Sensory Substitution and Assistive Devices for the blind

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Introduction: context

- Design and development of **assistive devices** for VIP
  - **Autonomy**, **safety**, **quality of life** and **integration in society.**

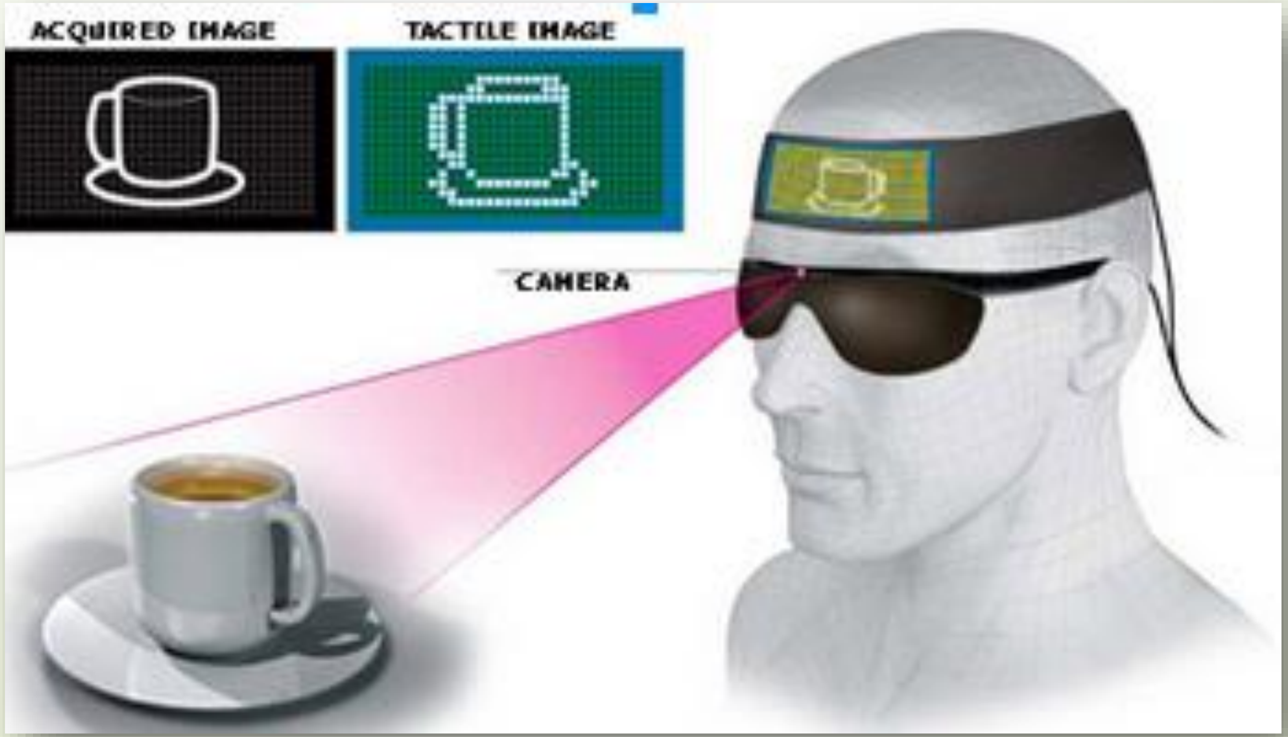
- **Accessibility to dynamic content**
  - Image, graphics, spatial information

- Current solutions rely on **language** (screen readers, braille)
  - Not very fit to convey this type of content

Introduction: sensory substitution

Sensory Substitution (Bach-y-Rita, 1972)

Convey **no longer accessible** information through an "**unusual" sensory channel.**



Introduction: Sensory Substitution Devices

- **<u>What information</u>** they provide: <u>general</u> vs <u>specialized</u>
- **<u>How</u>** they provide this information: <u>interface</u>, <u>code</u>
- How they **<u>gather</u>** this information: <u>sensors</u>, <u>algorithms</u>

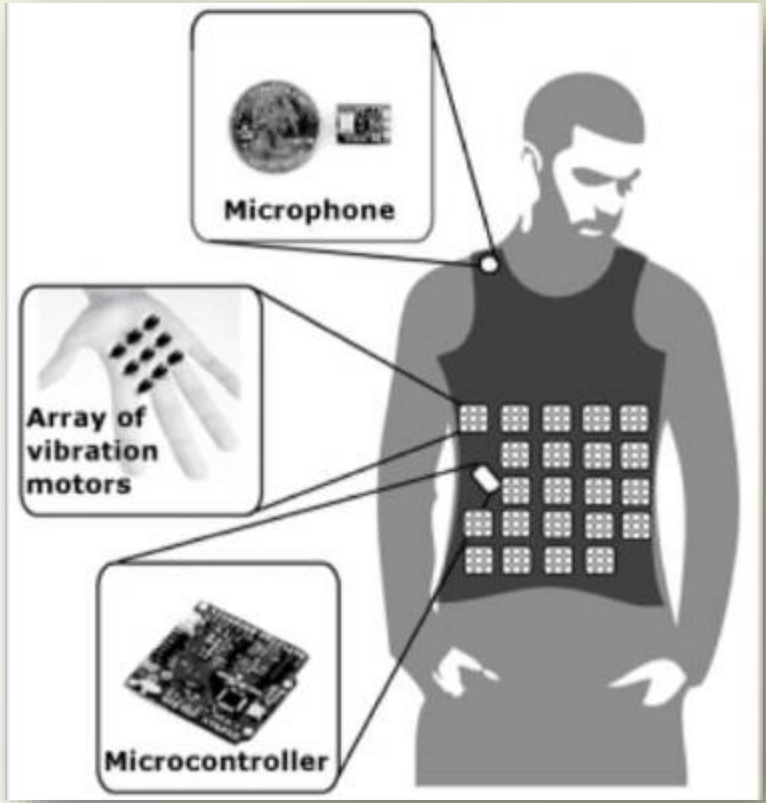
Introduction: SSD

Tongue Display Unit

(Kaczmarek, 2011)

The vOICe

(Auvray, Hanneton, & O'Regan, 2007)



(NeoSensory) VEST

(Novich, 2015)

Introduction: SSD

ALVU

(Katzschmann, Araki, & Rus, 2018)

FeelSpace (NaviBelt)

(Kärcher et al., 2012)

Introduction: SS as a design framework

- **Sensory Substitution** : non-visual communication framework
  - Unconscious, fast, parallel processing
  - Cognitive → Sensory

- **Famous examples**:
  - Discriminate shapes, objects, people
  - Find objects
  - Drive a robot or a drone
  - Navigate in a maze
  - Optical illusions, falling / equilibrium loss

- But there are still a lot of open questions and considerations.

Introduction: SS as a design framework

Modality considerations: tactile or audio feedback

- **Audition**: higher throughput but interferences
- **Tactile**: lower throughput but no interference, and spatialized

- Combining **multimodal feedback:**
  - Avoid saturation
  - Improves interpretability (redundancy)
  - Improves rehabilitation (Xu, Yu, Rowland, & Stein, 2017)

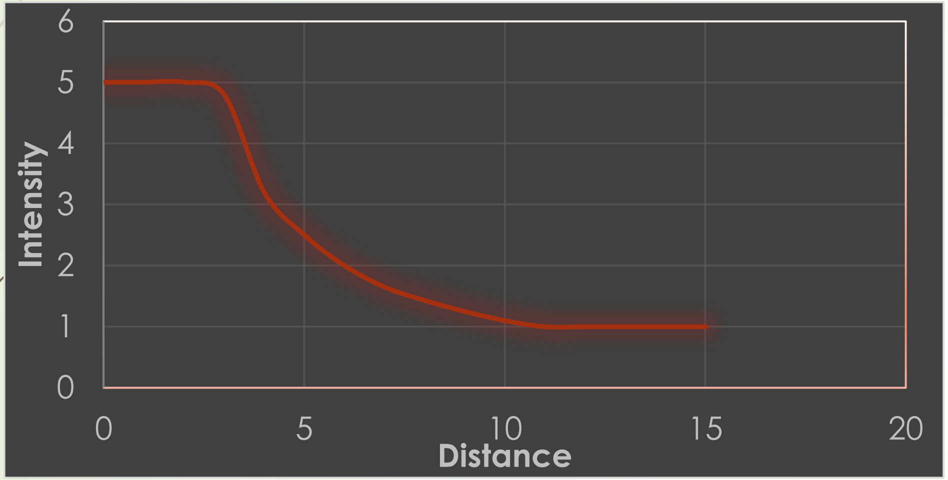
Introduction: SS as a design framework

<u>Interface design</u> (“low-level” considerations):

- Distance between actuators, number of actuators
  - Quantity of simultaneously information (Miller, 1994)
- **Physical parameters** (amplitude, frequency) ≠ **perceptual properties** (loundness, pitch …)
- **Continuous** or **step-wise** coding ? Discriminable steps ?
  - (Geldard, 1960; van Erp, 2005)

Introduction: SS as a design framework

Information transfer: what code to use



- Favor the **action-perception continuity** (Kristjánsson et al., 2016)
  - Makes sense of, and externalize percepts (Lenay et al., 2003)

