Human Factors: The Non-Visual

Slides adapted from various sources …

Need for non-visual modality

- Difference in nature of information
- Visual channel is occupied sometimes
  - Multi-tasking
- Disability
- Preference
- Fatigue
- Multimodality combination
  - Redundant → Ascertain information conveying
  - Alternative → Certain modality is occupied
  - Composed → Most fitting modality (Effectiveness / Naturalness)

Information channel

- Each sense modality can be thought of as a "channel" through which information is received and processed.

- Each channel has limited capacity or bandwidth in terms of the amount of information that can pass through it at one time. "Channel capacity," a concept derived from information processing theory, is useful in selecting the appropriate sense modality or modalities in display design.

Need for non-visual modality

The complexity of the nuclear power plant control room above challenges human capability to monitor and control without using non-visual displays.

Sound

- Sound is a real, physically measurable entity. The study of sound is highly complex and based on the mathematics of waveform computation and analyses.

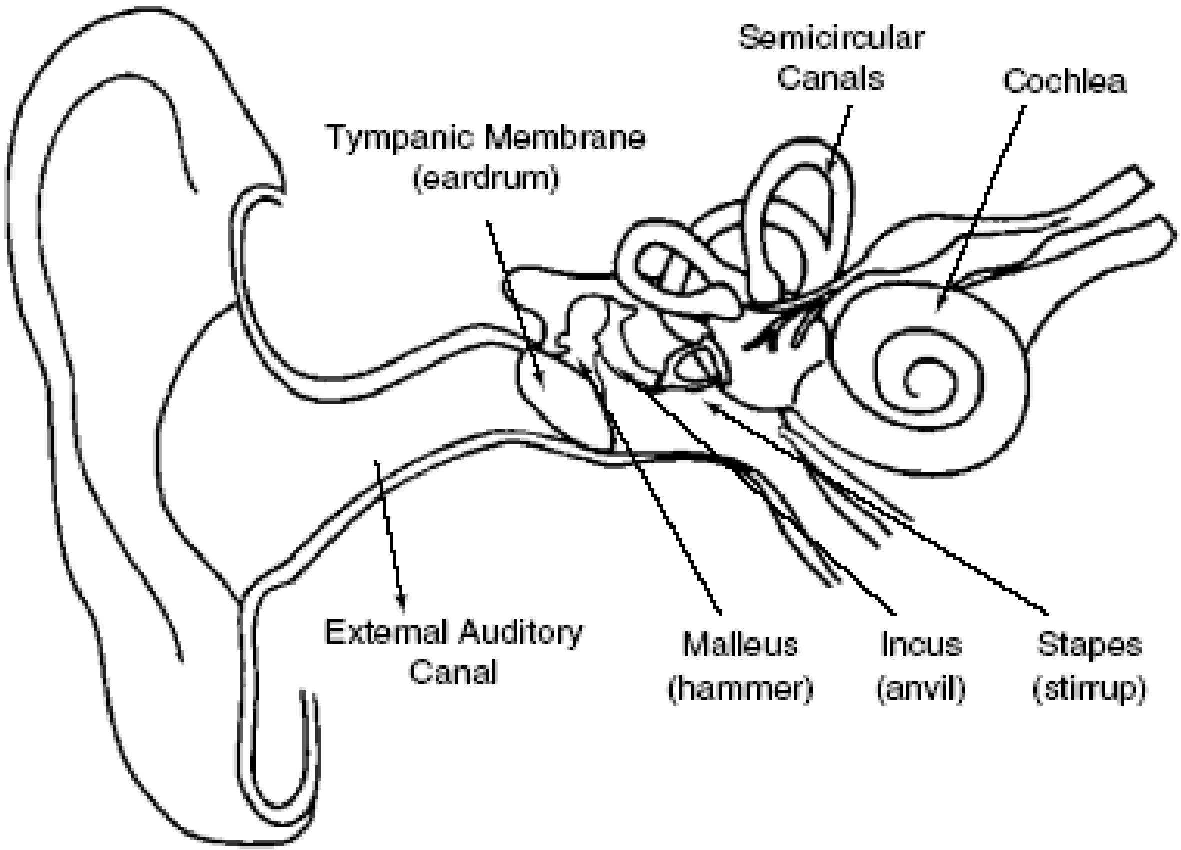
- Frequency - the number of sound waves per second produced by a sound source. Frequency is measured in cycles per second or Hertz. We hear frequencies between about 20 Hz to 20,000 Hz.

- Amplitude - the height of the wave and energy or strength of the sound. This also can be thought of as the power or pressure of the wave--the sound pressure level (SPL) which is measured in decibels (dB).

- Duration/Phasing - the time/temporal factor of a sound or sounds.

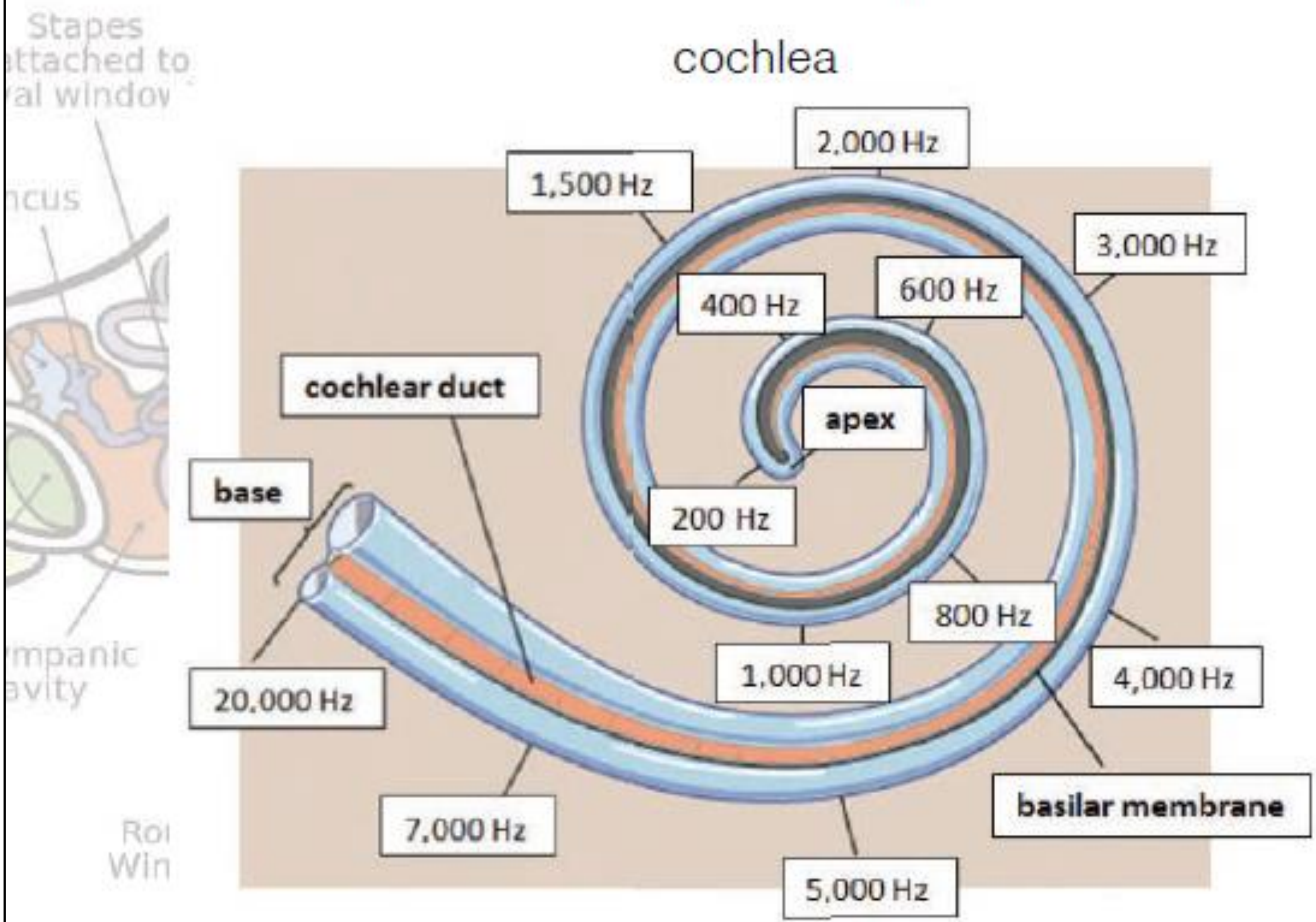
- Modulation - fluctuation in frequency and/or amplitude, usually associated with a temporal pattern.

Human Ear



Semicircular Canals
Cochlea
Tympanic Membrane (eardrum)
External Auditory Canal
Malleus (hammer)
Incus (anvil)
Stapes (stirrup)

- hair receptor cells pick up vibrations



wikipedia

Auditory system

- The human auditory system converts sound energy to mechanical energy to electrical energy. The outer ear collects sound waves and channels them to the middle ear where the eardrum and three tiny bones (the ossicles) convert the sound waves into vibrational energy.

- This energy, in turn, is transmitted to cochlea in the inner ear where it is transformed into nerve impulses. These nerve impulses are transmitted to the brain for interpretation and recognition.

- The human auditory system is extremely sensitive and responds to a wider range of stimuli than any of the other senses.

- If we assume that the softest sound that we can hear is at 0 dB and the upper limit is 132 dB (the point of pain).

Psychoacoustics

- Psychoacoustics is the study of how the human auditory system, including the brain, processes sound and the study of our resulting perceptions

- Pitch - roughly equivalent to frequency; pitch is a subjective impression (perception) that combines frequency and intensity. We are most sensitive to frequencies between about 2,000 to 5,000 Hz.

