Feeding human senses through Immersion

1. Properties of human senses
2. Sensory stimulation through Immersion
3. Overview of key human sense and their display in VR
4. Conclusion

1. How many human senses ? [TRV 2006]

Example of a tennis player in interaction with his surrounding environment while playing. He is equipped with sensors allowing to perceive:

- Light within 380-750 nm: the ball is seen
- the ball hitting the racket produces mechanical phenomena, including:
  - vibration propagating in air 20Hz-20KHz
  - vibration of the ball hitting the racket induces vibrations propagating within the body and felt by skin and and deep bone sensors
- racket shape, weight, texture, temperature, humidity is felt through skin
- The player movements are sensed by the vestibular system and proprioceptive organs
- heat, humidity, wind speed, sweat are felt by the skin and internal thermic regulators
- sweat odor is smelt by the nose and tasted by the tongue

The tennis player example [Chap2 in TRV2006]

Why is our culture ignoring so many senses ?

What is the property that links the 5 senses [DV2017] ?

The sensory stimuli reaches our body from its *external* side:

- Eyes
- Nose
- Ears
- Tongue
- Skin (i.e. *touching* : *acquiring properties about external touched objects*)

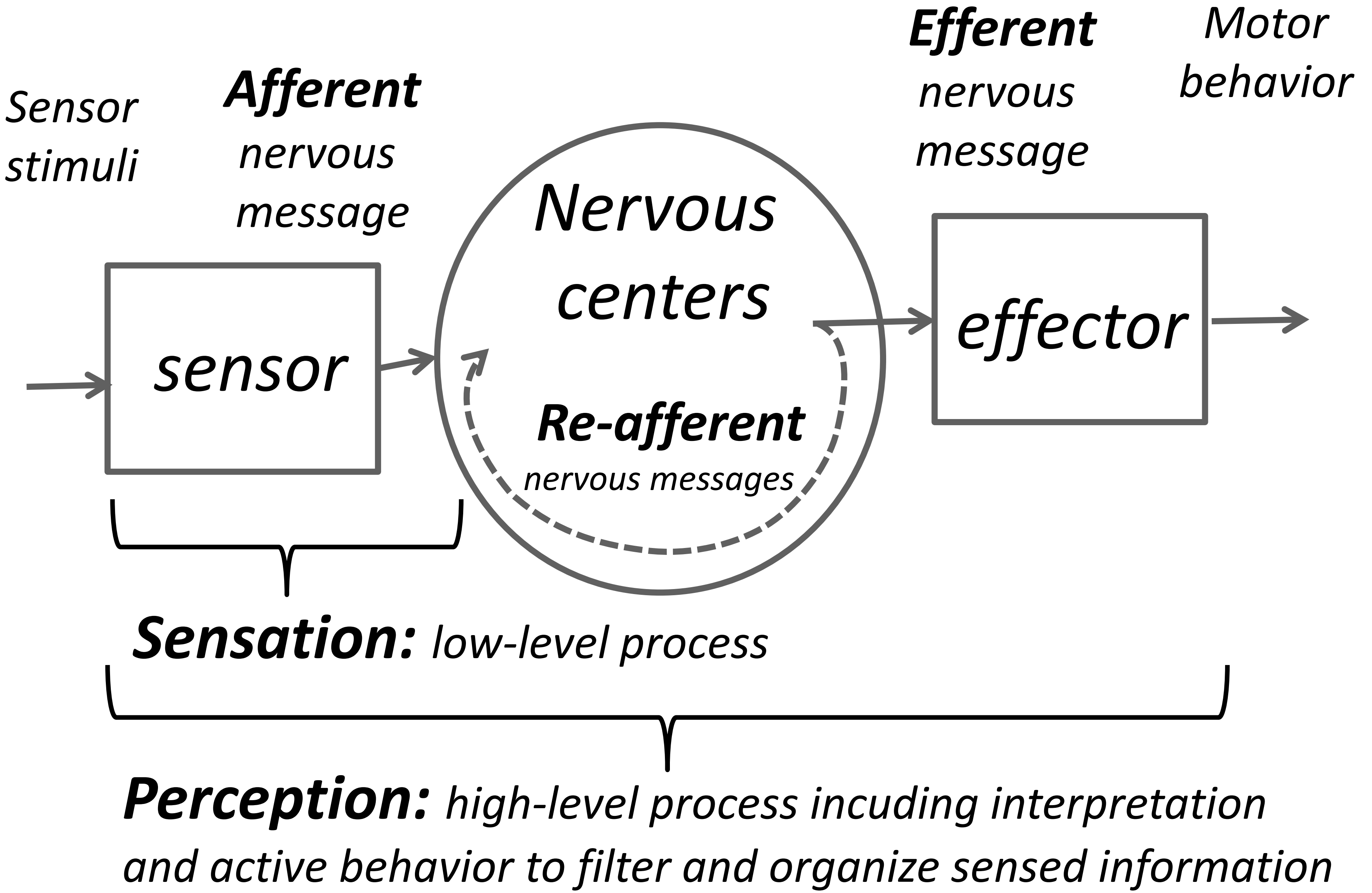
They provide information about the world around and including us

The other senses are felt within the *internal* side of the body:

- Posture
- Movement
- Force/Torque/Pressure/Skin *being touched*
- Balance
- Temperature
- Pain
- Etc…

They provide information <u>only</u> about <u>our</u> own body state

1.1 Terminology



1.2 Sensor stimulation

All stimulated sensors above a minimum threshold lead to the formation of **action potentials** (amplitude of a few tens of mV and a duration of 1 to 2 ms) transmitted at a speed from 1 to 100 m/s through the nerves.

- it takes **10 ms** to travel **1m** at the max speed of **100 m/s**
- strategic organs for survival have to be near the brain for fast closed loop control (e.g. eye movement)
- or there must be some intermediate autonomous control mechanism (e.g. low-level locomotion control at the spine level)

A stimulation must have a minimum duration to be sensed (~human sensing system acts as a lowpass filter)

Conversely, if the stimulation is maintained a long time the sensation disappears or is reduced (except for pain and some special case).