- Favor **ecologically plausible A-P loops** (O'Regan & Noë, 2001):
  - Leverage learned contingencies → **easier learning** and **more intuitive**

Introduction: SS as a design framework

<u>Problem representation</u>: what information to convey for a task

- Minimum necessary information for efficient problem solving
  - Balance between **precision** and **intuitiveness**

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Image comprehension

Image comprehension: objectives

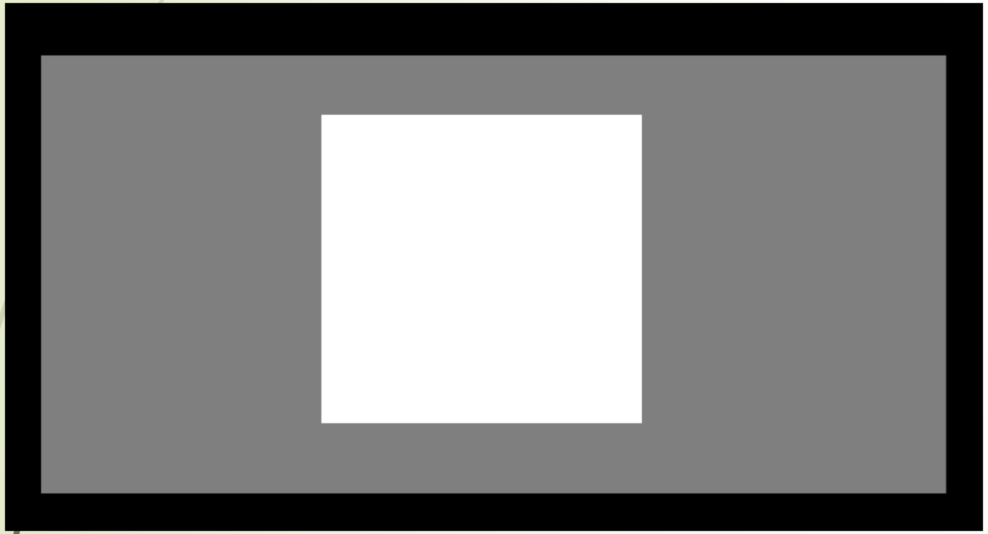
- **Low-cost interface** to convey **2D content** to VIP
- Using the **sensory substitution framework**
- **Combining audio** and **tactile feedback**

Image comprehension: audio feedback

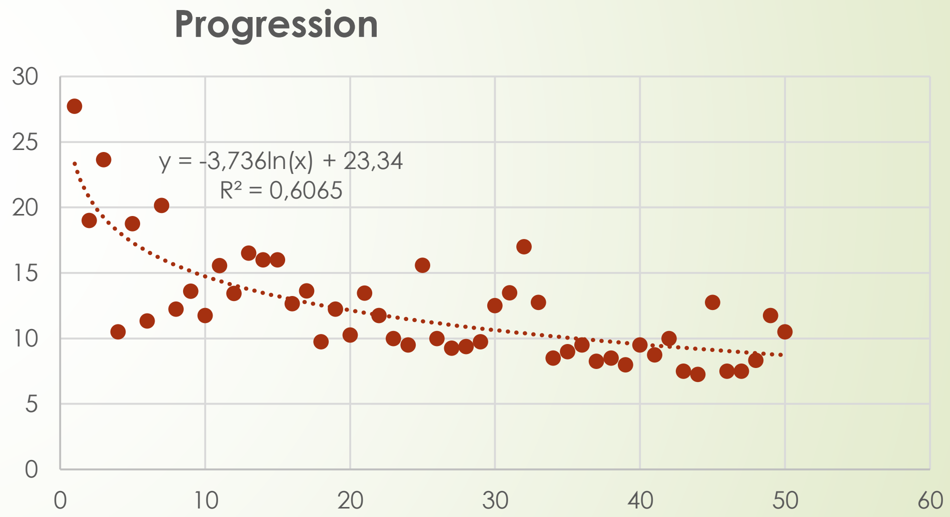
Audio-visual substitution 2D interface (AdViS)

- Finger-guided exploration with audio feedback
  - Color → pitch
  - Edges → sound transition

Image comprehension: audio feedback



Shape recognition :
91%
12,2 secs (± 4.2)

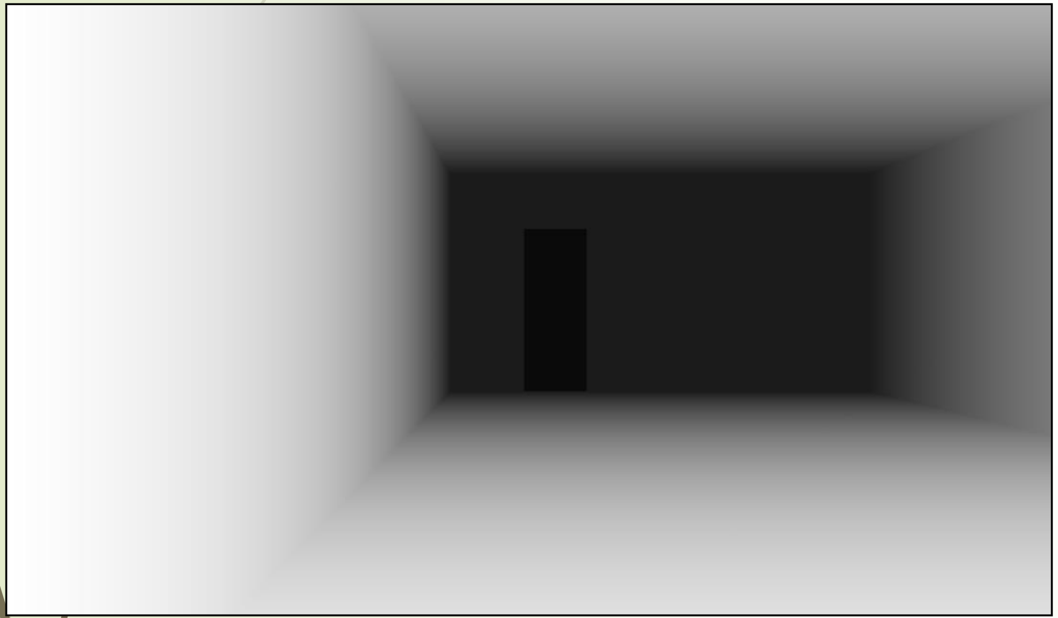


<u>10 first trials</u>
μ = 16,9 s (± 5.6)

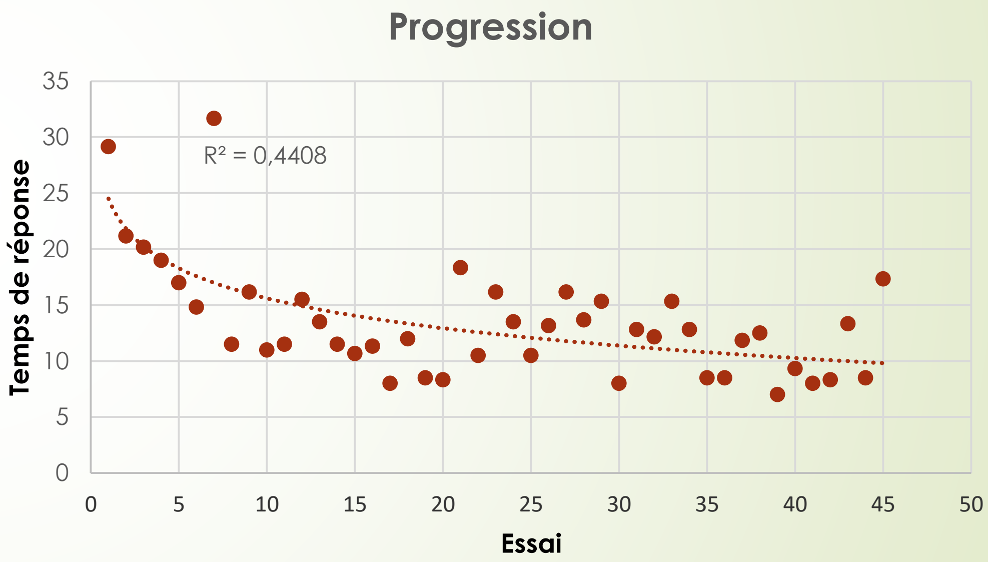
Wilcoxon unilatéral
p = 0.003*

<u>10 last trials</u>
μ = 9.2 s (± 1.9)

Image comprehension: audio feedback



Target relative localization:
89.8%
16,1 secs (± 10.7)



<u>10 first trials</u>
μ = 22,5 s (± 18,2)

Wilcoxon unilatéral
p = 0.006*

<u>10 last trials</u>
μ = 12.3 s (± 8.4)

Image comprehension: audio feedback

Oculomotor exploration:

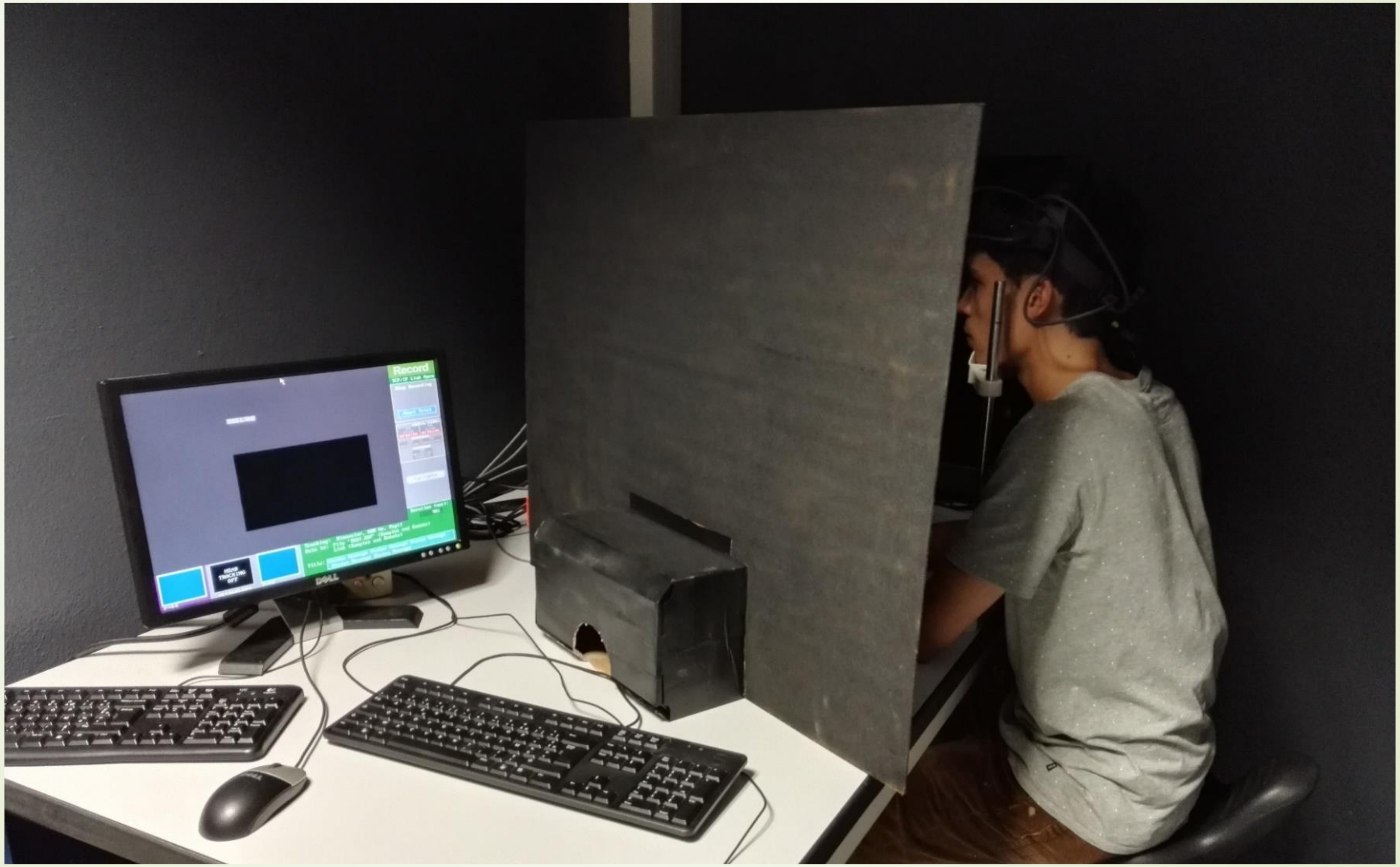


Image comprehension: audio feedback

<u>Preliminary evaluation</u> with the eye-tracker based guidance:

- Sighted participants in the dark
  - Late blind → still have some oculomotor control
- However, without visual feedback …
  - Difficulty to control the focal area's movements
  - Difficulty to localize your current fixation location

Image comprehension: audio feedback

- **Add some kind of global or positional information !**
  - Substitute eye movement estimation (visual odometry)
  - Provide fixation points

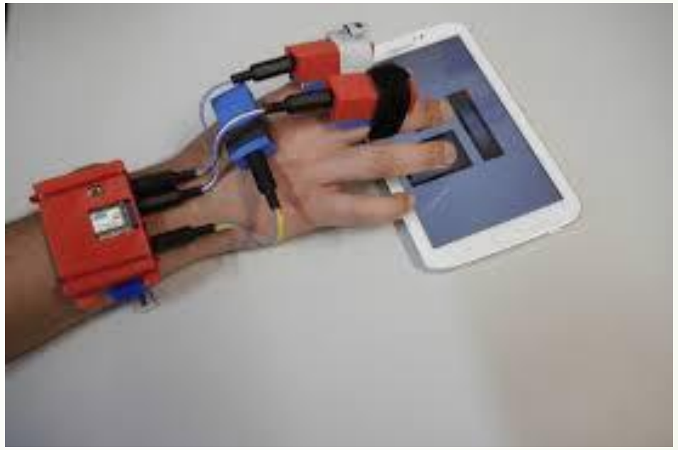
- Combine **local** (point-wise) with **global** information
  - *Analogy to peripheral & foveal vision*

- Testing different pointing feedback in 3D virtual environment (Guezou-Philippe, Huet, Pellerin, & Graff, 2018)

Image comprehension: tactile feedback

Tactile feedback for **image exploration** :

"Taxel" devices



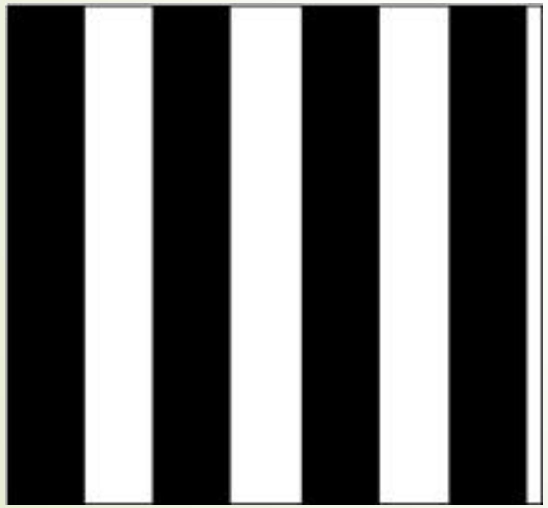
Vibrational devices

Electro-stimulation devices

Image comprehension: tactile feedback

<u>STIMTAC</u> : ultrasonic vibrations tablet (Vezzoli et al., 2016)

- Modulates **friction**
- Can create "tactile textures"



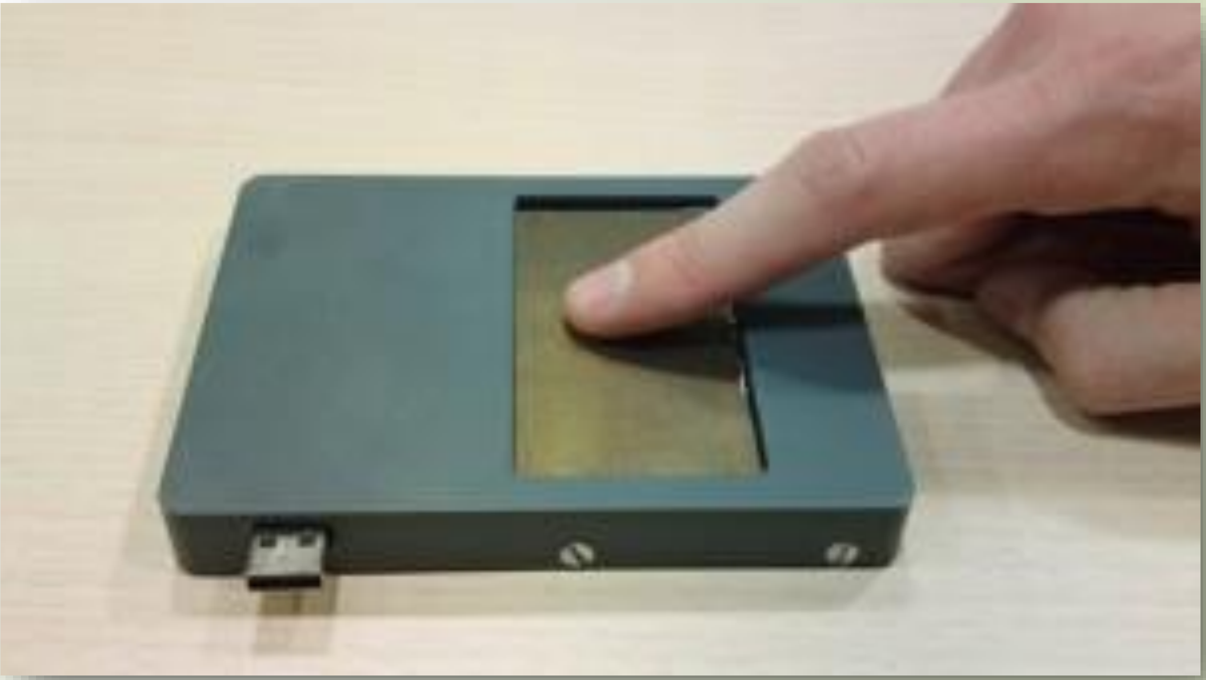
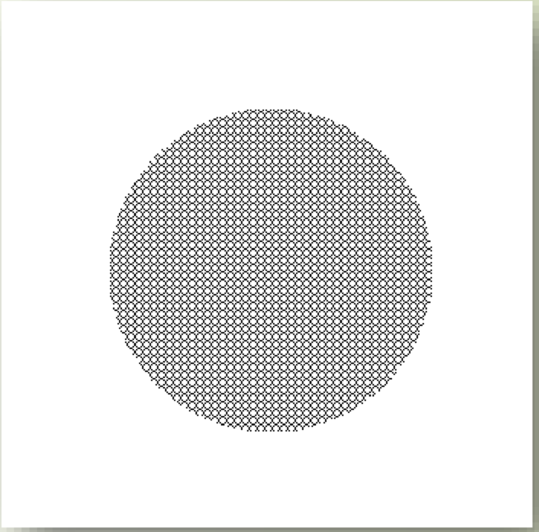