- Loudness - corresponds with amplitude and perceptually interacts with pitch.

- Sound Quality - is defined as timbre, the humanly perceived difference between tones even though the tones are of the same pitch and loudness. Other psychoacoustic perceptions of sound are: roughness, sharpness, tonality, pleasant vs. unpleasant, and sound localization.

Sound measurement

- Sound intensity (perceived as loudness) is measured in units of sound pressure level (SPL). To handle sound measurements and calculations over a range of 32 trillion units, a logarithmic scale is used. The units of this scale are decibels (dB).

- Because decibels are on a log-scale: a 3 dB increase equates to twice as much sound (power); a 6 dB increase 4 times as much; The following are examples of the sound pressure levels in decibels of familiar sounds.

140 dB - Jet aircraft start
120 dB - Propeller aircraft start
60 dB - Normal conversation
40 dB - Living room
20 dB - Bedroom
15 dB - Threshold of hearing

130 dB - Pain threshold
110 db - Rock band
50 dB - Office environment
30 dB - Whisper
10 db - Recording studio
0 dB - Weakest sound

Auditory display

- Auditory displays are most often used to attract and direct a user's attention. Auditory displays convey caution, warning, or danger information. Auditory displays can be powerful "attention getters," depending on the characteristics of the sound used and the surrounding environment.

- Examples are fire alarms, burglar alarms, ambulance, and police sirens. For these applications, auditory displays are preferred because they need not be in the field of view to be used. Generally, sound should be accompanied with visual indicators such as flashing or strobing red lights for redundant sensory coding.

Auditory display: Examples

This smoke detector uses an auditory display. Placed appropriately, it can warn inhabitants anywhere in a building or home of danger before the sight of fire or smell of smoke becomes apparent.

Aircraft cockpits have complex visual and auditory displays. The number of these displays has steadily increased, as aircraft have become more technically sophisticated (DC8/172, DC10/481, B707/188, B747/455)

Auditory channel: Advantages

- Sound Surrounds - Sound is omni-directional.
- Works for no or low visibility environments
- Attention Getting - Sound can be very obtrusive, immediately demanding our attention

Auditory channel: Disadvantages

- Startle Response - Sound can be so obtrusive that it interrupts and disrupts task performance even to the extent of wiping out/erasing immediate memory.
  - Gradual introduction

- Localization Difficulties - While sound surrounds us, it can be difficult to locate the source, depending upon the environment. Sound can be absorbed or reflected by barriers and objects.

For example, when one is driving and enclosed in an automobile, it is difficult to locate the direction of a police car or fire engine from the sirens alone.

Auditory Channel: Disadvantages

- Limited Memory for Abstract Sounds - We can discriminate thousands of different sounds; however, human memory for abstract sounds, is very limited--typically from 5 to 8.

- Sounds Masked by Other Sounds - We have difficulty filtering and separating sounds if one sound is "masked" by another of the same or similar frequency.

- Sound/Noise Habituation - We tend to become used to and not attend to continuous sound or noise unless it pertinent to the task at hand. "Background" music is a common example.

Auditory display considerations

- When designing auditory displays, loud (high decibel level) alarms should be reserved for life-threatening, critical events and lower levels used for less threatening alerts. Care must be taken in the selection of tones, decibel levels, and alarm/alert rates. While a powerful "attention getter," sound can also be a "task interrupter" and nuisance (startle effect). For this reason, it should be sparingly used (avoid “too loud”)

- Limit the number of alarms and alerts. Optimally, limit to 6 immediate action signals and 2 precursor, attention signals (avoid “too many”)

Auditory display considerations

- Signals must differ sufficiently that one signal does not mask another.
  - For 100% dectectability or rapid response, signals must be 15 dB above ambient, background noise (audio contrast / amplitude wise)
  - Signals must differ in frequency from the frequencies of background noise (frequency contrast)

- Signals should be between 500 and 5000 Hz and composed of at least 4 prominent frequency components, each within the range of 1000 to 4000 Hz.
  - Signals should be composed of regular, harmonic, frequency components instead of inharmonic components (perceived tonal sequence vs. noise).
  - Rapid (100 msec) glides in the signal's fundamental frequency command attention and convey urgency.

Auditory display considerations

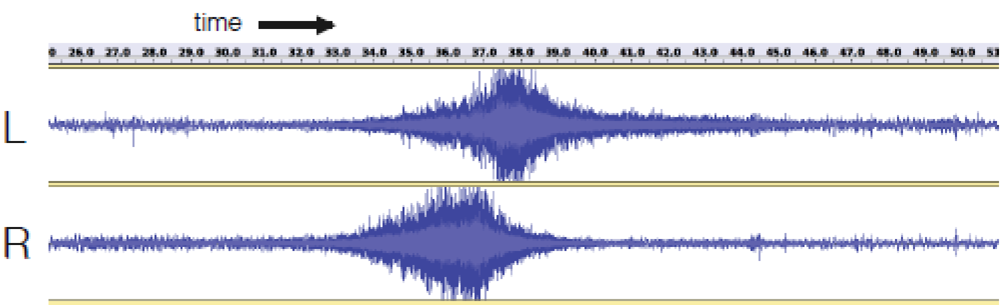
- To gain attention, modulate the signal, using intermittent "beeps" or rise and fall in pitch (1 to 3 cycles per second).
- Use temporal patterns to increase signal detectability and discriminability.
- Signals that must be heard from more 1000 feet away should be below 1000 Hz, as lower frequencies travel farther.
- Signals that must be heard through partitions or around obstacles should be below 500 Hz, as lower frequencies can travel through barriers.

Sound “content” effects design

- Beep
- Pure tones
- Iconic (“earcon”)
- As is
  - Recorded
  - Synthesized

Stereophonic Sound

- mainly captures differences between the ears:
  - interaural time difference
  - amplitude differences from body shape (nose, head, neck, shoulders, …)



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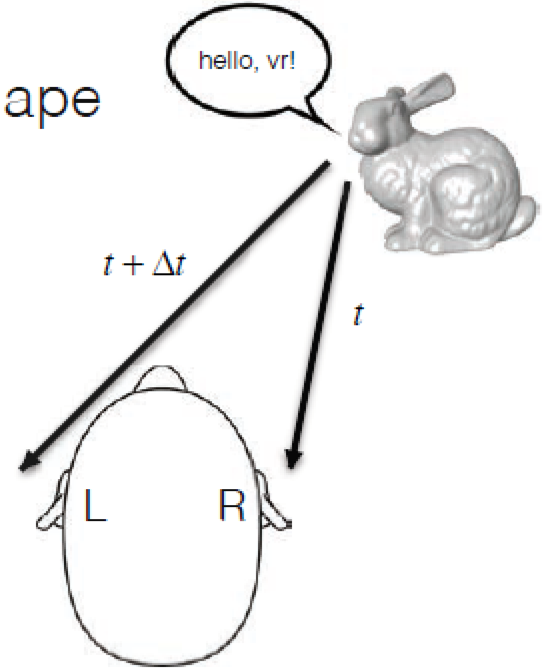
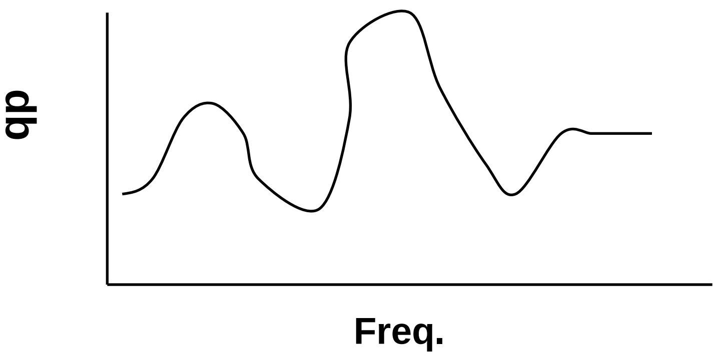


Sound directionality

- **Loudness**
- **Phase difference**
  - Stereo sound
  - Surround sound
  - Individual difference



- **Difference in energy distribution in frequency distribution**
  - HRTF (Head Related Transfer Function)
    - Sound with new energy distribution according to varying location of sound sources (for right and left ear)
    - Measure impulse response from source to ear drum (HRIR) @ many different locations
    - Take Fourier transform (HRTF)
    - Use HRTF to reproduce binaural sound from monaural source (for right and left)
    - Dynamics of Pinna causes individual difference (significant)

Sound display

- **Sound cards (practically)**
  - Volume control
  - Stereo / Surround
  - HRTF with 5.1 Surround ?
  - DirectSound