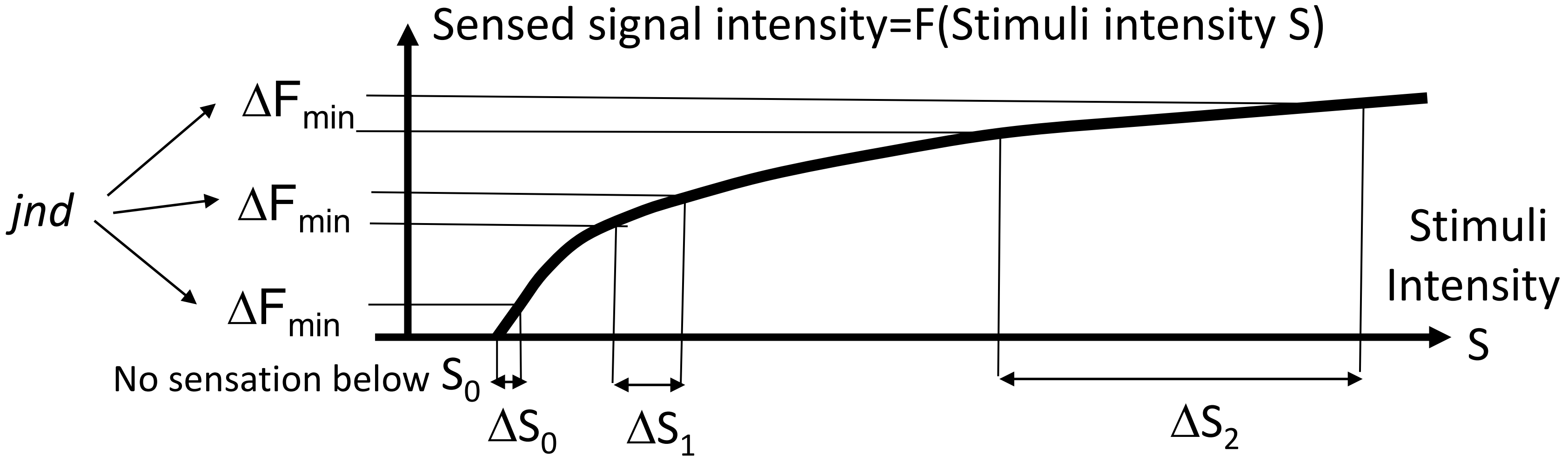
1.3 Sensor stimulation : Weber-Fechner law

The *just noticeable difference*, noted *jnd*, is the smallest variation ΔF_{min} of the sensed signal F that the human sensory system can produce.

Given a physical stimuli intensity S, Weber & Fechner observed that the requested physical stimuli variation ΔS to produce a just noticeable difference ΔF_{min}, is *proportional* to the physical stimuli intensity S *:*

$\Delta S = k.\Delta F_{min}.S$ so $\Delta F/\Delta S = k'.1/S$ *(= sensitivity decreases as S increases)*

The Weber-Fechner law is logarithmic : $F(S) = K.\mathbf{ln}(S) + Cte$



1.4 Sensor sensitivity

Absolute precision is low compared to the relative precision; human being has a great capacity of comparing two stimuli

Example:

- difficult to define an isolated color, easy to compare two nuances
- difficult to define absolute depth, easier to define the relative depth of two objects
- temperature, etc…

Sensors also have a maximum perceptible variation frequency (bandwitdh)

2. Sensory stimulation through Immersion

The quality of a VR experience depends on the quality of the sensory stimuli ***synthetized/displayed*** through **immersive techniques**.

Immersion: is the **objective** level of fidelity of the sensory stimuli produced by a technological system [S2003] => technical features.