Image comprehension: tactile feedback

<u>**Preliminary evaluations**</u> (**Rivière** et al., 2018)

- Simple shape recognition
- N = 12 (LB & CB)

- **Results**:
  - Very poor recognition rates
  - Impossible to « follow » the edges of an object

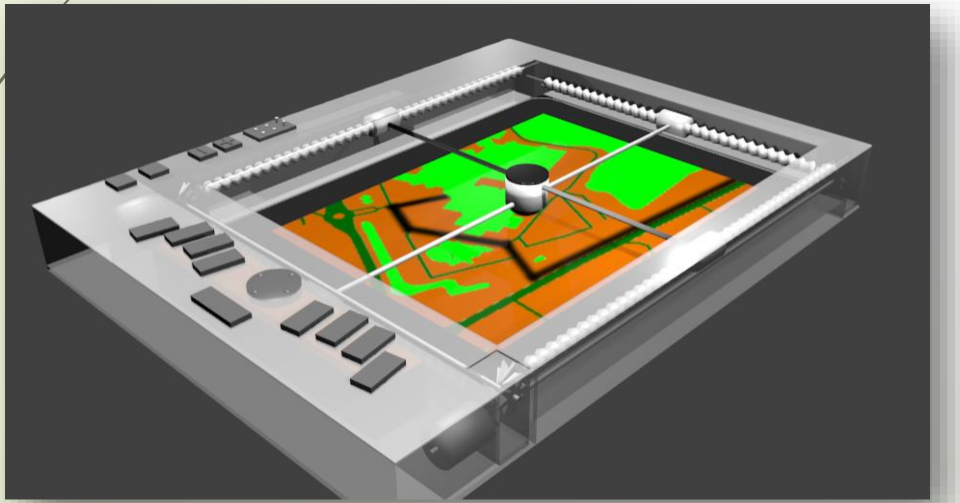


- Developped another type of interface

Image comprehension: tactile feedback

F2T (Force Feedback Tablet) (Gay, **Rivière**, & Pissaloux, 2018)

- Mobile joystick : resist, facilitate or guide movement
- Passive or active guidance



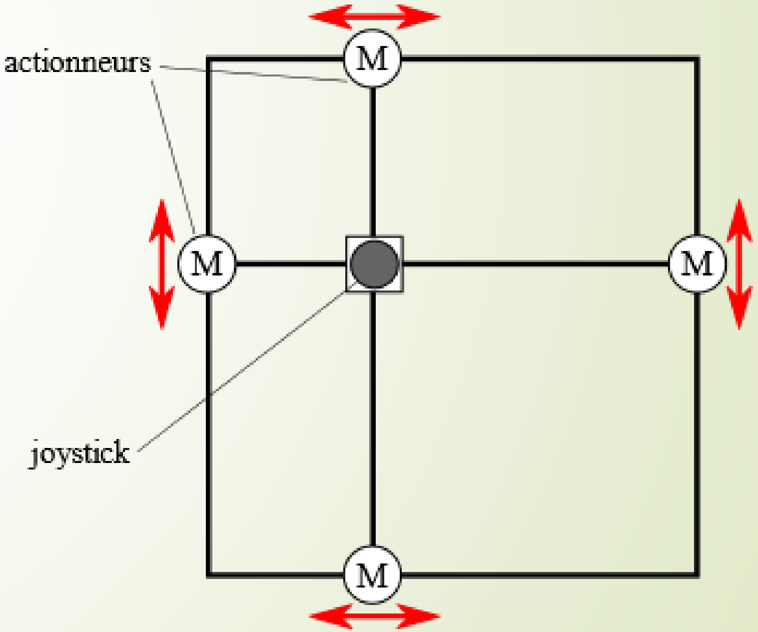
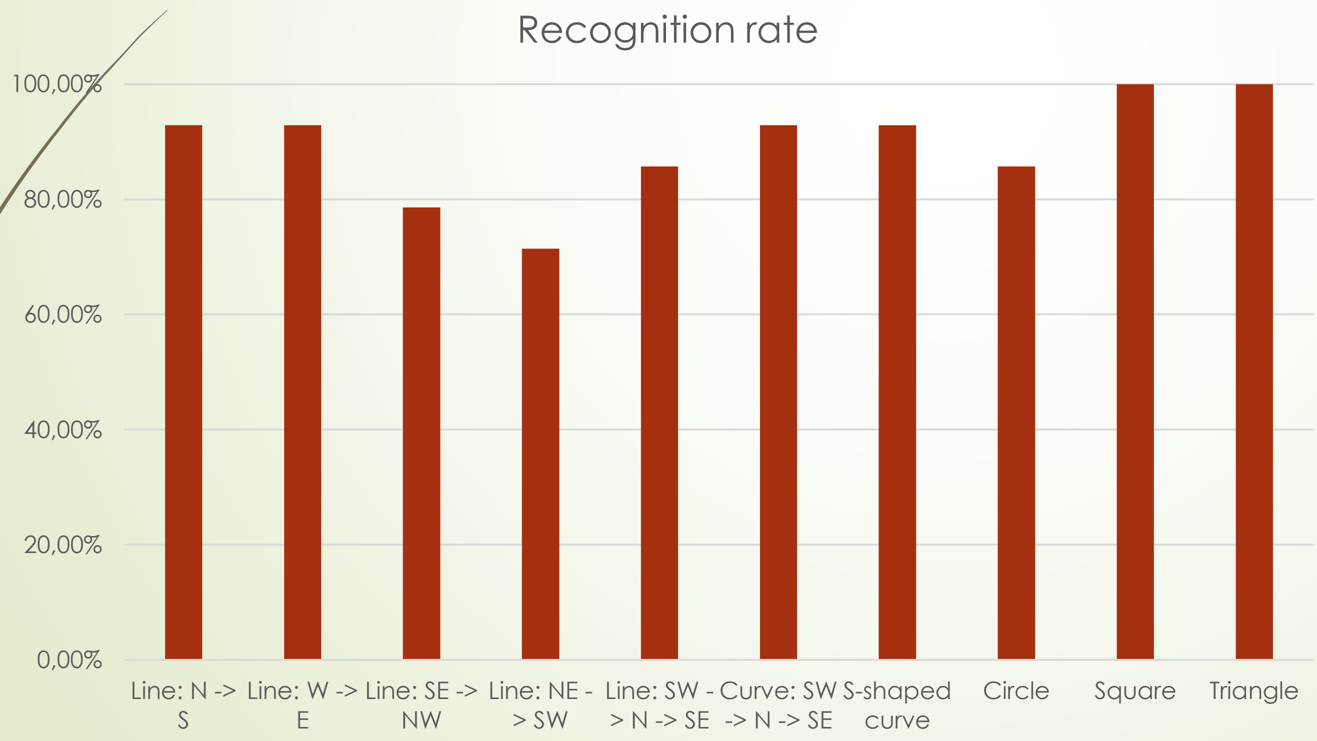


Image comprehension: tactile feedback

- **Preliminary evaluation with VIP** (**Rivière** et al., 2019):
  - Simple directional stimuli (cardinal directions)
  - Simple geometrical shapes



Simple shape and movement recognition is very accurate :
μ = 89.3%

Image comprehension: applications

Access to art and culture : audio-tactile display of paintings

- **Transcription of paintings:**
  - **Tactile:** spatial / edges information (F2T)
  - **Audio:** semantic description (headphones)

Image comprehension: applications

Access to art and culture : audio-tactile display of paintings

Preliminary evaluation (exploratory):

- N = 14
- Guided (active) exploration with synchronized audio description

Likert scale + semi-open questionnaire :

- Tactile info facilitates the comprehension and mental representation of the painting

Image comprehension: applications

<u>Access to art and culture</u> : audio-tactile display of paintings

- **Free exploration**
- **Automatic segmentation of the painting:**
  - <u>Supervised method</u>: Mask-R-CNN, …
  - <u>Unsupervised methods</u>: watershed, …
- Regions → different force-feedback