- **Speakers**
  - Location problem

- **Headphones**
  - Feels like sound from head

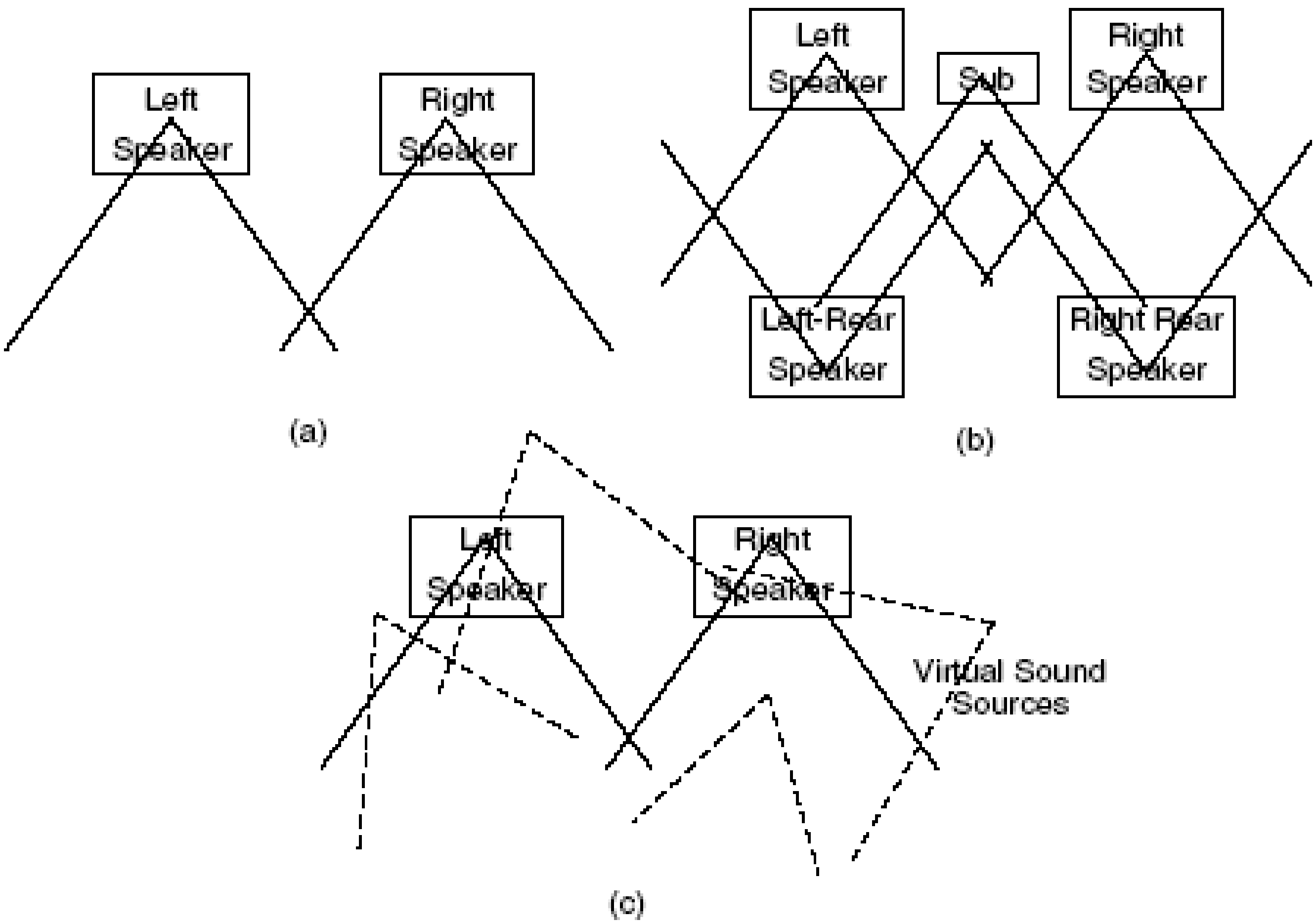


FIGURE 6.34. Various sound systems: (a) stereo; (b) 5.1 surround; (c) HRTF-based 3D sound. (Adapted from [Kra01] with permission from IEEE © 2004.)

Haptics and Tactility

- Tactile: Displays that capitalize on the user's sense of touch are termed tactile, tactual, or cutaneous displays
  - Braiille: Pure form of tactile interface
- Haptic: Combine somatosensory modalities such as tactile and kinesthetic
  - Haptic refers to "active touch" to emphasize the importance of movement/kinesthetics when exploring an object by touch.
- Tactual and haptic displays
  - Receive/provide and process mechanical energy
  - Secondary to visual/aural
    - Keyboards: visual + haptic/kinesthetic + sound feedback
    - Best with other modal displays

Haptics: Force Feedback + (Tactile)

- **Feeling of kinesthetic (Force feedback)**
  - Muscle and associated cells / nerves: pressure and torque
    - Paccini / Rupini / Golgi
    - Minimum activation force: ~ 0.5 - 2.5mN
      - Depends on the user characteristics

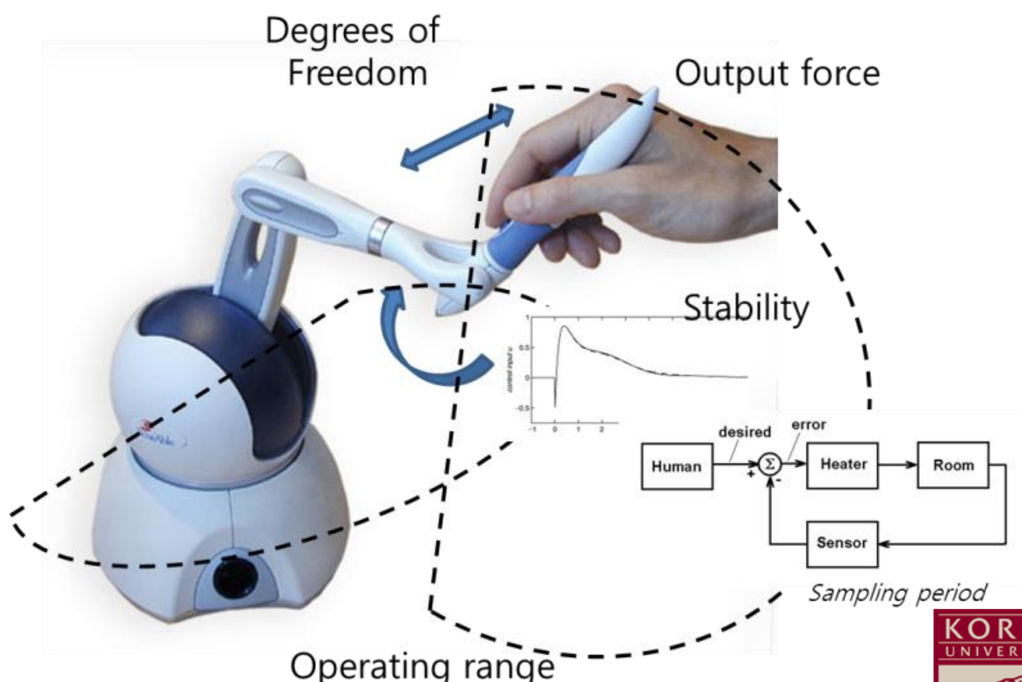
- **Haptic – both input and output**

Haptics: Force Feedback + (Tactile)

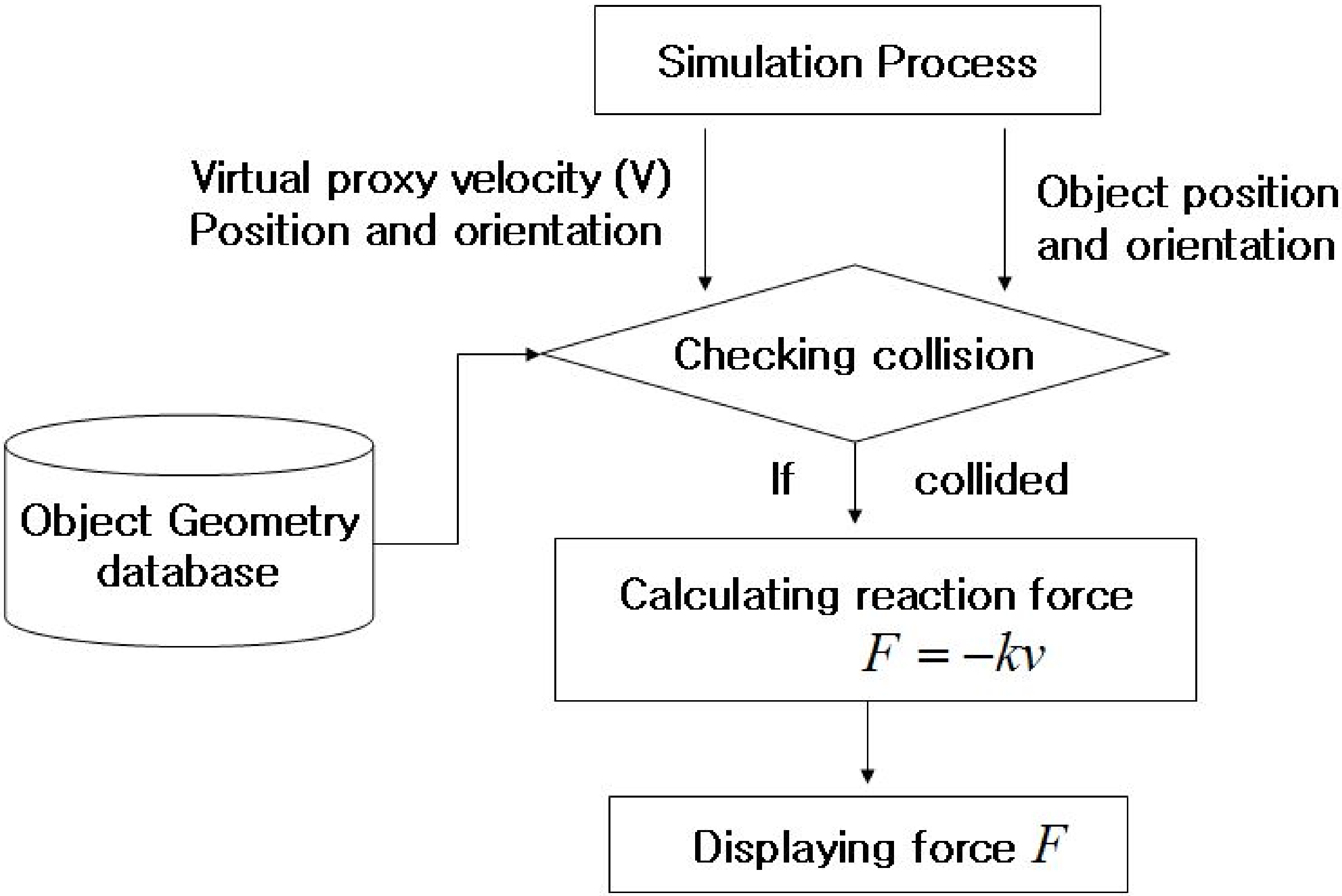
- **Devices (Active)**
  - Robotic
    - Manipulators
    - Exoskeleton
  - Joystick, Mouse, Game Controllers
- **Passive**
  - Everyday objects / props
  - Low cost and metaphoric
  - Limitation:
    - Large force = large mass
    - Clunky
    - Operating range