- Measurable and controllable as it depends only on **technology**

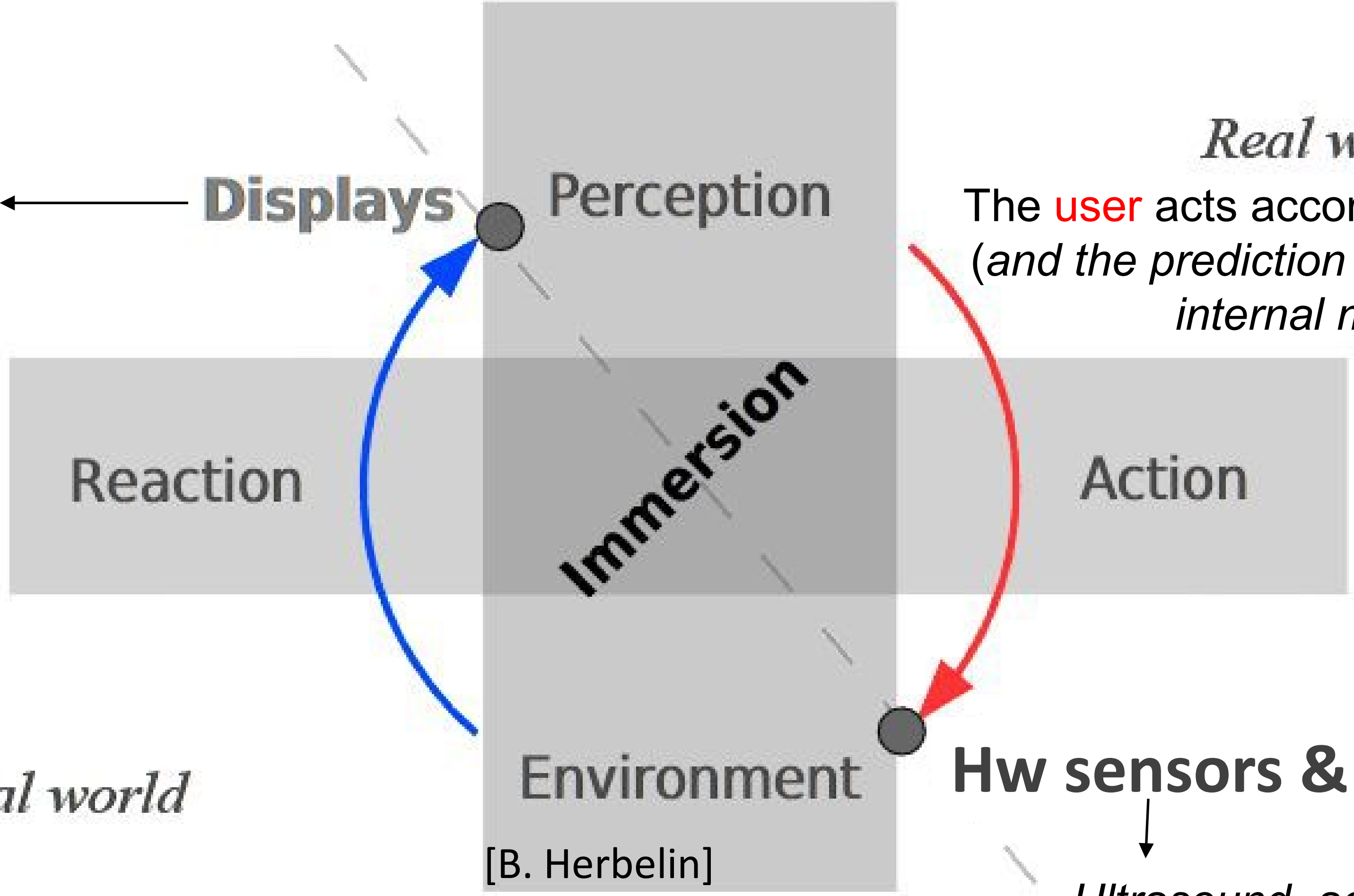
- Different systems can be compared

- in academic VR, the word «immersion» has nothing to do with involvement, enjoyment, etc… which are subjective feelings

[B2007] Bowman, D., McMahan, P.: Virtual Reality: How Much Immersion Is Enough? Computer, 40(7), 36--43 (2007), & Course notes from D. Bowman / Immersion & Presence

2.1 Immersion is achieved with technical systems

Visual
Audio
Haptic



Real world

The user acts according to perception (*and the prediction made through the internal models*).

Virtual world

Hw sensors & interaction devices

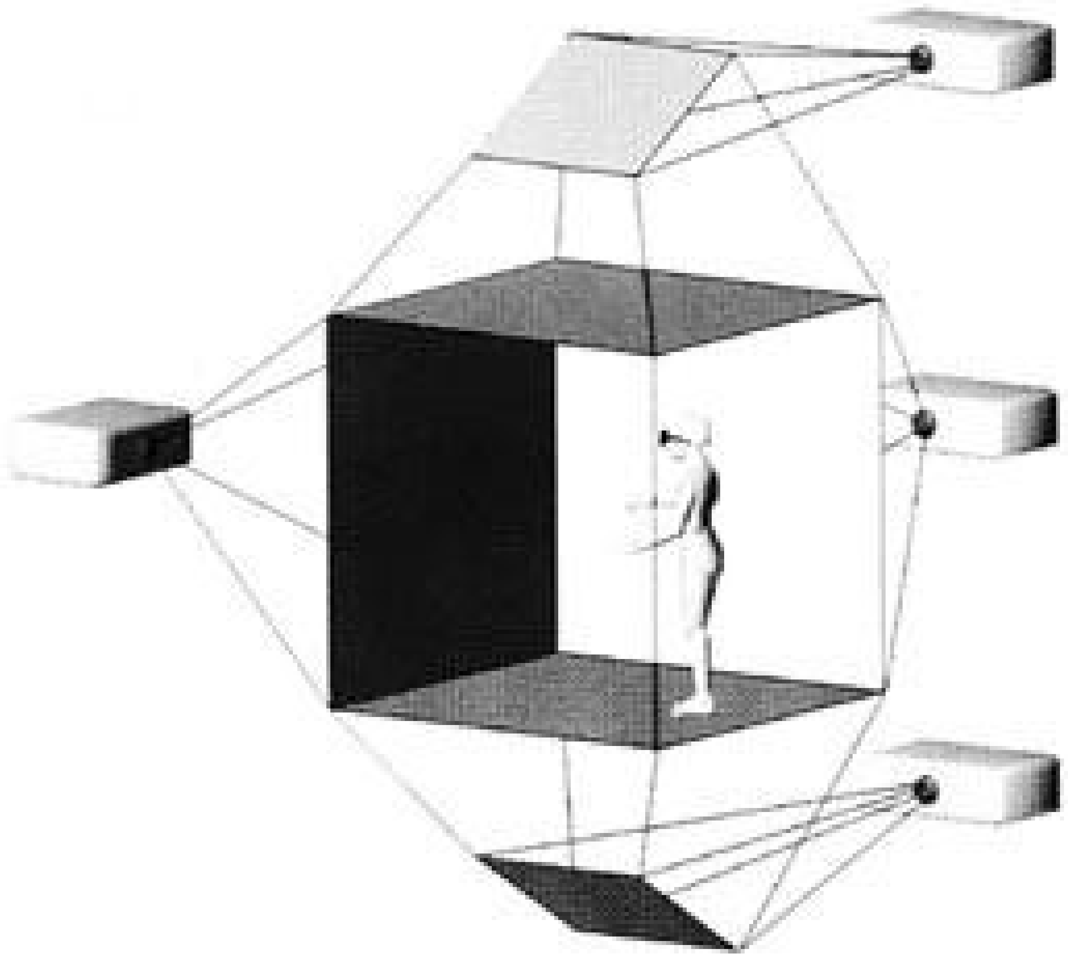
Ultrasound, accelerometers, magnetic or optical trackers, often integrated in data suits

2.2 More on displays

- Surrounding the user senses
– wearable or human scale

- Covering fully the senses
– stereoscopy, spacial sound,..