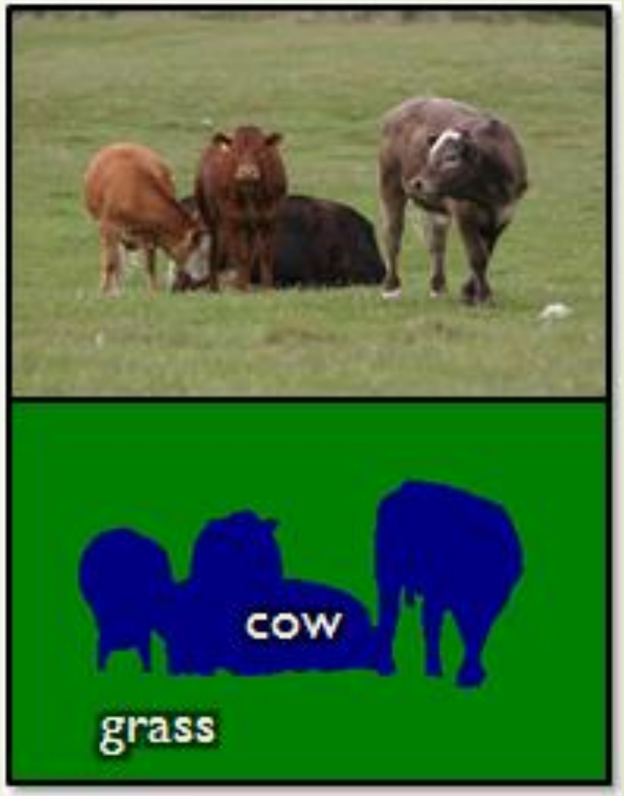


Image comprehension: applications

<u>Journey preparation for VIP</u>: audio-tactile virtual environment for dynamic map exploration

- **Standard map → audio-tactile virtual exploration**
  - <u>Tactile</u>: simplified representation with the F2T
    - Pulled from GIS provider (Google Map)
  - <u>Audio</u> : 3D cues to match real sound sources
    - Ambient sounds → area discrimination (road, forest, …)
    - Specific sounds → recognizable sound sources (fountain, church, …)
    - Audio descriptions (crosswalk, street names, …)

Spatial comprehension

Spatial comprehension: objectives

High-level objectives: device to provide spatial information on the surroundings in real time while navigating

- **Autonomous navigation**
- With **more than** turn-by-turn directions

- Efficient **interface** and **code** to convey this information

Spatial comprehension: objectives

- Current **mobility assistive devices** focus on **locomotion.**
  - **Mobility = locomotion + orientation !**

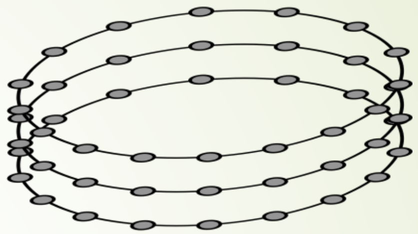
- **Provide large-scale orientation information**
  1. Where they are,
  2. Where they want to go,
  3. How to get there.

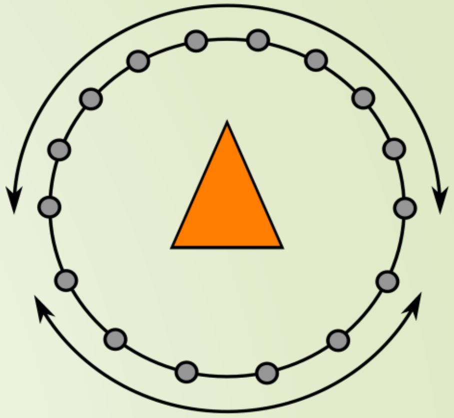
- **Construct a mental representation** of their surroundings.
  - **Autonomy & Safety**

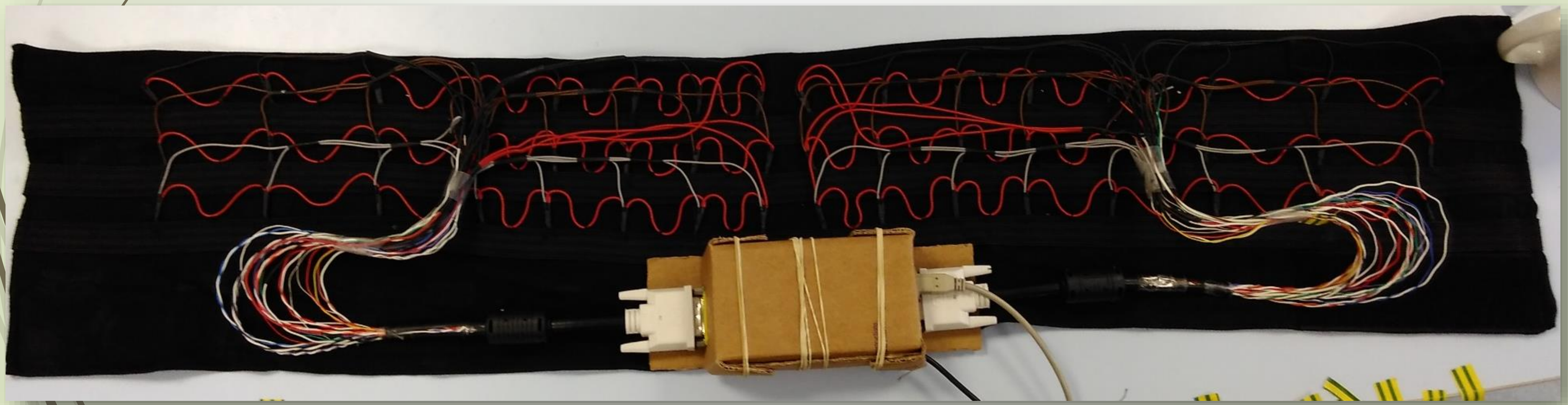
Spatial comprehension: interface

Interface: waistband fitted vibrators

- Front : 3 layers of 10 vibrators
- Back : 3 layer of 6 vibrators
- Control: Arduino Mega → Vibrators
  - **Intensity** and **frequency** (temporally and spatially)







Spatial comprehension: spatial gist

- **Spatial cognition** (Waller & Nadel, 2013):

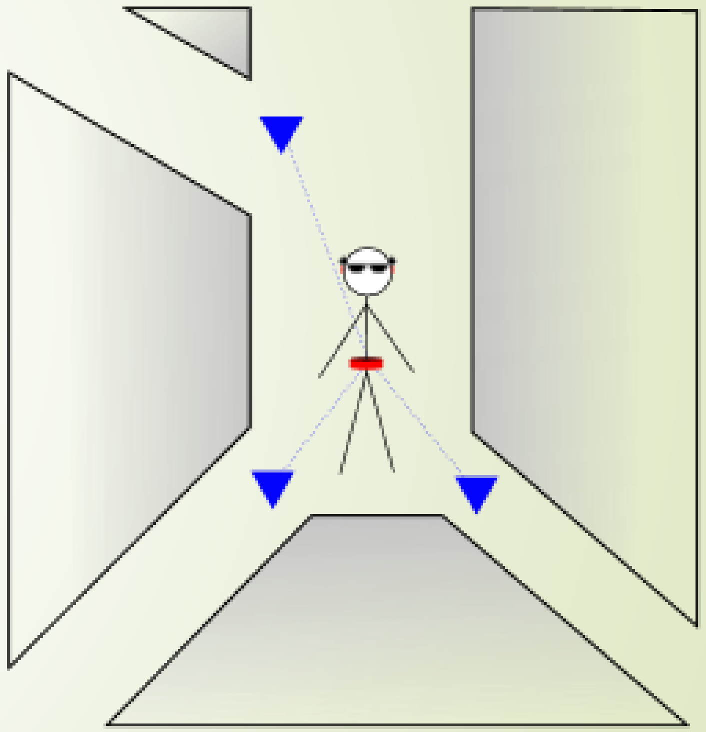
Integrate multisensory information → Extract relevant features → Build mental representation

- Which **information humans use to orient themselves ?**
  - Which rely on vision → provide them through substitution
- **Hierarchical models of orientation :**
  - Wang & Spelke, 2002
  - Spelke & Lee, 2010

Spatial comprehension: spatial gist

<u>**Substituted navigation model**</u> (**Rivière**, Gay & Pissaloux, 2018):

- **Nodes** (medium-scale)
- **Points of Interest / landmarks** (large-scale)
- **Destination** (large scale)