Parameters to consider

- Amount of force needed
  - 3-4 N for size discrimination, object identification and object detection
- Degrees of freedom
- Operating range
- Sampling rate



Haptic Rendering: ~1000 Hz



Tactile / Cutaneous

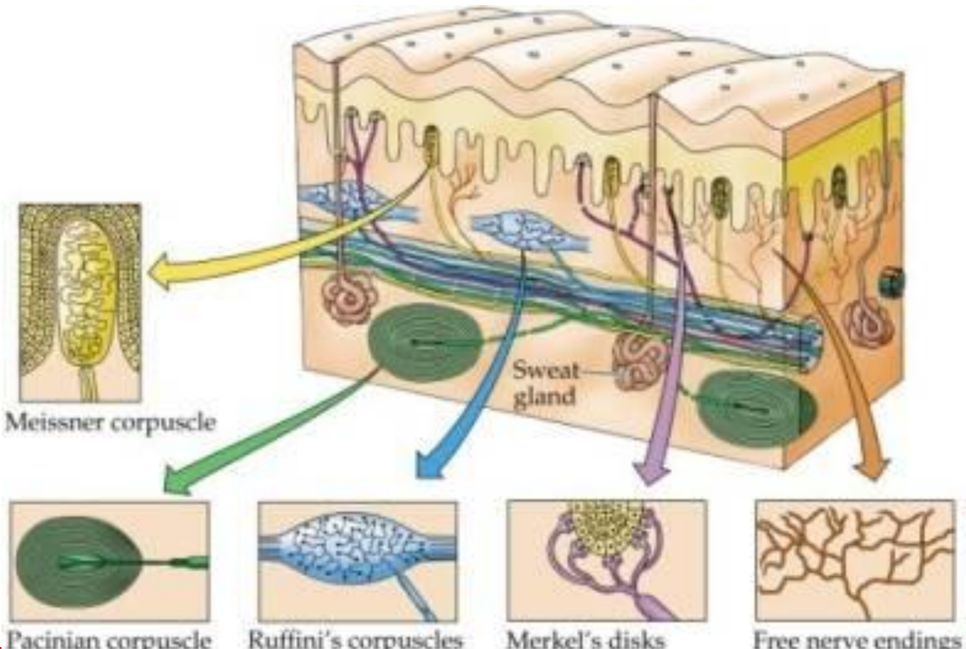
- **텍타일 해상도 – 물리적인 객체에 대한 피부 감각은 인간 몸 부분마다 다르다**
  - HCI 목적으로 빈번히 사용되는 손가락 끝은 가장 민감한 부분 중 하나
  - 손가락 끝은 40 마이크로미터(μm) 크기의 물리적인 객체도 느낄 수 있음

- **진동 – 진동과 같은 빠른 움직임은 대부분 100-300Hz의 시그널을 가진 것으로 알려진 파시니 소체 (Pacinian corpuscle)에 의해 주로 느껴진다. 약 250Hz의 진동 주파수는 편안한 지각을 위한 최적 주파수로 알려져 있다 (Frequency)**

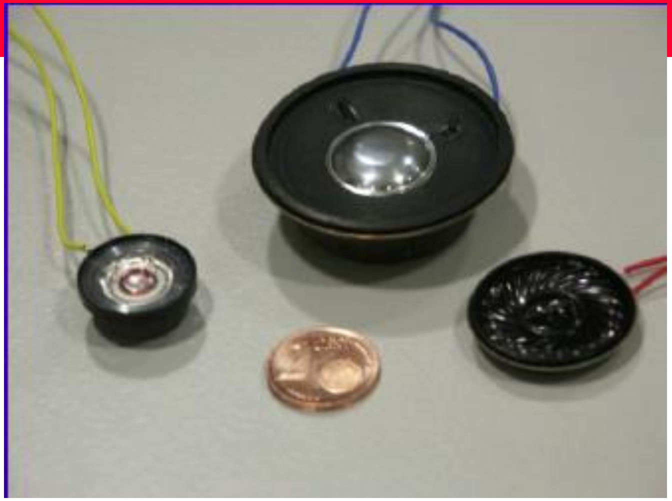
- **압력 – 인간이 감지할 수 있는 가장 가벼운 정도의 압력은 약 1000 N/m²라고 알려져 있다. 이 정도는 손가락 끝 부분의 약 0.02 N 정도이다. 최대 임계치는 큰 힘에 대해서는 측정하기 어렵고, 운동감각은 최대 임계치가 느껴지는 동안 시작된다 (Amplitude)**

Tactile / Cutaneous

- **물리적인 텍타일 감각은 피부 세포들과 자극의 특정 타입들을 위해 구성된 신경들의 조합으로 느낌**
  - 약간의 압력이나 천천히 누르는 것에 대한 마이스너 소체 (Meissner’s corpuscle)
  - 흔들림에 대한 메르켈 수용기 (Merckle receptor)
  - 더 빠른 진동 자극에 대한 파시니 소체 (Pacinian corpuscle)
  - 그리고 피부 이완을 위한 루피니 원통(Ruffini cylinder)



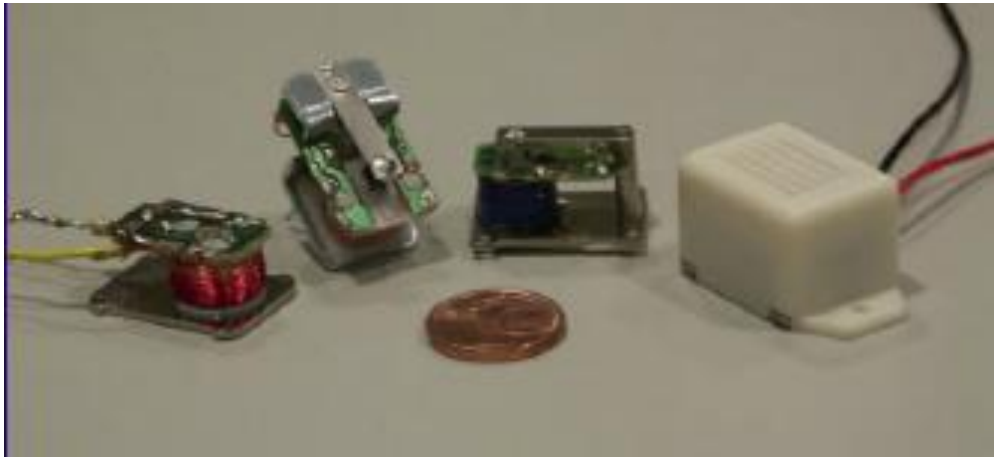
Actuators



- **Miniature Loudspeakers**
  - come in various sizes
  - very inexpensive
  - wide range in frequency
  - too big for desired forces and frequency

Actuators

- **Electromagnetic Alarm Buzzers**
  - very inexpensive
  - disturbing magnetic fields
  - limited contact area / low frequency