- Covering every senses
– vision
– hearing
– force feedback (robotic arm)
– touch (vibrating devices, braille-like)
- others



A fully immersive visual display : the CAVE

3. Overview of key human sense and their display in VR

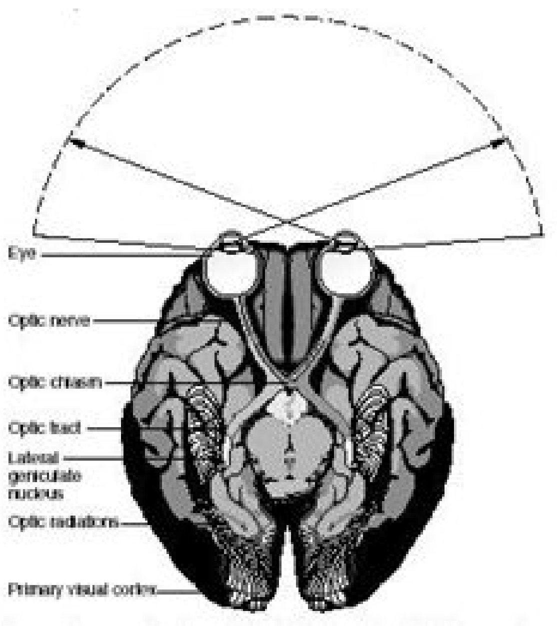
3.1 Vision
3.2 Audition
3.3 Skin and kinesthetic sensors
3.4 Balance
3.5 Taste & smell

3.1 Vision

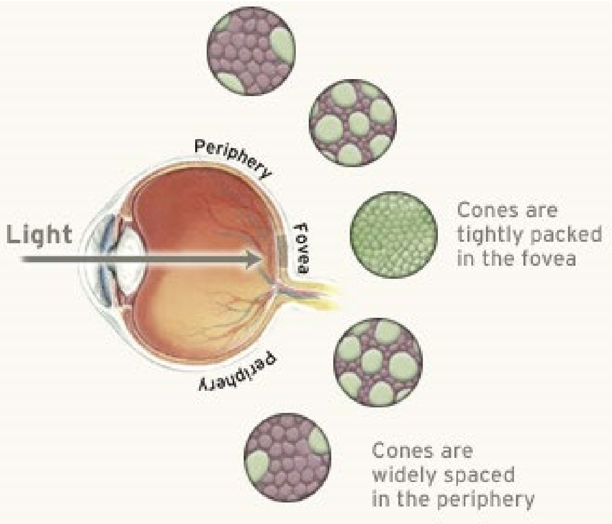
Field of view
Horizontally:
90-100° on head side, 50-60° on nose side

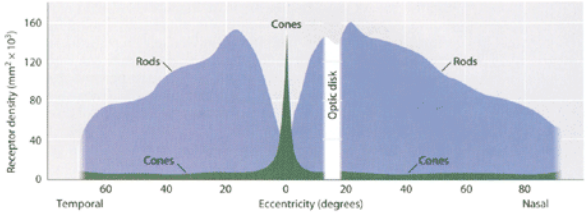
Vertically:
45-60° above, 70-75° below

Eye movement: ~+/- 45° Horiz. & Vert.
Eye coordination for depth perception



The *visual acuity* is highly precise and
color sensitive (with cones) for the **fovea** region=1mm diameter





Fovea resolution:

1% of retina, 2-3° visual cone

drop of cone photoreceptors density from center:
center: ~160'000 photoreceptors / mm^2
0.5 mm: ~100'000 photoreceptors / mm^2
4 mm: < 10'000 photoreceptors / mm^2

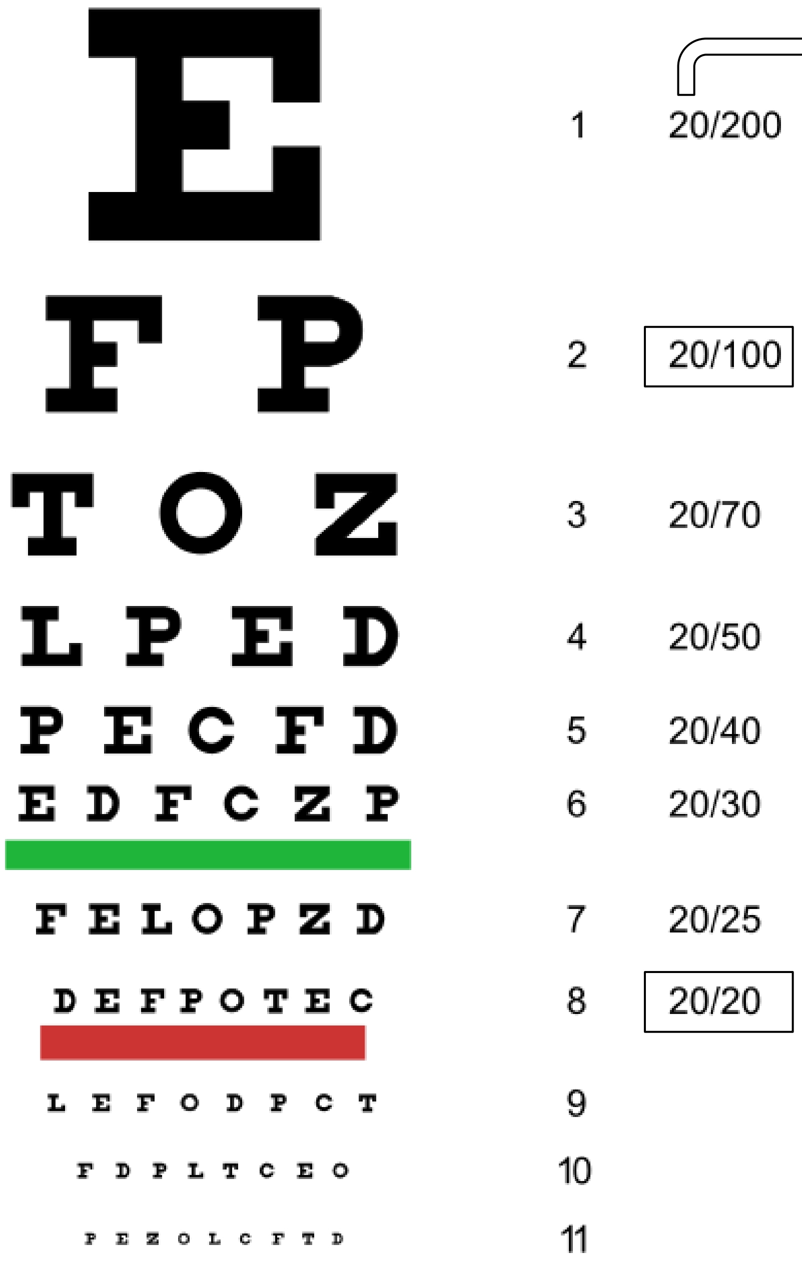
~6 millions cone vs 125 millions rods (light & movement)