Emergence of mental representations

(accurate and intuitive enough to allow for **efficient navigation)**

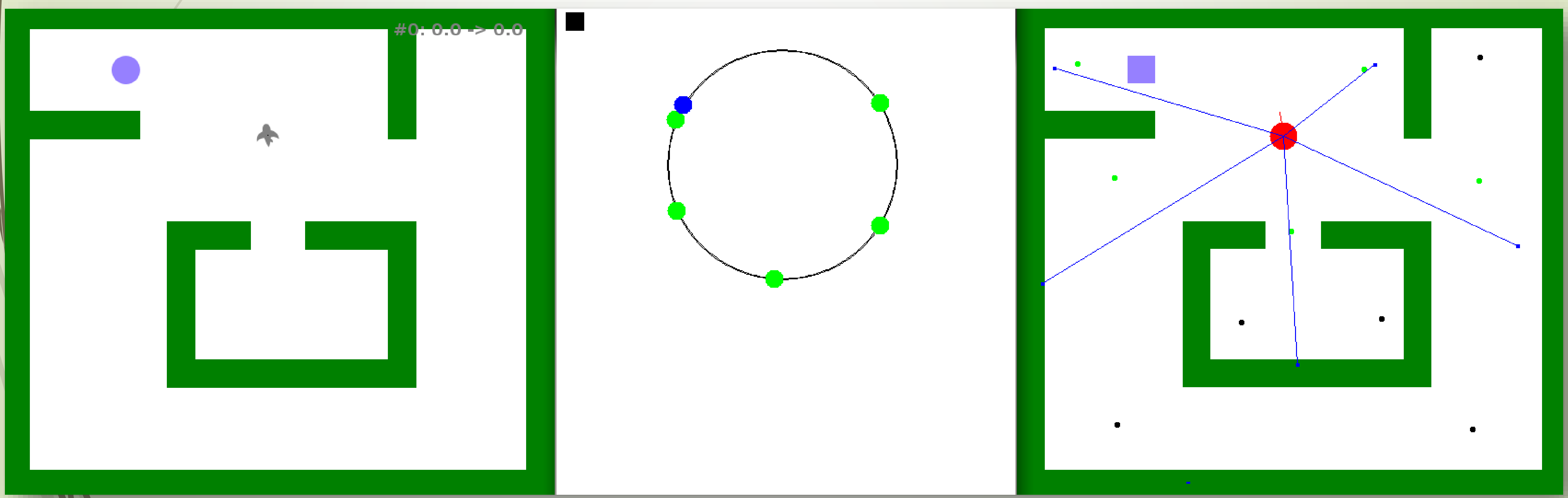
Spatial comprehension: tactile code

Proposed **vibration code for the spatial gist**:

- **Features' position** provided in **ego-centered referential** :
  - Distance → pulse intensity
  - Orientation → which vibrator is active
- **Type of spatial feature** → type of burst (vibration "signature")
- **Audio feedback** (on demand) for landmarks (PoI) identity

Spatial comprehension: virtual navigation

First evaluations: virtual environment



Spatial comprehension: real-world navigation

<u>Real-world localization and mapping</u>:

- **Extract required features** by combining multiple sensors
  - Embedded, real-time, lightweight
  - Indoors and outdoors
  - (With or without a pre-existing map)

Spatial comprehension: real-world navigation

Indoor localization: estimate one's location without GNSS data

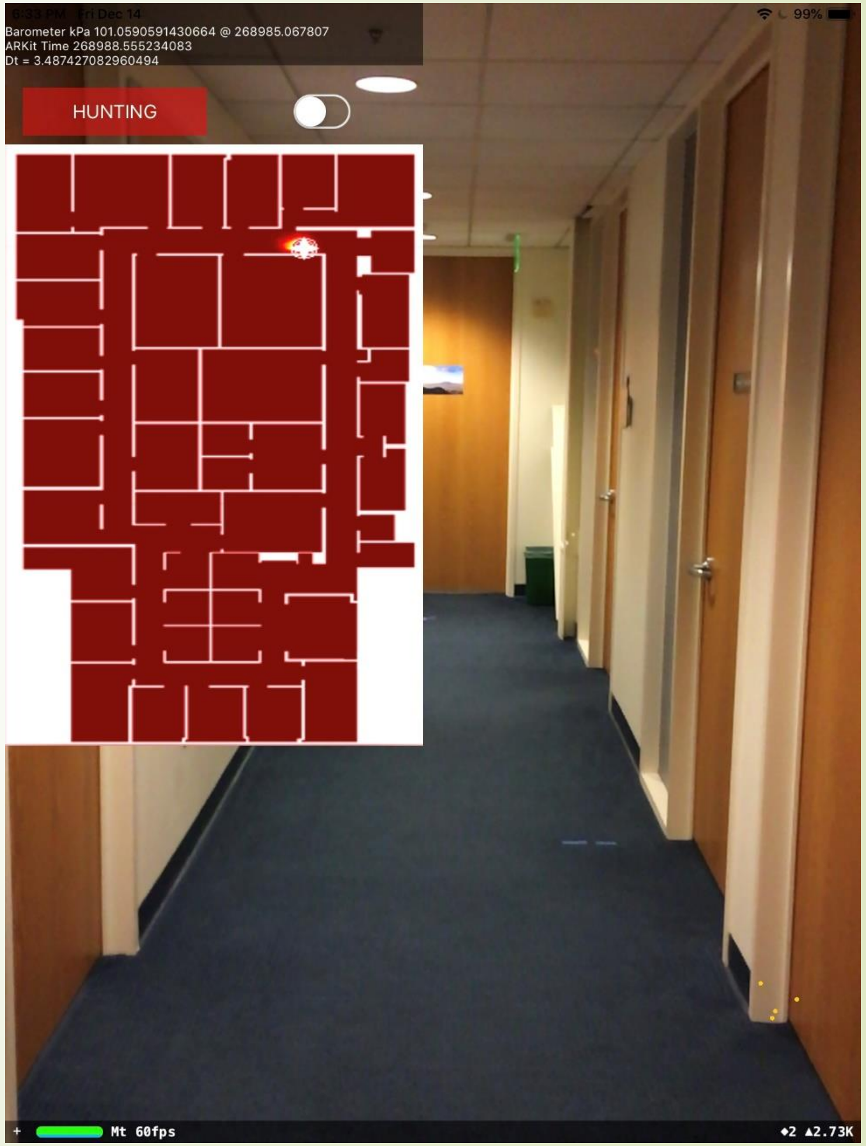
- **Sensor fusion** and **filtering**:
  - Inertial (IMU)
  - Magnetic / WiFi (fingerprinting)
  - Beacons
  - Vision
  - …

- **General principle**: Take continuous measurements to progressively decrease the uncertainty on the estimated state.

Spatial comprehension: real-world navigation

iLocalize (Fusco & Coughlan, 2018)

- Localization based on a floor plan
- Particle filtering with :
  - ARKit's Visual Inertial Odometry (VIO)
  - Exit sign detectors
- Efficient and easily available odometry method which can use existing hardware (smartphones)



Spatial comprehension: real-world navigation

<u>Indoor Atlas</u>: indoor localization framework

- Relies on :
  - GPS, IMU, WiFi, Magnetic, Barometer, Beacons
  - Indoor and outdoor localization (with transition)
  - Floor change
  - Wayfinding

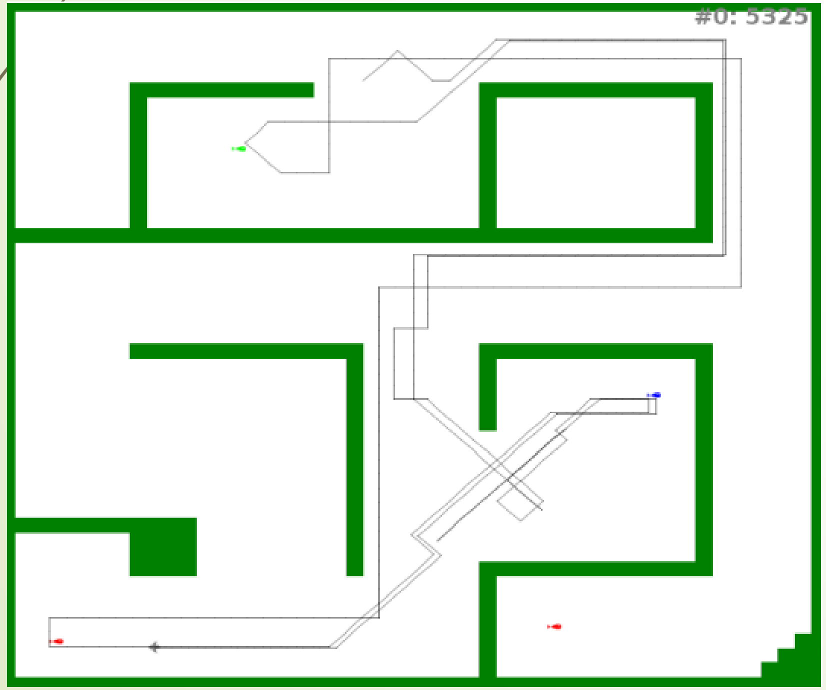
- Perfect addition to VIO !