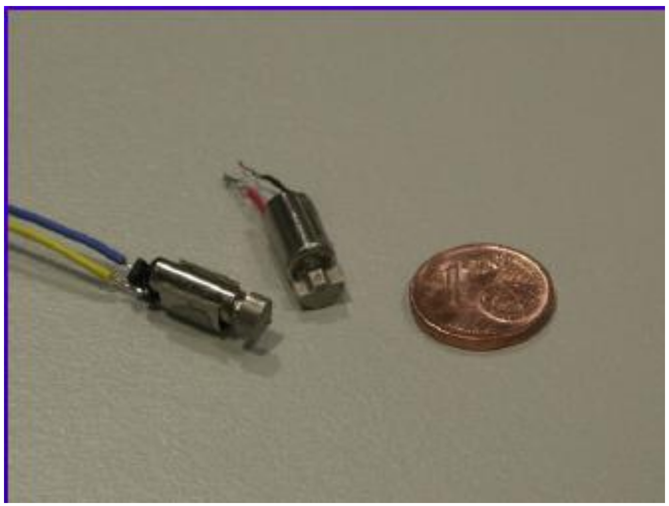


Voice coil 진동자

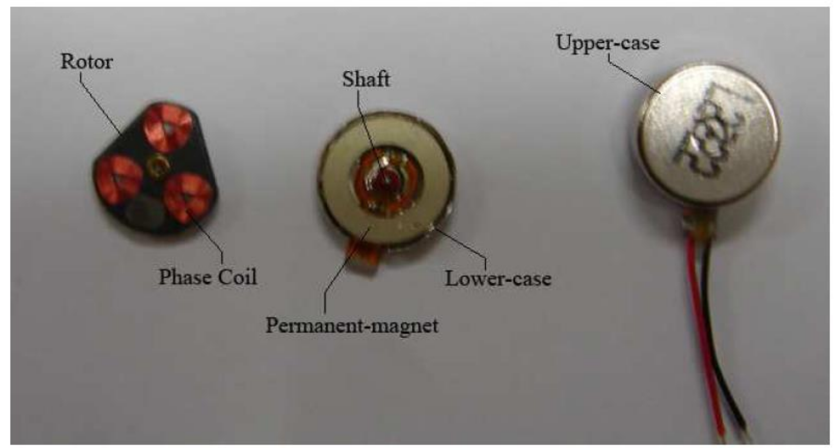
Actuators

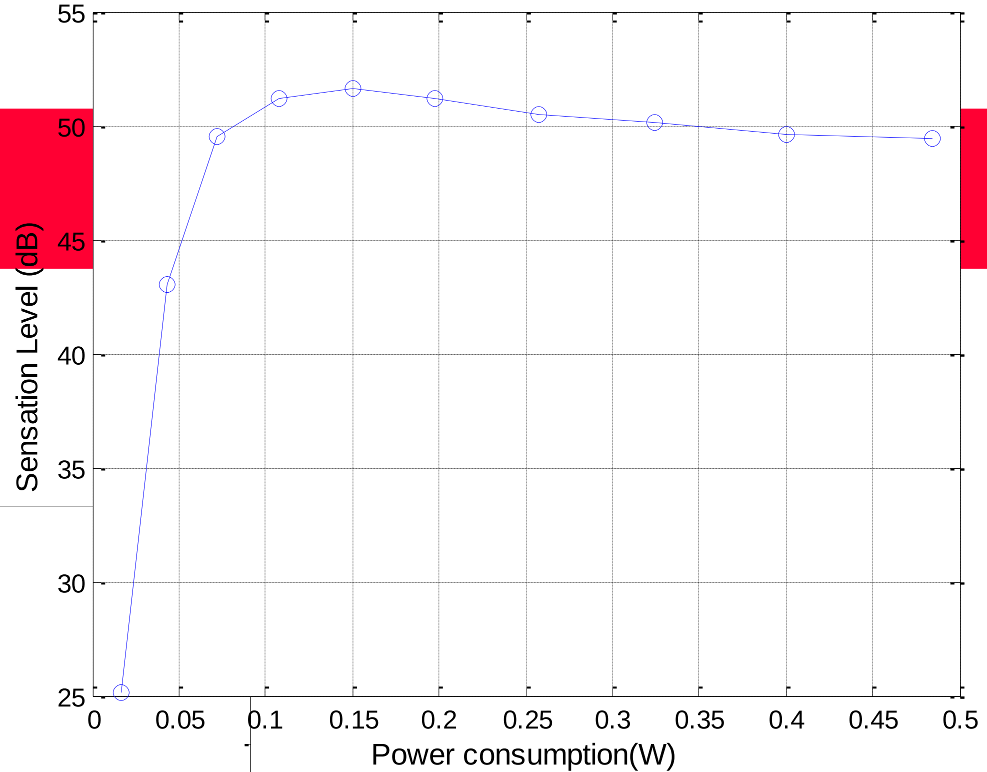
- **Cell phone vibro-motors**
  - inexpensive
  - easy to apply
  - complicated to control (amplitude / frequency coupled)

Micro 모터

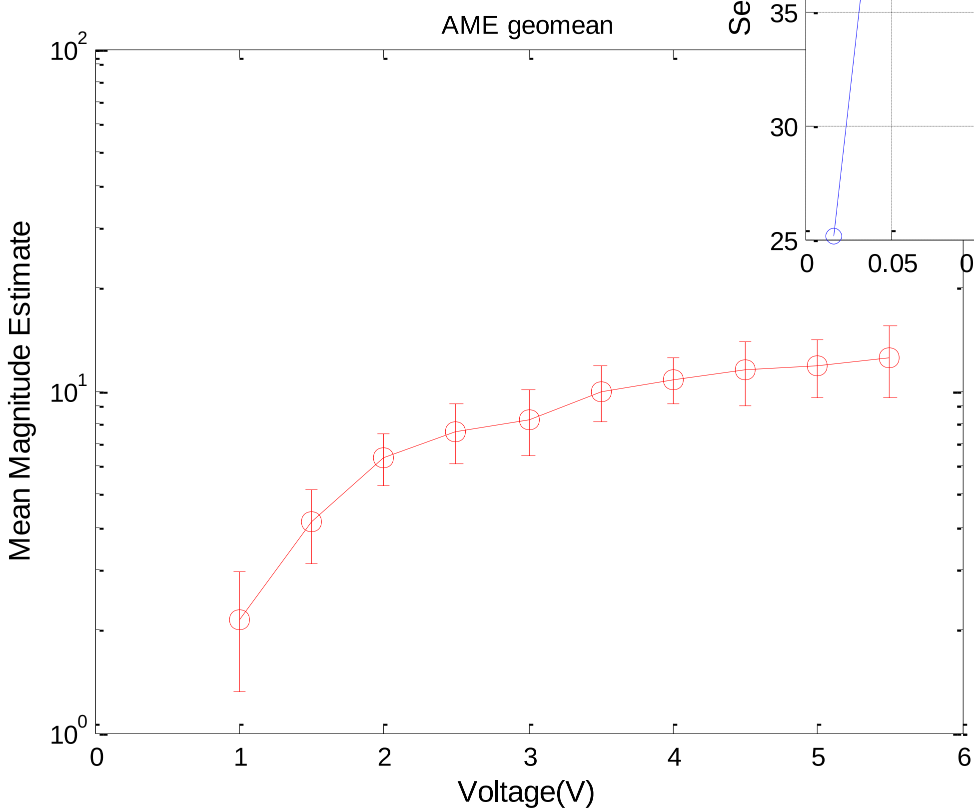


진동모터





Sensation Level (dB)
Power consumption(W)
55
50
45
40
35
30
25
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5



AME geomean
Mean Magnitude Estimate
Voltage(V)
10^2
10^1
10^0
0
1
2
3
4
5
6

Actuators

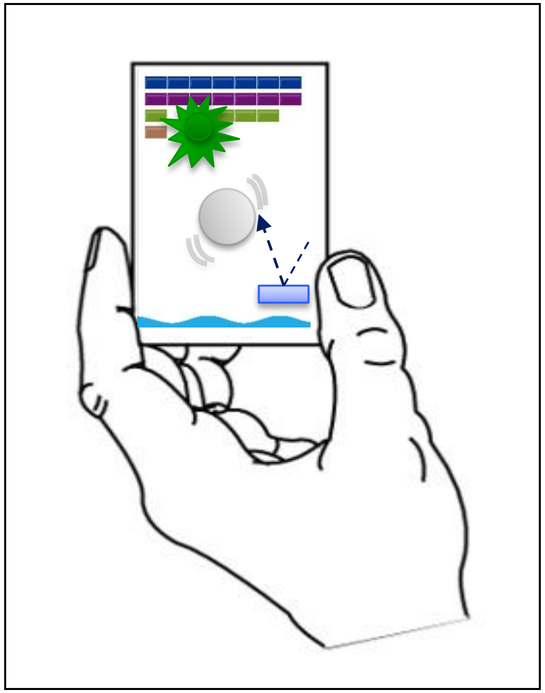
- **Piezoelectric Bending Actuators**
  - no magnetic pollution
  - simple (maintenance free) design
  - flat and small form factor
  - quite expensive
  - fragile
  - limited vibration amplitude
  - Into future touch screens?

Limitations of tactile interaction

High mechanical complexity

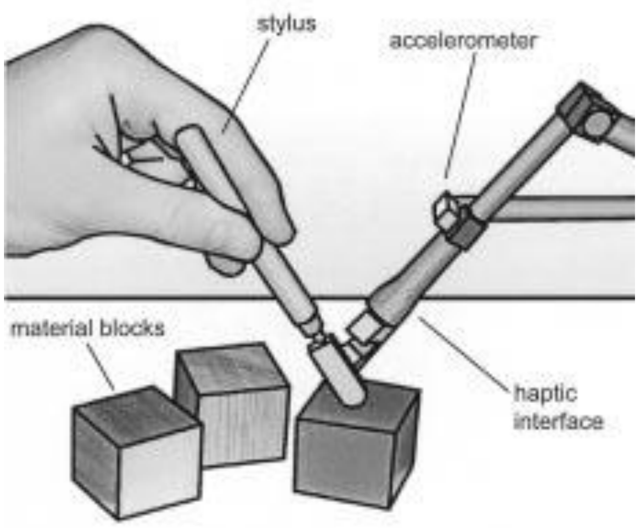
Costly hardware

Unnatural interaction



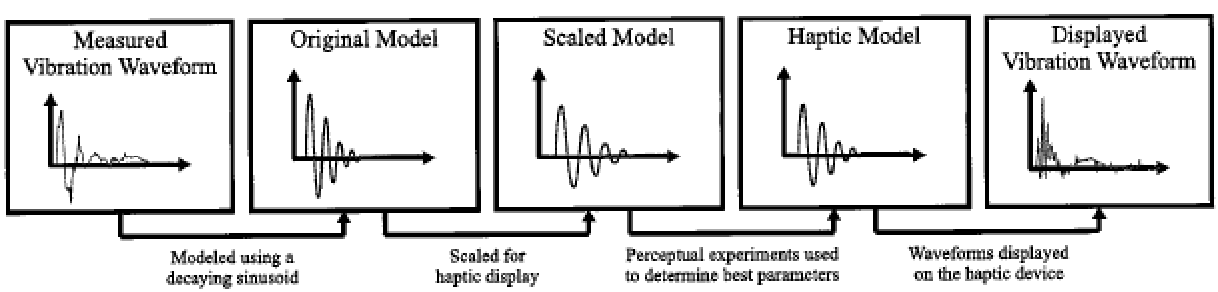
Indirect stimulation / Single vibrator :
Difficult to associate detailed content

More than just on/off:
Allison Okamura (later with Immersion)