Visual accuity

At **20 feet** ≈ **6 metres**, a typical human eye with normal vision can separate **1 arc min** (= 1/60 of a degree)

⇔ can resolve lines with a spacing of about **1.75 mm**.

Normal vision (separating 1 arc minute) corresponds to a *pixel density* of **290–350 pixels per inch (PPI)** for a display on a device held **25 to 30 cm** from the eye



distance in feet betwen the subject and the chart: 20 feet ≈ 6 m

You need to stand at 20 feet away for something that can be seen at 100 feet in normal vision

Vision considered normal at 20 feet distance (= 6/6)

Snellen chart from https://en.wikipedia.org/wiki/Visual_acuity

Visual saccades

Due to the small size of the high-resolution fovea region, the eyes keep making movements called **saccades** to explore the field of view:

- Around 3 saccades per second
- Max speed: 600-900°/s

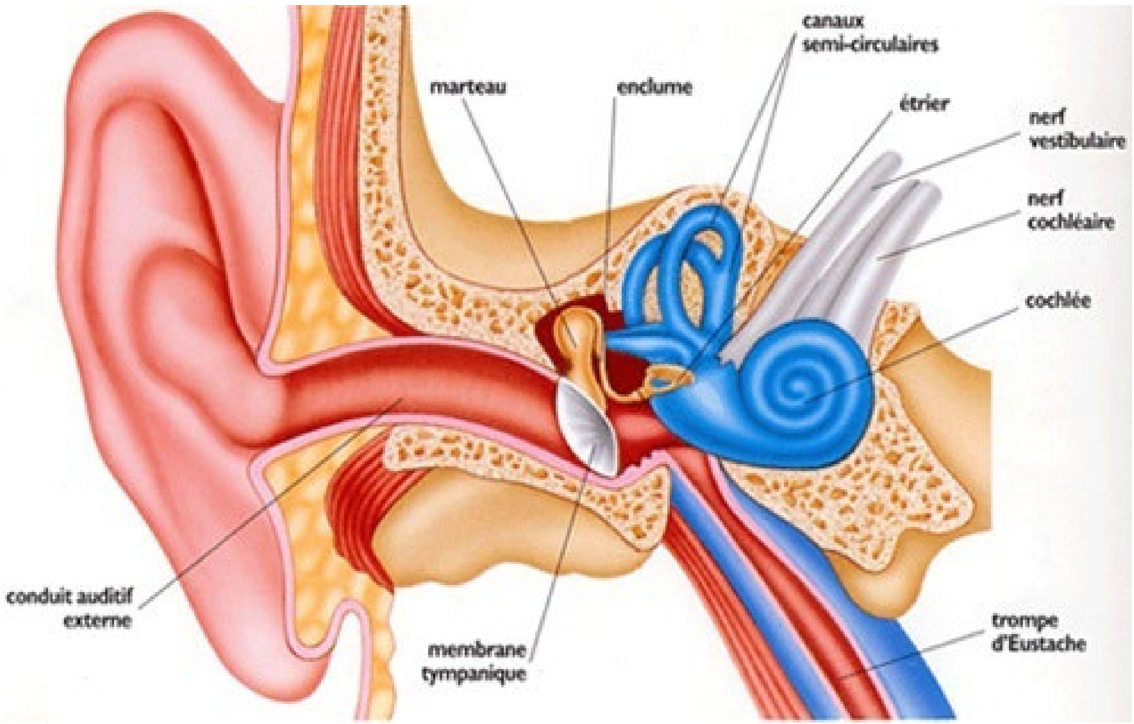
- each saccade lasts 20 to 200 ms
- each **fixation** lasts 100 to 500 ms

- the brain filters out the signal (=we are blind) during the movement between two temporary static locations (fixations). It has been used in various applications [Qi18]

Saccades are unvoluntary movements, i.e. not under direct conscious motor control

- *Stereovision/Depth perception is presented in the next hour.*
- *Immersive solutions (Head-Mounted Display) are detailed in the VR system course*