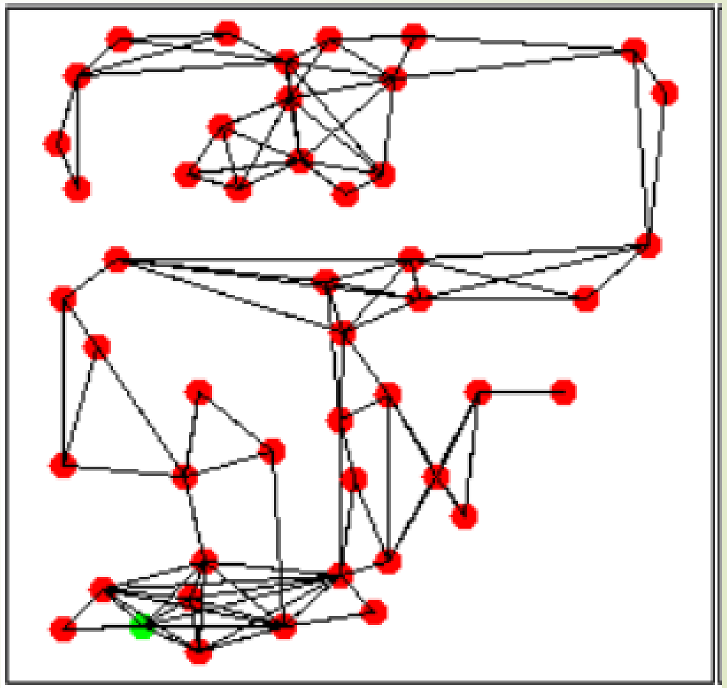
IndoorAtlas

Spatial comprehension: real-world navigation

Future work:

- How to best combine Indoor Atlas & iLocalize location estimates
- Test the localization system : real-world navigation (with the Belt)
- Map-free indoor localization





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litis

cnrs

CesamS

uB UNIVERSITÉ DE BOURGOGNE

ccaH Association reconnue d'utilité publique

FIRAH Fondation Internationale de la Recherche Appliquée sur le Handicap

SKERI

Thank you

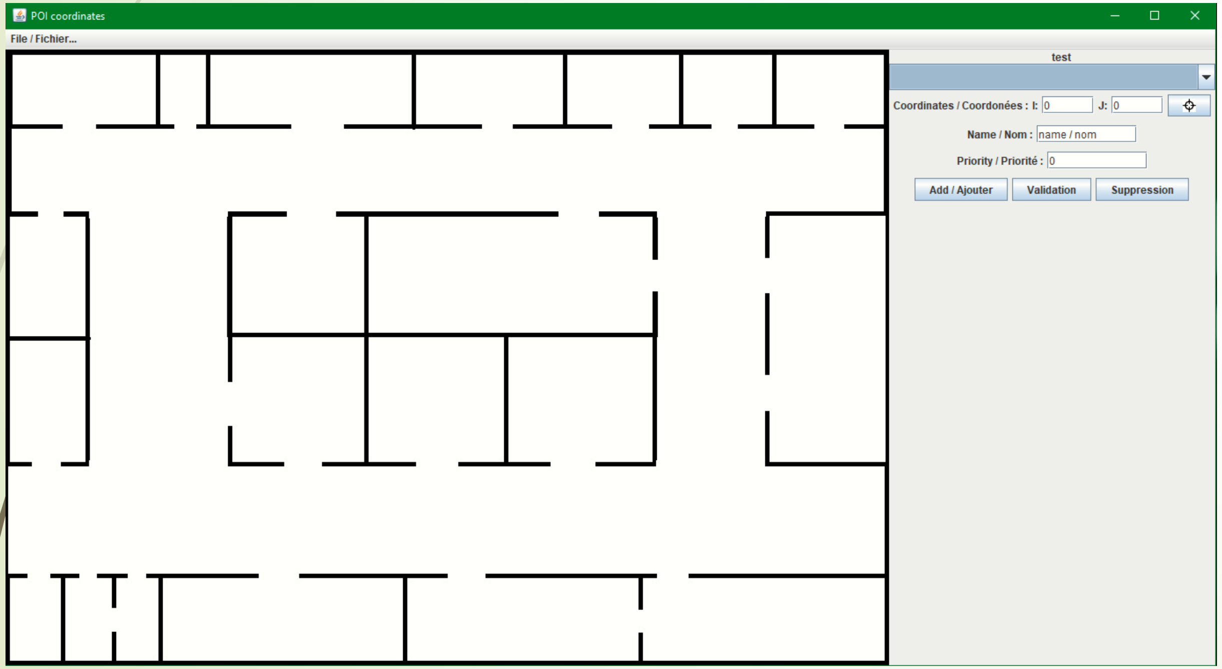
References

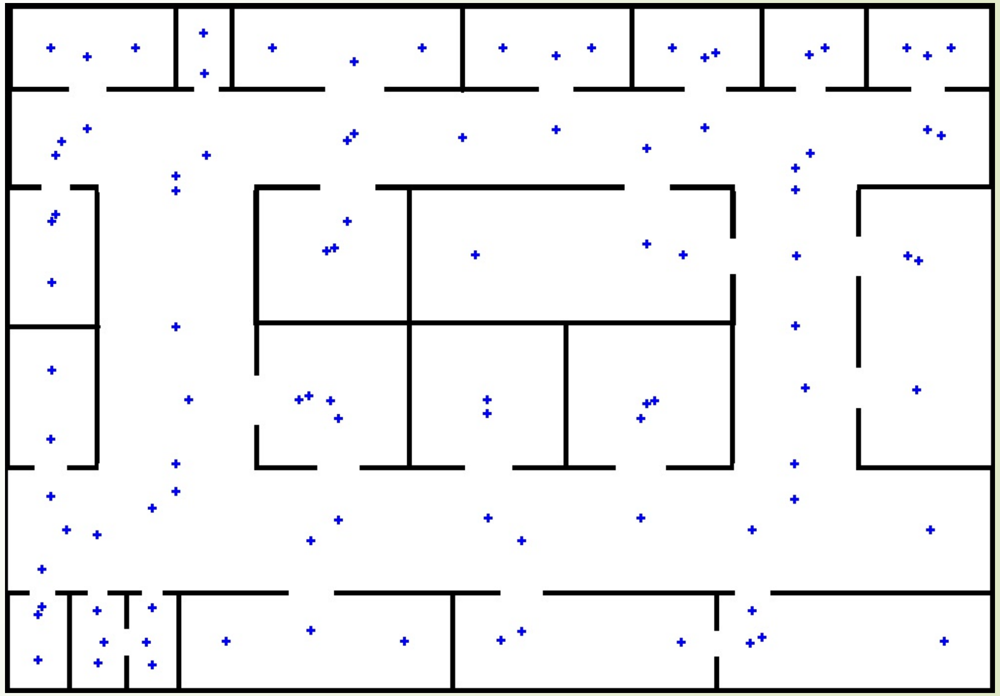
- ??

III. Sensors & signal processing: algorithms

<u>Positioning & tracking indoors</u>: node graph extraction (map available)