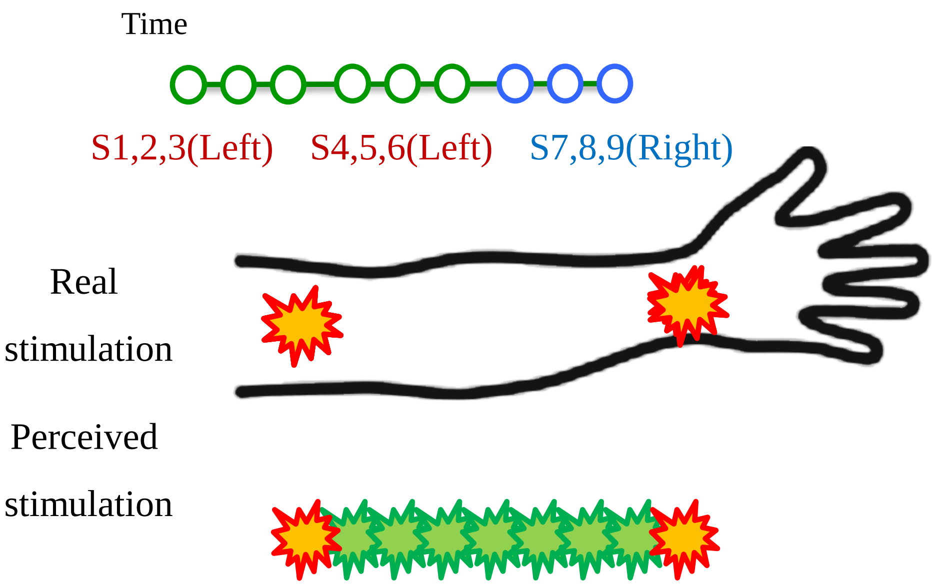
$$Q(t) = A(v)e^{-Bt}\sin(2\pi\omega t).$$

Material	A (s^{-1})	B (s^{-1})	ω (Hz)
Rubber	-240	60,000	30
Wood	-150	80,000	100
Aluminum	-300	90,000	300

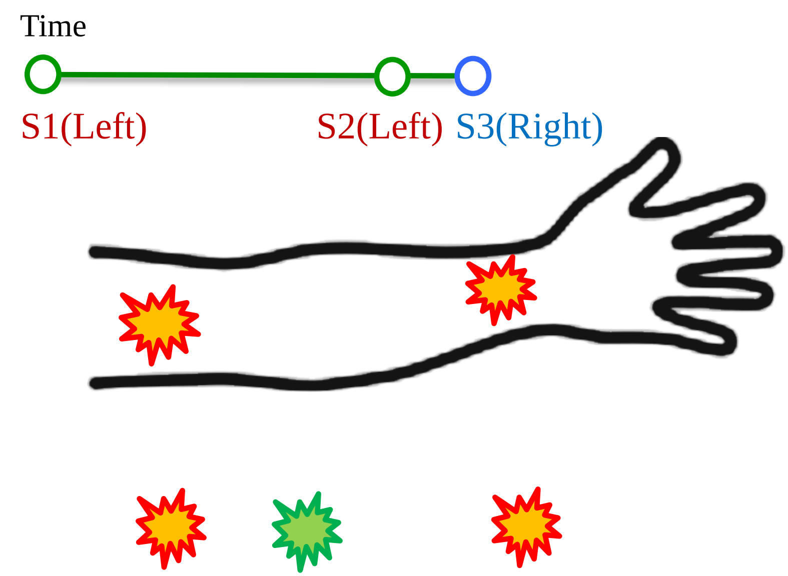


Phantom Sensation: (1) “Saltation”

Inter-stimulus interval (ISI)



The Cutaneous Rabbit: A Perceptual Illusion. *Science*, (Geldard, 1972)



The Cutaneous Rabbit revisited (Flach, 2006)

Phantom Sensation: (2) “Funneling”

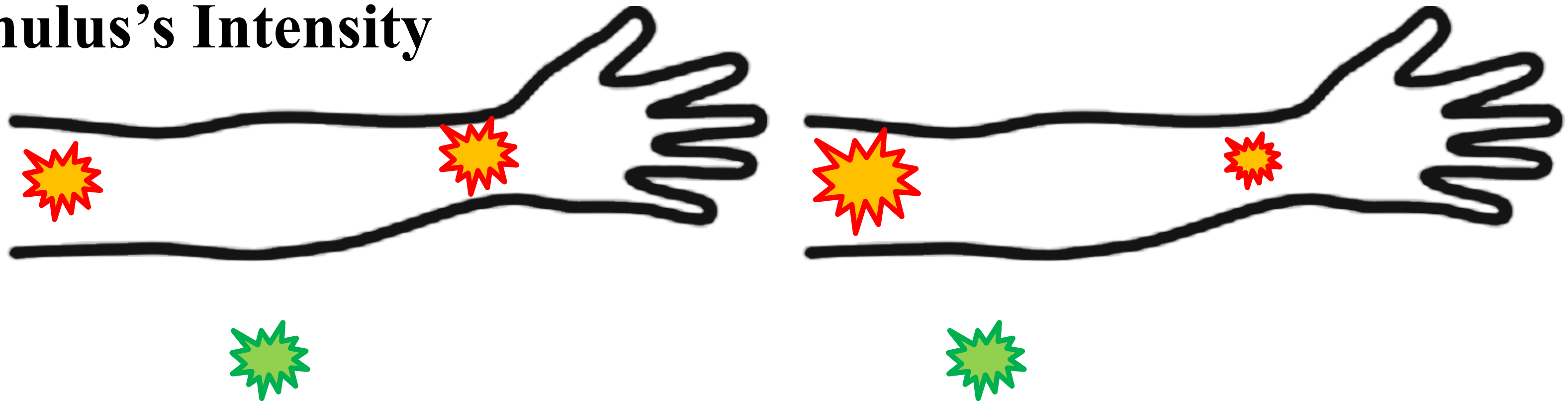
Stimulus’s Intensity

Real

stimulation

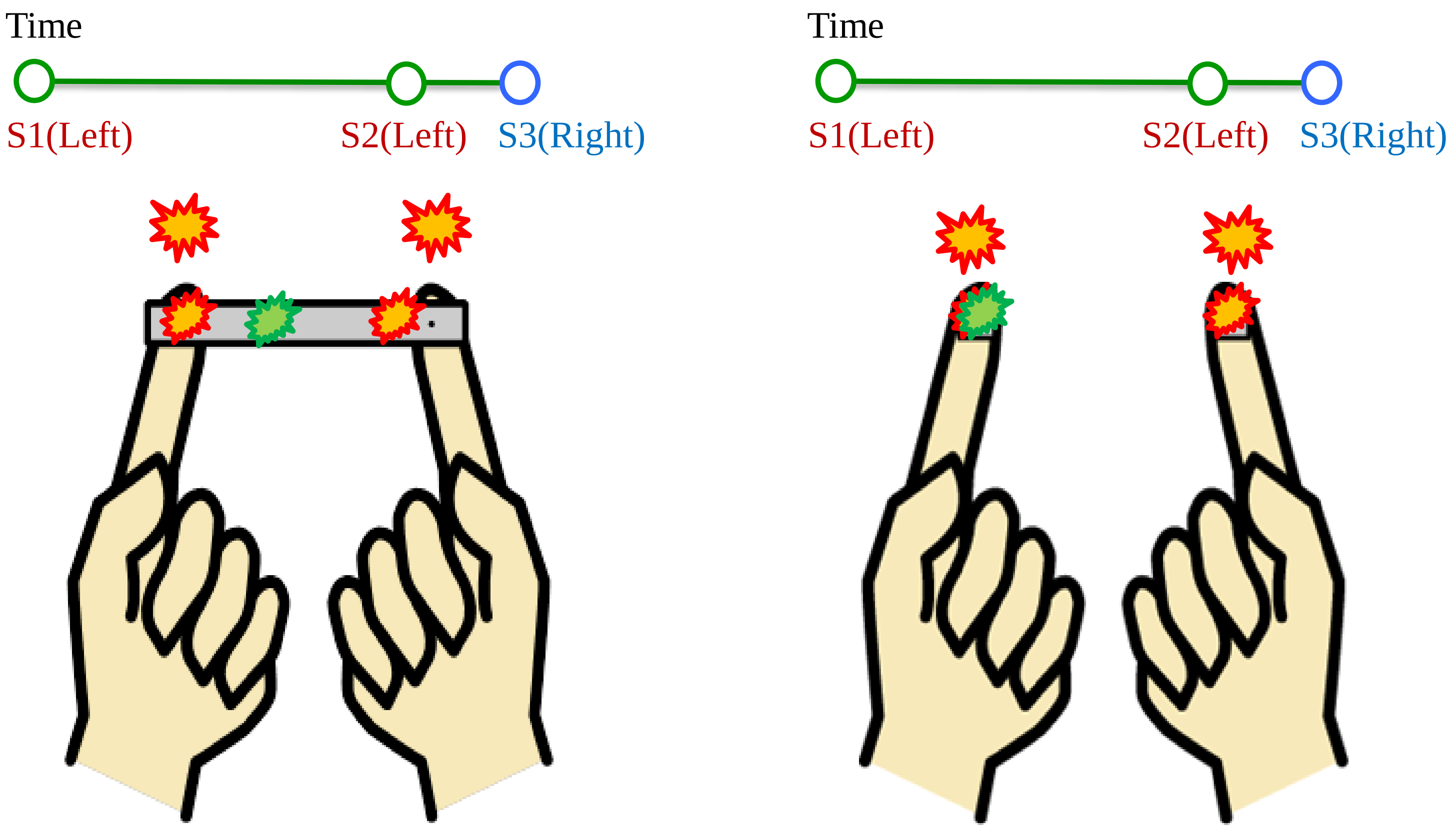
Perceived

stimulation



Information Transmission by Phantom Sensations.
IEEE Transactions on Man-Machine Systems, (Alles, 1970)