3.2 Audition



20Hz-20 Khz

A minimum duration is necessary

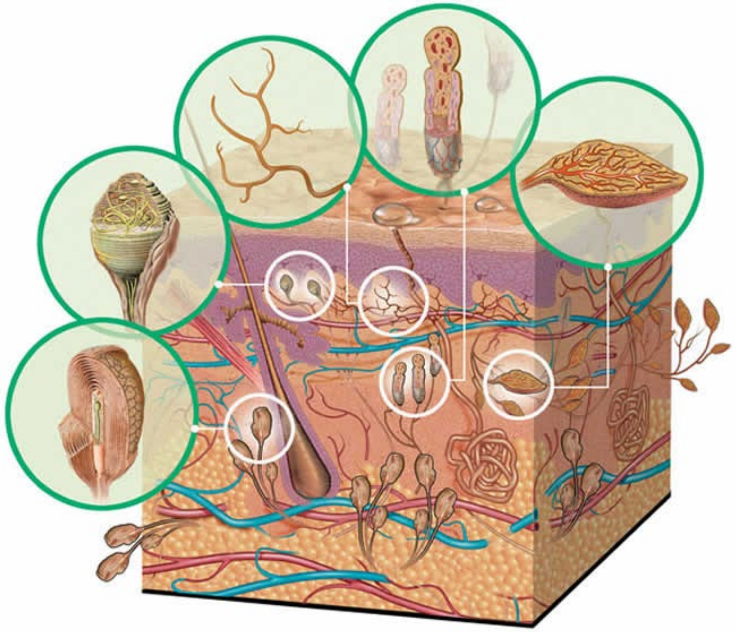
Masking effect of the first arrived sound over a different source.

High sensitivity of spatial sound perception: 1° in front (15°laterally) but low accuracity of distance perception.

Sensitivity to reverberation improves in blind persons

3D sound rendering is available in UNITY3D
=> important for coherent 3D spatial awareness and for conveying emotions.

3.3 Skin, Kinesthetic sensors, extero/interoception



Nociceptors: sense pain

Thermosensors: 2 types
-Sensation of cold
-Sensation of heat
Very specific distributions on the skin

Mechanical sensors :
Highly variable density, e.g. high density on finger tips (2500/cm^2)

Proprioceptive deep sensors: movements & muscle, tendons, joint tension (**kinesthetic sensors**)

Exteroceptive sensors: **tactile** with different time responses

Interoceptive sensors: stimuli from inside the body (pain, internal organs such as heart, lungs, digestion, etc..)

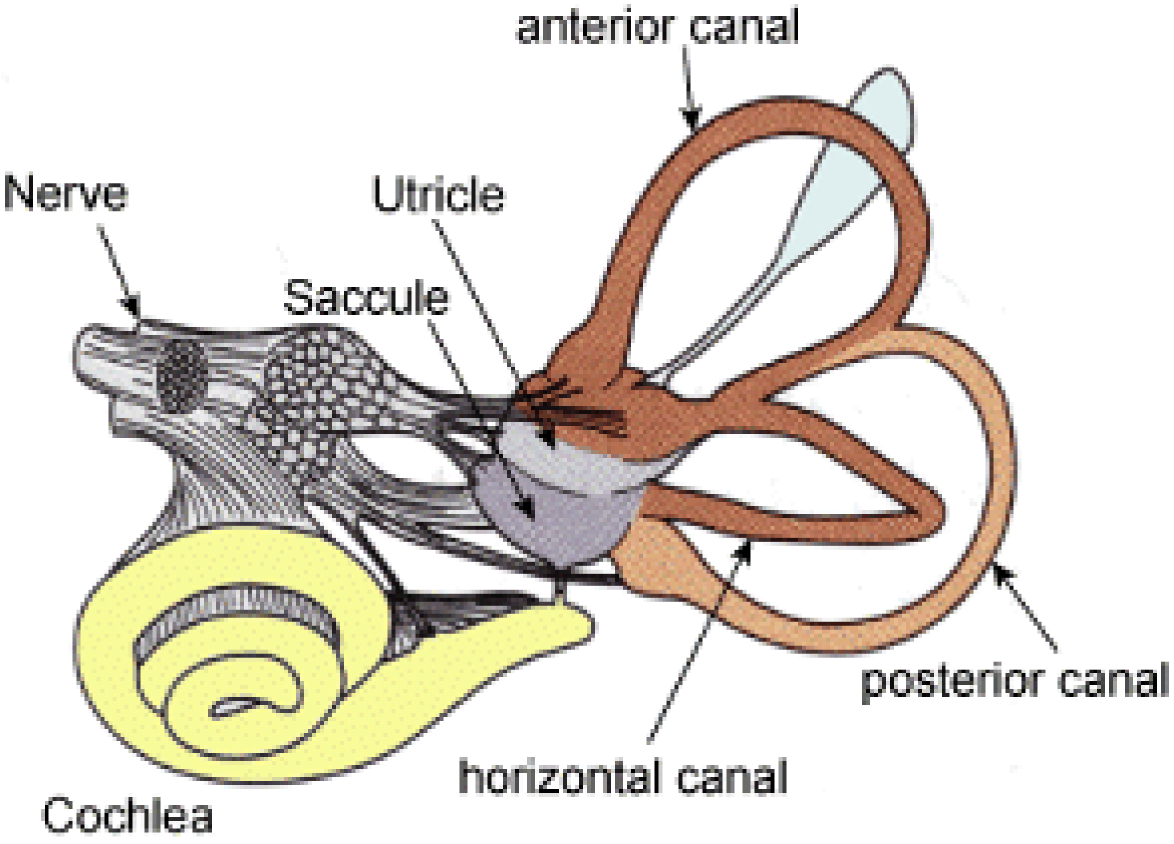
3.4 Vestibular system / the sense of balance

-**Three semicircular canal:** for sensing angular acceleration and angular velocity

