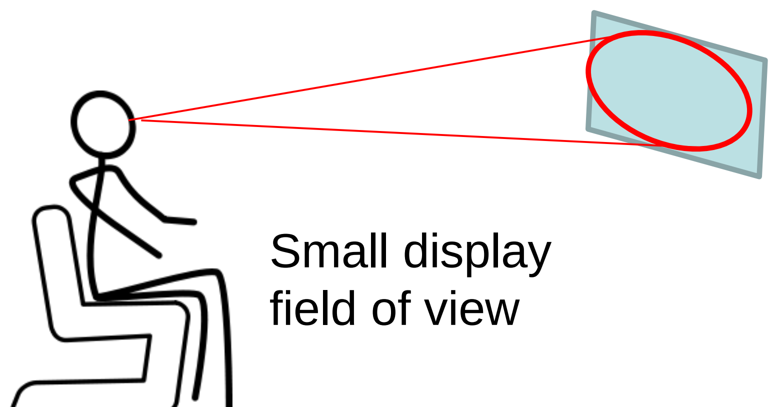
- Typical examples (horizontal FOV):
  - 20" monitor at 60cm distance ≈ 35° FOV
  - 42" HDTV at 3m distance ≈ 15° FOV

- Larger field of view ➔ greater viewer immersion
  - Recall: human visual field roughly 220° horizontal, 120° vertical
  - e.g. IMAX is full visual immersion, so are some CAVEs

- *Q: So why not just move nearer the display??*



Large display
field of view



Small display
field of view

Pixel Density

- Pixel density measured in pixels-per-inch (PPI)
- Analog CRT: resolution is not fixed by the monitor
  - Graphics adapter can set different resolutions ➔ different PPI
- LCD monitors: *native resolution* for the monitor because each pixel is a physical cell ➔ PPI is fixed
- Typical PPI's
  - 50" HDTV at 1080p = 45ppi
  - 20" LCD monitor with UXGA resolution = 100ppi
  - iPhone "Retina" display = 329ppi

Steve Jobs: *"It turns out there's a magic number right around 300 pixels per inch, that when you hold something around 10 to 12 inches away from your eyes, is the limit of the human retina to differentiate the pixels."*

Homework: is this valid by geometric calculation and human visual acuity?

Intensity Characteristics of Displays

- Brightness
  - Monitors / TVs: specified by peak luminance
    - Luminance = luminous power per unit area
    - e.g. LCD HDTV ≈ 500 candelas/m^2
  - Projectors, specified in luminous flux
    - flux = power per unit 3D angle
    - e.g. portable projectors ≈ 2000 lumens
  - *High brightness more important in well-lit places*
  - LCD displays have high peak luminance

- Black Level
  - The black level is luminance of black pixels
    - Most displays always leak light
  - *Low black level more important in dark places*
    - e.g. for realistic night scenes in pilot / air traffic controller training simulators
  - CRTs and OLEDS have low black levels

Intensity Characteristics of Displays

- Contrast
  - Contrast ratio = peak luminance : black level
  - Not very useful – does not account for ambient light
  - Better: high luminance for bright places, low black levels for dark
- Color Gamut
  - Range of colors that a display can reproduce
  - Typically **Red**, **Green** and **Blue** are used as the primaries
    - *But 3 primaries cannot recreate **full** color gamut of human vision*
  - Sharp Quattron uses a 4th primary color **Yellow** to “expand” color gamut, and Sharp has prototyped with a 5th primary color **Cyan**

3D Displays Overview

- Two human visual cues used
  - **Stereopsis**
    - seeing 2 slightly different images in each eye
  - **Motion parallax**
    - seeing slightly different images as you *move* around

- Terms used in classifying 3D display attributes
  - **"Stereoscopic"**
    - different image to each eye, viewer must wear special glasses
  - **"Autostereoscopic"**
    - different image to each eye, *does not* require special glasses
  - **"Multi-view"**
    - different images depending on *viewer's position*
  - *Note*: "Multi-view" can be used independently of "(auto)stereoscopic"
    - possible to have "multi-view 2D" (motion parallax only), "multi-view stereoscopic" or "multi-view autostereoscopic" (both motion parallax and stereopsis) displays

Stereoscopic and Autostereoscopic Displays

- Stereoscopic Displays (most common)

  Two approaches:

  1. Using circularly polarized glasses
     - 3D cinema and LG 3DTVs
  2. Using active shutter glasses
     - Panasonic / Samsung 3DTVs
     - Better quality, but require batteries

  – Good for many simultaneous users

- Autostereoscopic Displays

  Two approaches:

  1. Lenticular lens (brighter but blurry)
     - Philips, some earlier 3D displays
  2. Parallax barriers (darker but sharper)
     - Most other autostereoscopic displays
     - e.g. Nintendo 3DS, LG Optimus 3D phone