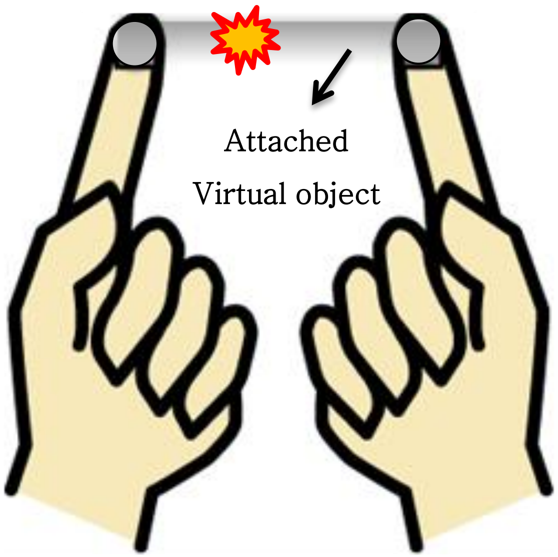
Phantom Sensations from "Out of the Body"



The "Cutaneous Rabbit" Hopping Out of the Body.
The Journal of Neuroscience, (Miyazaki, 2010)

"Out of the Body" experience

- Mediating object
- Interaction object

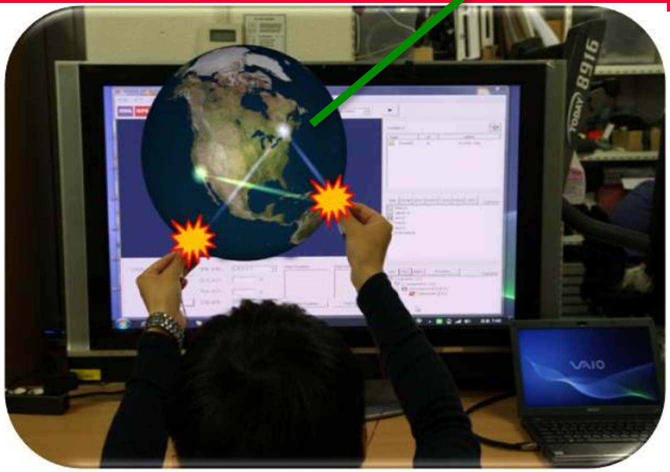


Application Scenarios

(1)

(2)

Stereoscopically rendered object



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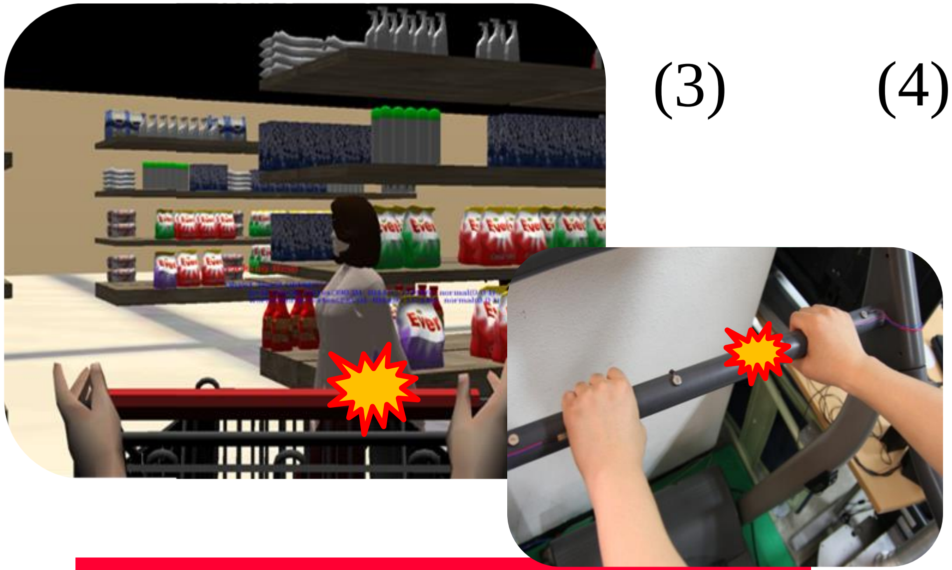
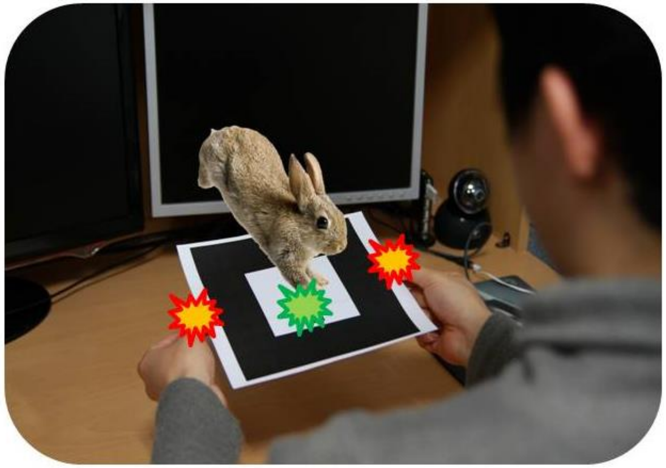
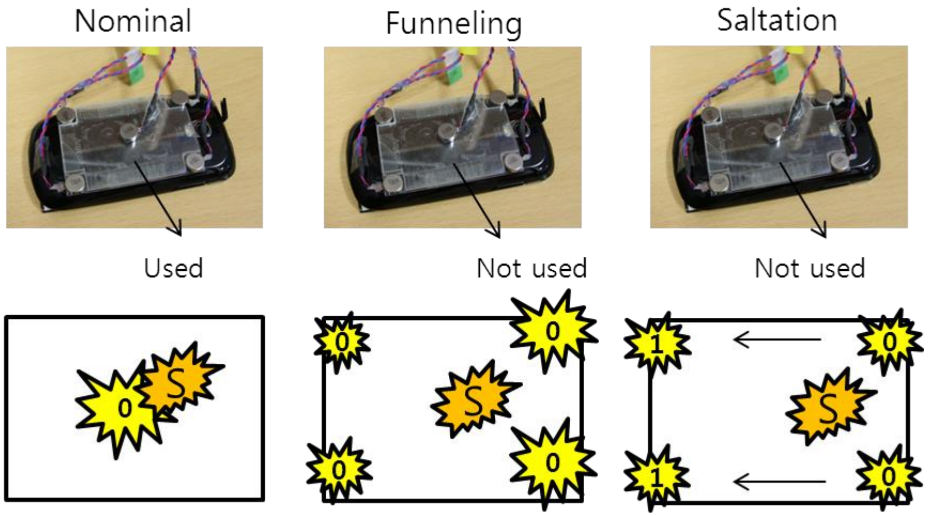


(4)



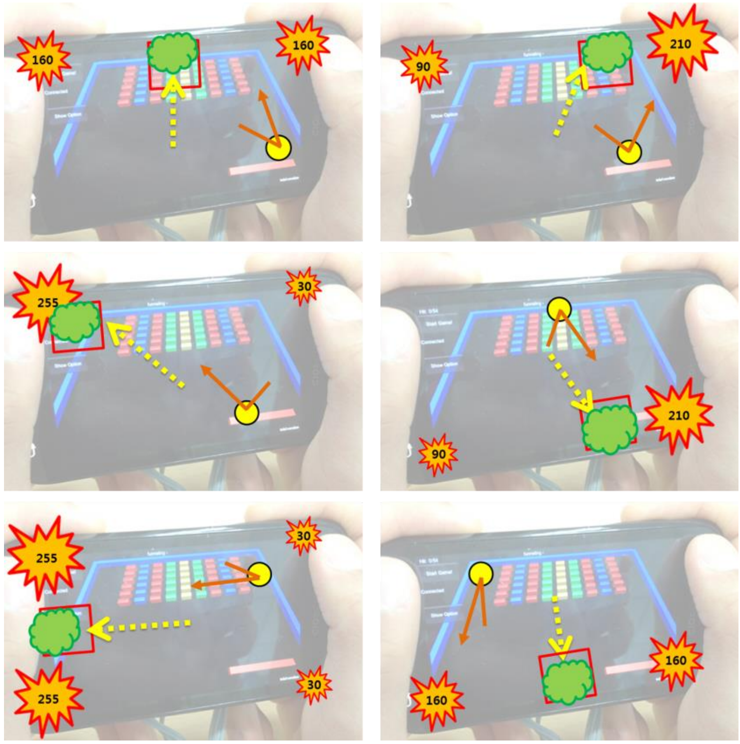
1D → 2D



Stimulation at the middle
Location of sensation not controllable

Simultaneous stimulation at 3 corners
Location of sensation controlled with relative amplitudes