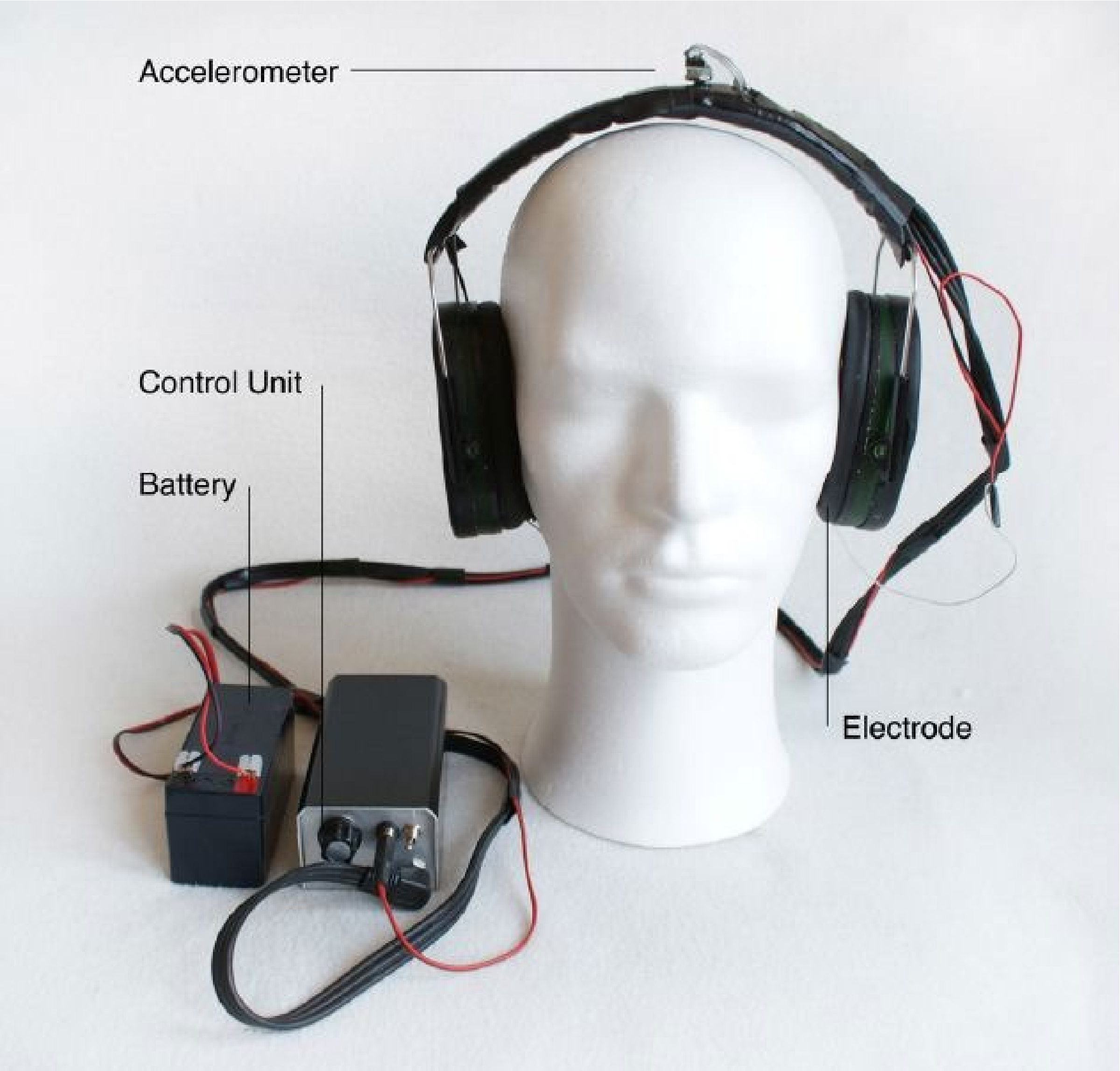
- **two otholitic organs (utricule):** for sensing linear acceleration

-> Important to sense the vertical direction of gravity

-Note: the vestibular system is very difficult to trick (either prototypes or expensive devices), making the rendering of acceleration or lack of gravity nearly impossible.



- Galvanic Vestibular Stimulation (prototype from NTT 2011)



“a helmet conducts a low voltage electrical current (eg, painless) into the balance guiding region inside the ear; which causes the head to tilt to the side of the head where electricity is applied.”

https://www.youtube.com/watch?v=B2uXNx8UBZs

[NTT2011]

3.5 Other sensors : smell & taste

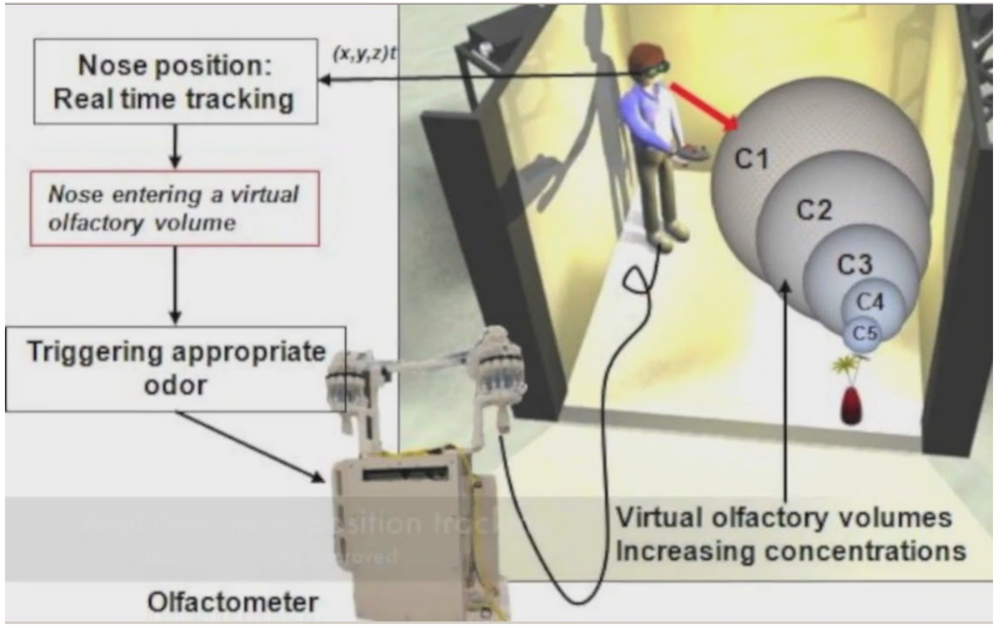
Specialized chemical sensors

Olfaction is not much exploited in daily activities but its importance should not be underestimated