  – Typically limited to 1 (or very few) viewers

  – Narrow sweet-spot for viewing 3D

Multi-view Displays

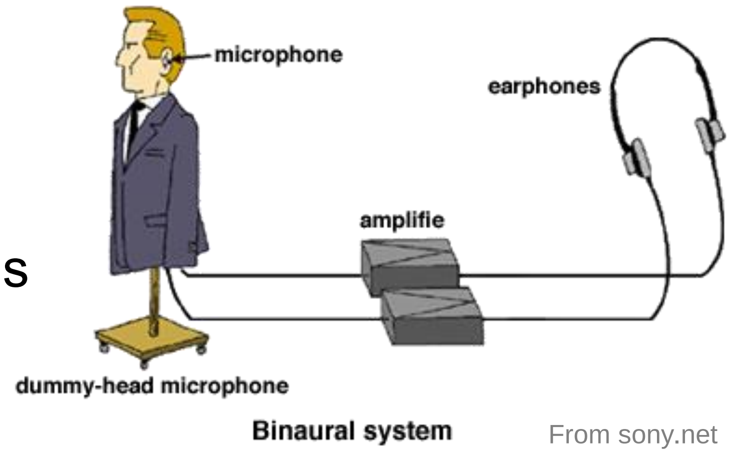
- Multi-view typically enabled by tracking user's head
- Multi-view 2D Displays
  - Same image to both eyes, but changes with viewer's position
  - Johnny Lee's demo http://www.youtube.com/watch?v=Jd3-eiid-Uw#t=149s, iPad app *i3D* www.youtube.com/watch?v=bBQQEcfkHoE
  - Single user only
- Multi-view Stereoscopic Displays
  - Normal stereoscopic system with user tracking
  - NTU's BeingThere Centre demo (Kinects + OptiTrack + glasses)
  - Typically single user only
- Multi-view Autostereoscopic Displays
  - Two forms:
    1. Autostereoscopic display + user tracking
       - Typically single user only
    2. Light field / holographic display – send different images to different viewing directions simultaneously
       - Can handle multiple users
       - USC ICT's demos: https://youtu.be/YKCUGQ-uo8c, https://youtu.be/PjP4SvHjkdo
       - Holografika: https://youtu.be/3oX-aOJMX34

Audio

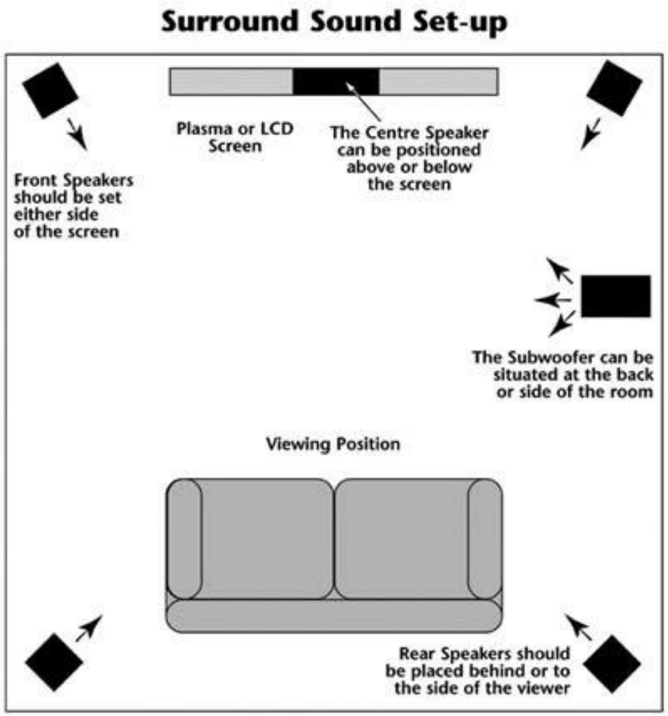
- Purposes of Audio
  - Entertainment, communication, user feedback
    - User feedback not just alerts, but e.g. can also be used to cue material properties for virtual objects (see later video)
- Different frequency range limits
  - Music: full frequency range of human hearing
  - Human voice: 100Hz to 8kHz (including voice overtones)
    - Telephones restrict 300Hz to 3.5kHz – reasonable for speech
- Equipment
  - Earphones / headphones
  - Loudspeakers
    - May require specialized drivers (subwoofer, tweeter, etc.)