- Indoor map → Cleaning → Node extraction → Node pruning

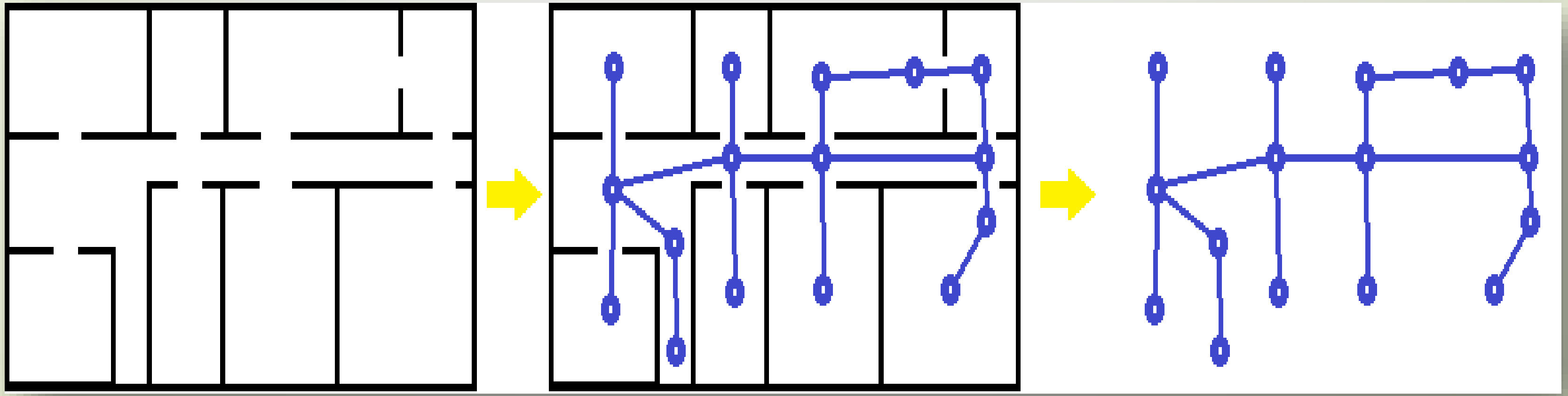




III. Sensors & signal processing: algorithms

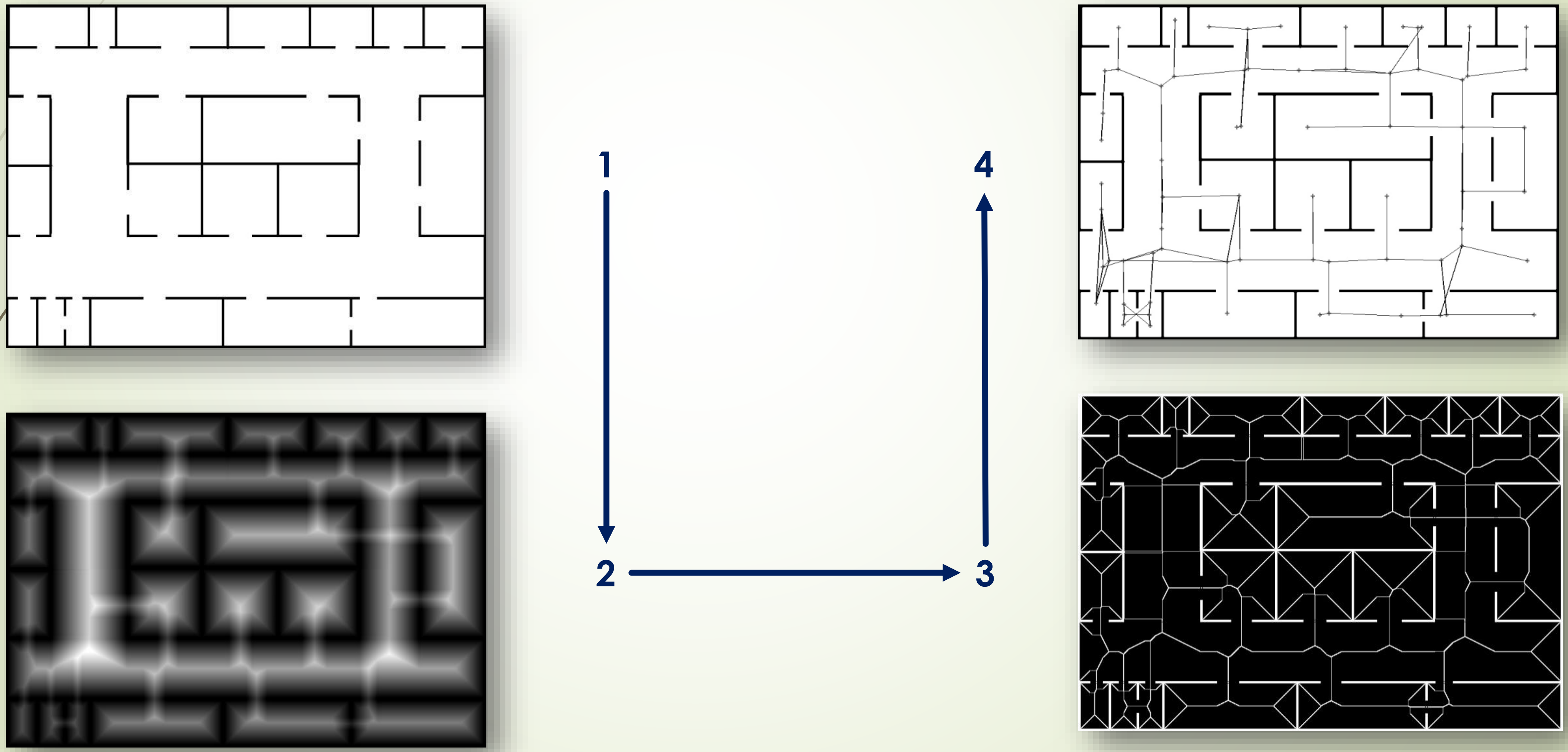
Positioning & tracking indoors: node graph creation (no available map)

- Generate its "map" **of the environment** based on:
  - His movements (or "interactions"): path-integration
  - Rudimentary visual sensors to recognized "interesting locations"
    - Characterized by "Place Cells" (PC)



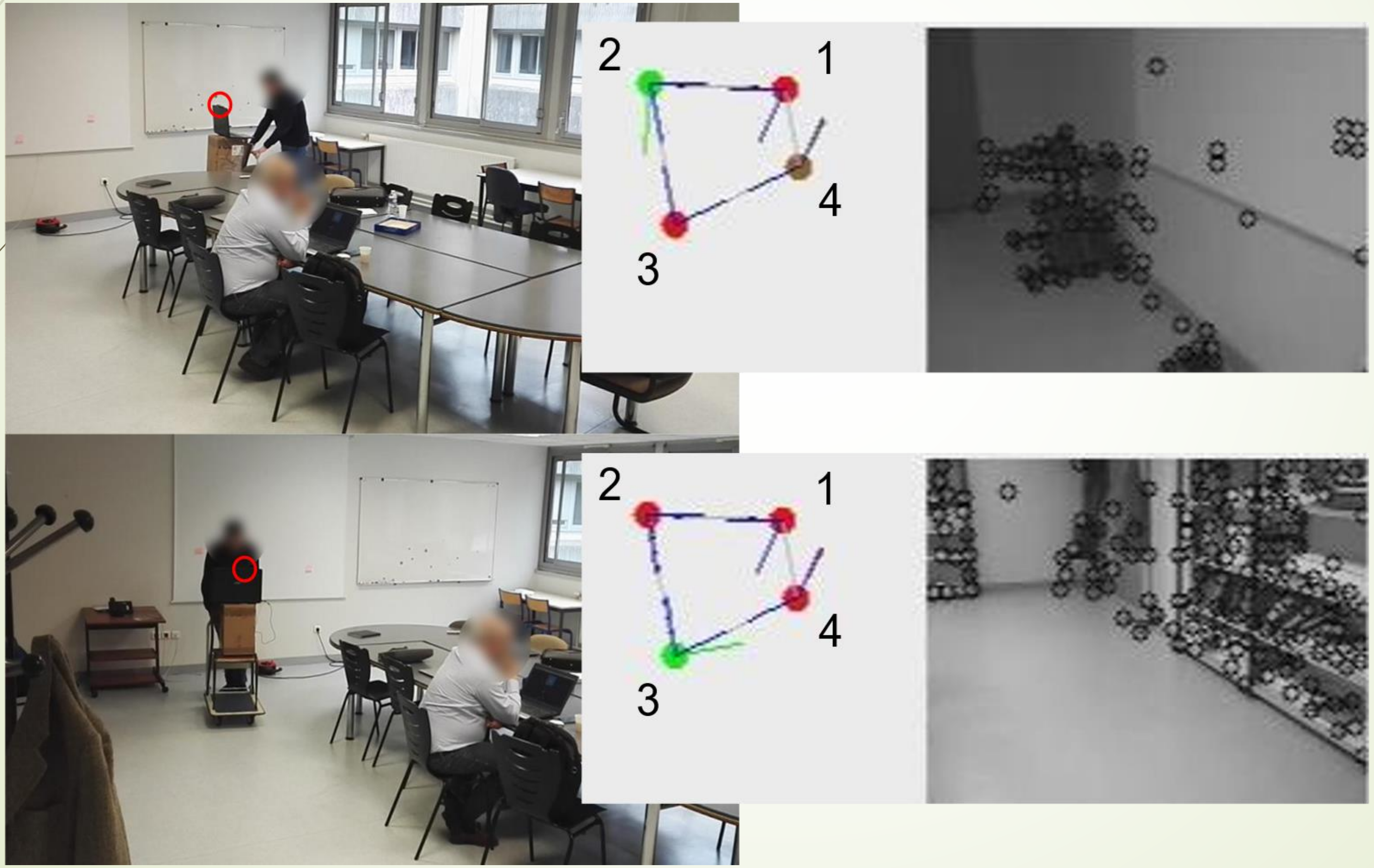
Second prototype: travaux en cours

- **Mobility graph extraction process**



Second prototype: travaux en cours

Mobility graph extraction in real-world settings



Current projects state: ACCESSPACE

- Developing an **electronic travel and orientation aid** for VIP, based on a **vibrating belt** conveying the **spatial "gist" of the environment**.

- Will allow VIP to **intuitively perceive the large-scale geometry** of their surroundings, and thus to mentally represent it.

- **Autonomously navigate** towards a destination, free to **chose their own preferred path** among all the possible ones, **avoiding obstacles along the way.**

Past, current & future projects

Current project 3 : NAV-VIR

- French – Polish collaboration.
- Develop an **audio-tactile virtual environment (VE)** for VIPs.
- It will allow VIP to:
  - Discover and explore a simulated version of any real-life environment (e.g. a city)
    - This VE will include a simulated soundscape of the surroundings (traffic, chatter, …) and tactile feedback of the user's current location and surrounding map.
  - Practice their efficiency with the provided interface through educative games.

Past, current & future projects

Current project 3 : NAV-VIR

- **Interfaces:**
  - Tactile feedback tablet (F2T) or tactile glove (with vibrators on each finger)
  - Stereo headphones

- **Communication:**
  - Spatialized simulated audio environment, depending on what's around the user's position (traffic, coffee shops, churches bells …)
    - The goal is to provide distinguishable sounds that the VIP will recognize when doing the actual journey, allowing to localize himself based on this information.
  - Spatialized 2D tactile feedback through a specialized interface (F2T or Gloves)
    - Will provide a dynamic simplified 2D map of the current path