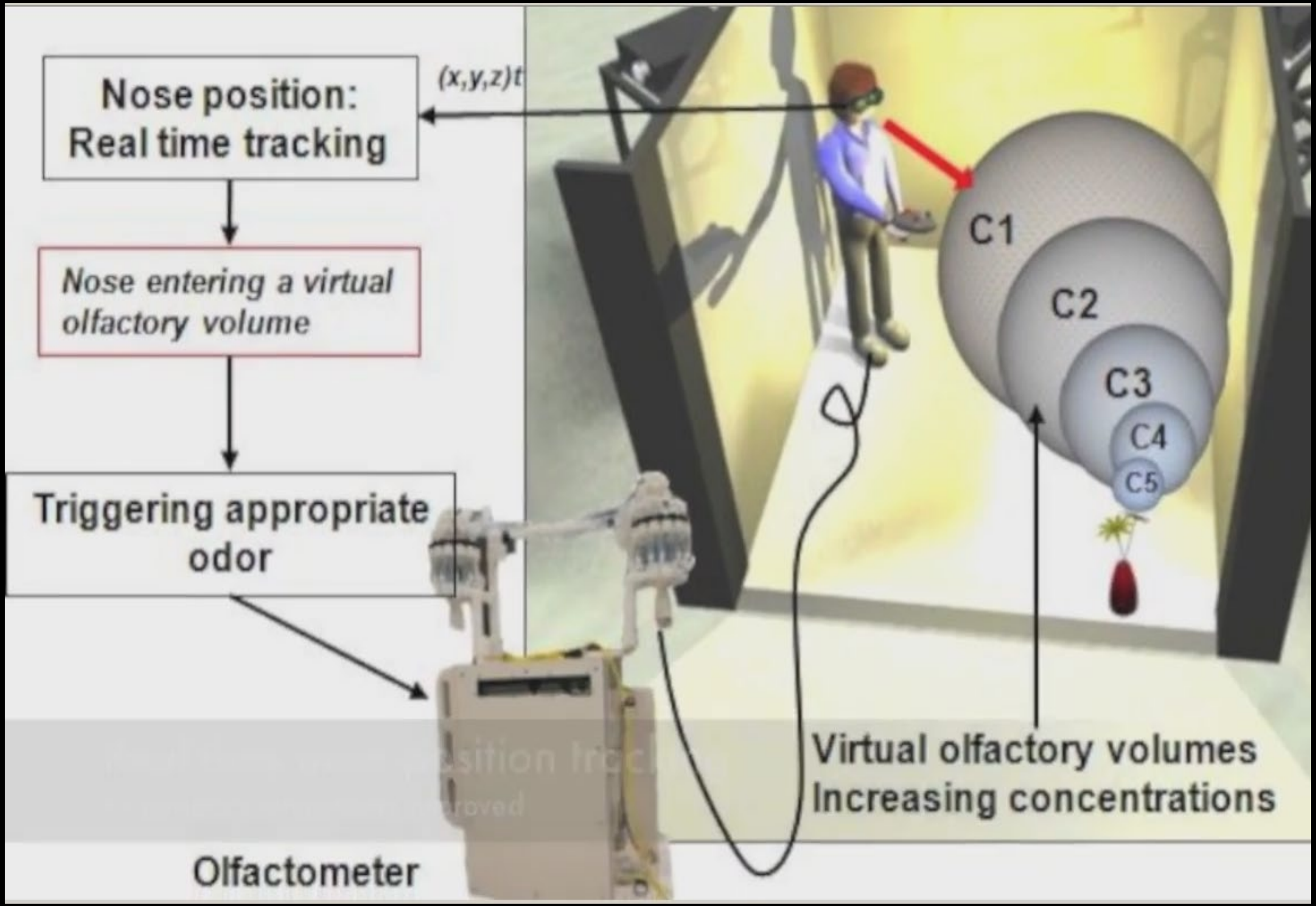
Odors & taste are associated with affective valence (good vs bad)

Seldom exploited in VR.
Some commercial solution exist for scents in high-end cinema theater
e.g. 4DX auditorium

<u>academic VR exemple</u>:
Olfaction in Geneva
(Swiss Center for Affective Sciences)
Up to 28 odorants



[virolfac system in Univ. Geneva center for affective sciences]



(x,y,z)t
Nose position:
Real time tracking
Nose entering a virtual olfactory volume
Triggering appropriate odor
C1
C2
C3
C4
C5
Virtual olfactory volumes
Increasing concentrations
Olfactometer

4 Conclusion

The spectrum of human senses is large but vision is dominant over the other senses.

Immersion is the **objective** level of fidelity of the sensory stimuli produced by a technological system.

Most of the effort in immersion technology have focused on visual displays for which a broad range of technical means is available (complementary lectures follow).

Some classes of sensory stimuli are difficult to produce :

- critically useful for a wide range of applications:
    - Motor activity, e.g. walking (proprioception) => *future lecture on navigation*
    - Haptic (force) & vestibular (balance) => *future dedicated lecture*
- Seldom exploited due to narrow class of applications & technical difficulties:
    - smell, taste

[References]

[B2007] Bowman, D., McMahan, P.: Virtual Reality: How Much Immersion Is Enough? Computer, 40(7), 36--43 (2007), & Course notes from D. Bowman / Immersion & Presence

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[Qi18] Qi Sun, Anjul Patney, Li-Yi Wei, Omer Shapira, Jingwan Lu, Paul Asente, Suwen Zhu, Morgan McGuire, David Luebke, and Arie Kaufman. 2018. Towards Virtual Reality Infinite Walking: Dynamic Saccadic Redirection. ACM Trans. Graph. 37, 4, Article 67 (August 2018), 13 pages. https://doi.org/10. 1145/3197517.3201294

[TRV 2006] Traité de Réalité Virtuelle, Ed. P. Fuch, vol 1, chap2, Eds A. Berthoz & J.L. Vercher

[W2015] http://en.wikipedia.org/wiki/Weber-Fechner_law