Surround Sound

- Stereo audio
  - Sense of direction, but not true surround sound
  - microphones, loudspeakers and listener's ears are in different locations (relative to sources)
- Binaural audio with headphones
  - Microphones placed in ears of a dummy head, or synthesized via Head-Related Transfer Functions (HRTF)
  - Hear *Virtual Barbershop* www.youtube.com/watch?v=IUDTlvagjJA, or this https://youtu.be/3FwDa7TWHHc
- Loudspeaker-based surround sound
  - Standards: 5.1 or 7.1 surround sound
    - Refers to number of audio channels
  - Channels feed to 5 (or 7) speakers placed around the listener(s)
  - The ".1" is a low-frequency non-directional channel fed to subwoofers



From sony.net



From speakers-surround-sound-info.blogspot.com

Audio Games

- There are a number of audio-only games
  - Removes visual channel of feedback
  - Interesting experience, try them if you can

- Video on audio-based games
  - See www.youtube.com/watch?v=IJ7dCkWdPC0
- iPad/iPhone games
  - *Papa Sangre*
  - *NightJar* www.youtube.com/watch?v=gyO-09wsLR4

- Physical immersive audio game
  - *Auditory Horror* www.youtube.com/watch?v=Nlqfa2EValg

Text-to-Speech

- Text-to-Speech (TTS) uses a speech synthesis engine
  - Text first transcribed into phonemes with prosodic parameters (rhythm, intonation, stress)
  - Speech waveform then generated with pre-recorded wave samples, or synthesized from theoretical models

- Useful when text information needs to be conveyed to a user:
  - who is visually impaired, or
  - whose visual attention is focused elsewhere
    - e.g. road names read out in a GPS navigator

- Also useful to users with speech disabilities who want to communicate verbally
  - e.g. Stephen Hawking

- Demos: https://cloud.google.com/text-to-speech/, https://text-to-speech-demo.ng.bluemix.net/, www.oddcast.com/demos/tts/tts_example.php?clients
- Also check out the online virtual movie maker ~~Xtranormal www.xtranormal.com~~ Voki www.voki.com

Haptics

- Haptic devices provide tactile feedback to users
  - Some even with temperature feedback
- Basic vibration cues ("force feedback")
  - Mobile phone vibration
  - Logitech iFeel mouse
    - Vibrations going over edges of windows, etc.
  - Joysticks / Gamepads
    - e.g. Playstation DualShock, Logitech Wingman Force 3D joystick
- Sensation of virtual 3D shapes
  - Resistive feedback via air bladders (crude) or actuators (more accurate)
  - Datagloves, e.g. VRLogic *CyberGrasp*
    - See www.youtube.com/watch?v=iS0EE7DZeO4
  - Pen-based devices, e.g. Sensable *Phantom*
    - Less tangible but more accurate feedback
- Texture sensation
  - Based on micro-vibrations (see module on Humans)

VRLogic CyberGrasp

Sensable Phantom

Motion Simulators

- Motion simulator applications
  - Originally for flight training (www.youtube.com/watch?v=VZ_FsT5Preo)
  - Now widely used for entertainment, e.g.
    - XD Theatre at Singapore Discovery Centre
  - Also “home” systems
    - BlueTiger, JoyRide, Force Dynamics, D-Box
  - See http://www.youtube.com/watch?v=gDBQI12n4Zo
    - Note how heavy deceleration works

- Advanced simulators use a Stewart platform design
  - 6 prismatic actuators for full 3D movement

- Simulation based on motion cueing techniques
  - long acceleration simulated by tilt to align virtual force direction with real gravity
  - short acceleration by *acceleration onset cueing*:
    - Initial identical acceleration by simulator,
    - then a gradual and imperceptible return to the neutral position

Digital Scent Synthesis

iSmell

Scent Dome

- Scent generation
  - aromatic compounds pre-dissolved in solvent
  - when needed, atomized into a fine spray
- Odor release systems
  - Fixed set of odors, e.g. tobacco, coffee
  - Smell-O-Vision and AromaRama (1960s) in cinemas
  - Some limited recent scented movie systems
- Scent synthesis from basis scents
  - Some dot-com era attempts, but no commercial success
  - DigiScents *iSmell*: combination of 128 primary scents
  - Also: TriSenx *Scent Dome*, AromaJet *Pinoke*
- Recent efforts (2010 onwards)
  - Scentcom (partnership with Singapore’s Lynxemi)
    - MEMS-based *Miniature Digital Scent Module*
  - ScentSciences *ScentScape*
    - 20 primary scents. See http://www.youtube.com/watch?v=M75cMkPYX28#t=238s
  - Sensory Acumen *Game Skunk*
  - *Hana Yakiniku*

ScentScape

"4D" Experiences

- "4D" rides and theater stimulate multiple human senses
  - 3D visuals
  - surround sound
  - tactile input – e.g. wind, water drops
  - vestibular input – via motion simulation
  - temperature sensation – cold, heat (often via controlled flames)
  - olfactory input – via odor release

- Examples
  - Universal Studios Singapore:
    - Transformers The Ride, Shrek 4D
  - Korea's CJ-CGV 4D cinemas
  - Hong Kong's 4D Extreme Screen