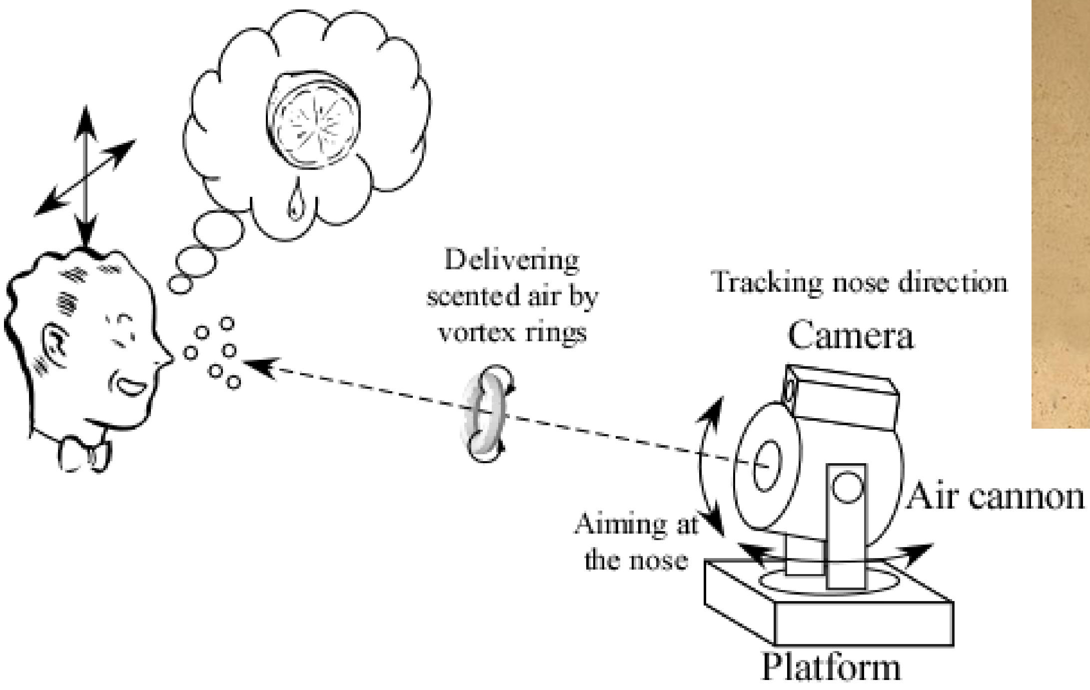
Timed stimulation at 4 corners
Location of sensation controlled with ISI's

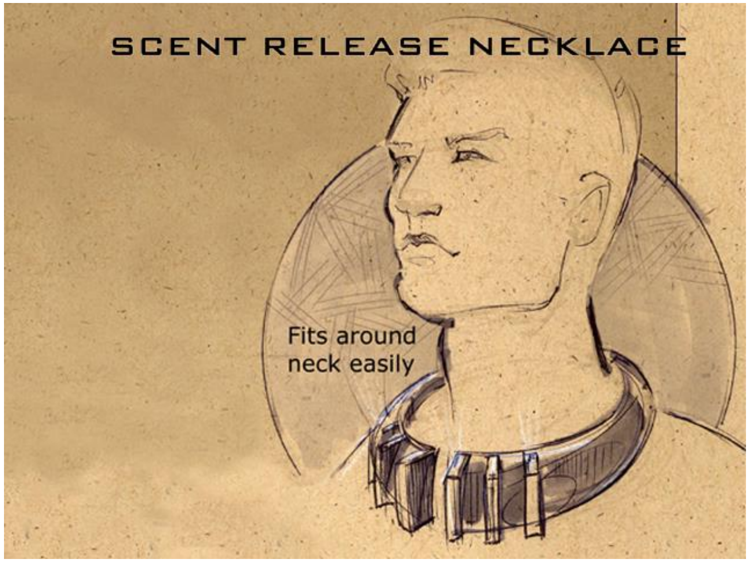


Olfactory


Basic
Dual Color
Retail
Custom
Deluxe
Dual Color
ARD-05
The classic AromaUSB just get better
Refillable AromaUSB in dual color plastic. Preloaded with fragrance and ready to use with pull-to-use protective tape. Good for promotion with custom logo printed.
Custom imprint and color
Individual polybag packed
Fragrance preloaded
Ready to use with pull-to-use protective tape
Fragrance refillable

Olfactory


Delivering scented air by vortex rings
Tracking nose direction
Camera
Air cannon
Aiming at the nose
Platform


SCENT RELEASE NECKLACE
Fits around neck easily

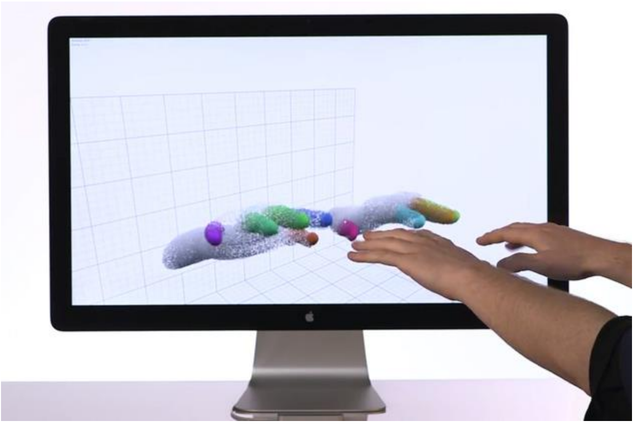
Voice input method

- **독립된 단어 인지 기술**
  - 단순 명령어
  - 화자별 훈련 혹은 비교적 조용한 배경 (환경)을 요구
    - Recognition as high as 95% → Still not used as much … why? (Segmentation problem?)
  - 핸즈프리 인터페이스 (hands-free interface)로 유용 (Telematics)
  - Google voice (Server based)
- **연속 단어 인식**
  - 명령 + 파라미터: "grep –o test.txt" (grep dash o test dot t x t)
  - 문맥에 의한 단어 인식 (Difficult)
- **Natural language understanding**
  - Difficult too much variation
  - Apple SIRI (Server based) / IBM Watson (AI based common sense knowledge)

Gesture input method

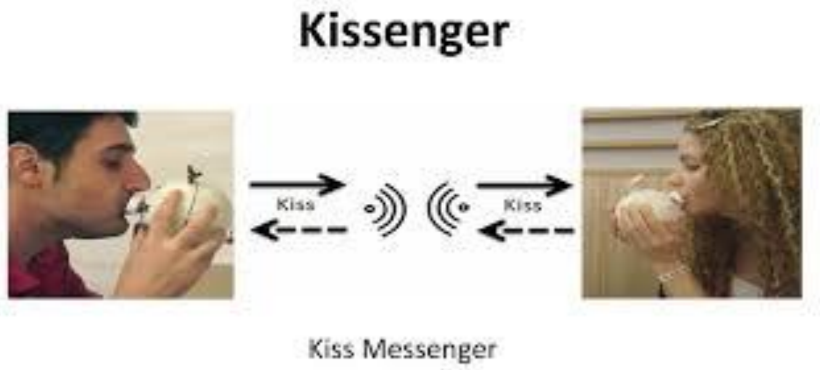
- **Interaction problem**
  - Fatigue
- **Technical challenge**
  - Tracking
    - Depth sensing
  - Segmentation

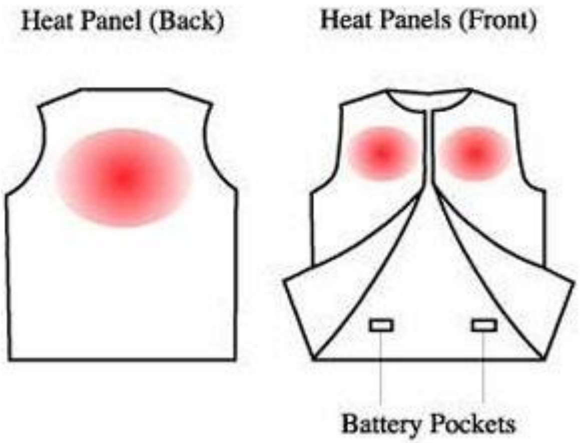
    → Mode



Others: …

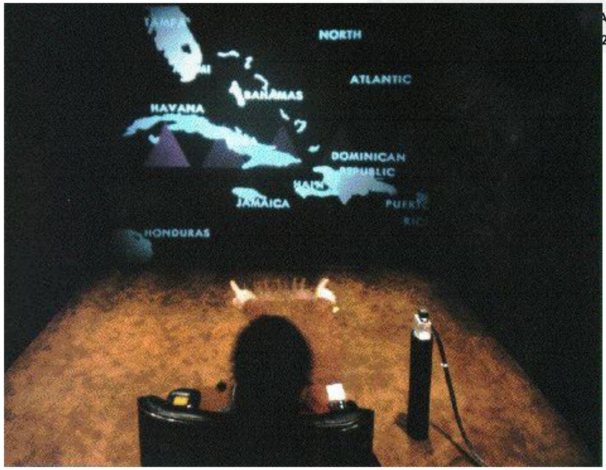
- Facial expression
- Brain waves
- Physiological signals
  (HR, SC, EMG, …)
- Gaze
- 3D
- Taste
- Thermal
- Air/Wind
- Proprioception / Vestibular

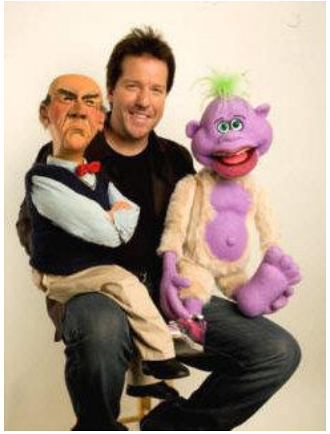




Multimodal integration

- **Devising the right mix for the given task**
- **Tuning to the user**
  - Visual vs. Aural vs. Touch person
- **Synchronization in time**
- **Multimodality for**
  - Redundancy and safety
  - Division of labor
- **Maintaining consistency**
  - Competition theory
- **Cross modal effects**
  - One modality changes the perception of the other (Ventriloquist effect)





Other issues

- **Learning and adaptation**
- **Aesthetics and emotion**
- **Conscious acts vs. reflexive**
  - Attention
  - Awareness
- **Fatigue**
- **Social**
- **Stimulation vs. Perception**