CAVE
and Immersive spaces

EPFL Immersive Interaction Group

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Outline

- General concepts
- Two criteria for comparing CAVEs
- Different configurations
- Hardware
- CAVE computation
- IIG CAVE
- Recent advance in experimental museology

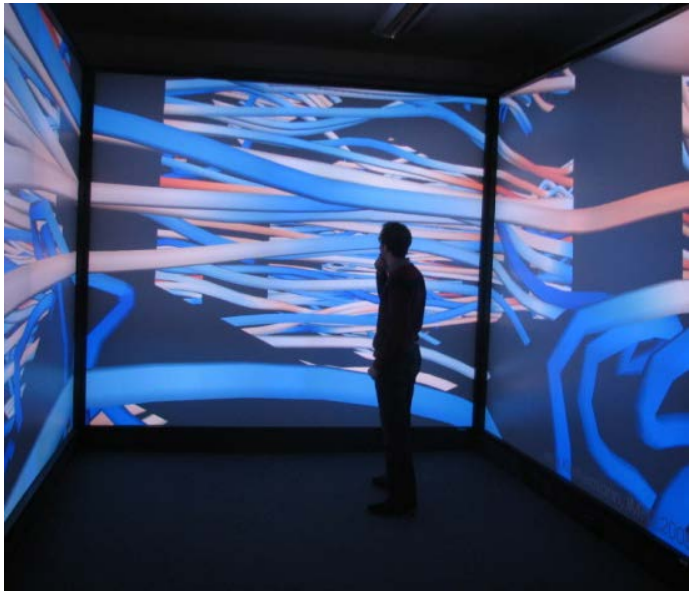
General concepts

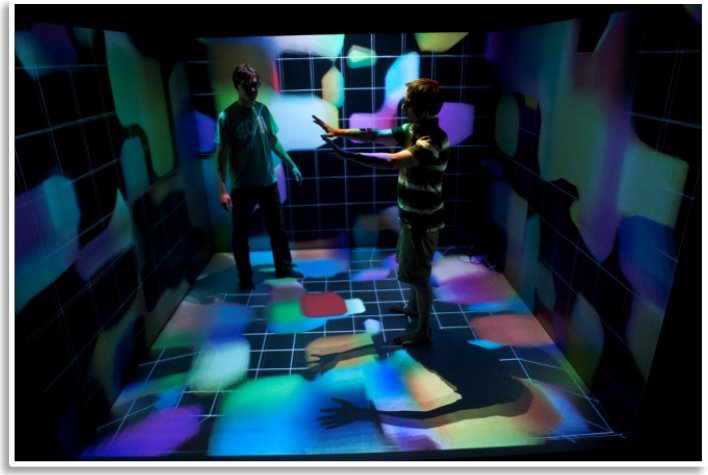
- **CAVE** stands for
  - *Cave Automatic Virtual Environment*

- **Main ideas :**
  - **Immersive display:**
    - Project the 3D scene on multiple walls around the user
  - **Minimally invasive**:
    - Head tracking (cap or Kinect)
      - Derives the user's eyes position to exploit motion parallax
    - Stereopsis can be achieved with light stereo glasses
      - At the cost of doubling the displayed images (per person)

General concepts

- Purposes:
  - ***Interacting with <u>complex</u> models***, *static* (architecture) or *dynamically evolving over time* (simulation)…
  - ***Easier to discuss*** *with team members around you*
  - ***Multiple users can share the immersive space*** *(at the higher cost of displaying individual perspectives)*.

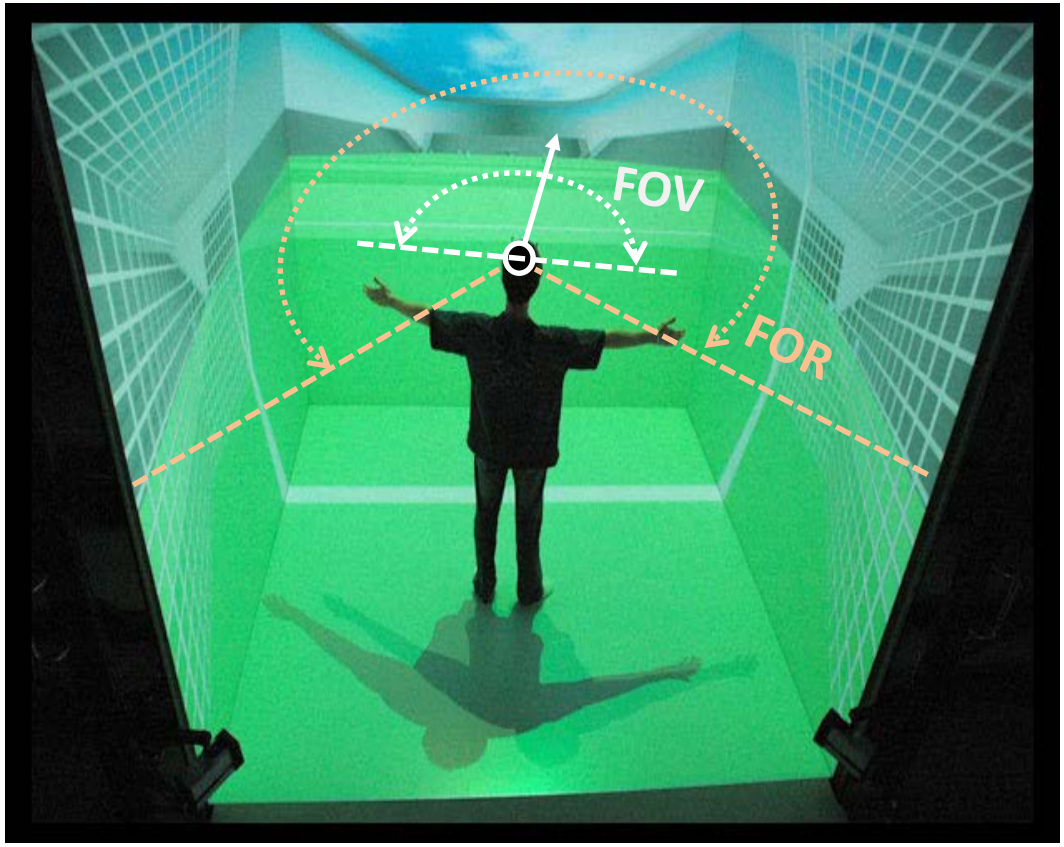




Two criteria for comparing CAVEs

- Field of View (FOV):
  - ***Measured horizontally in degrees***:

    how much of the scene is visible at any given instant of time



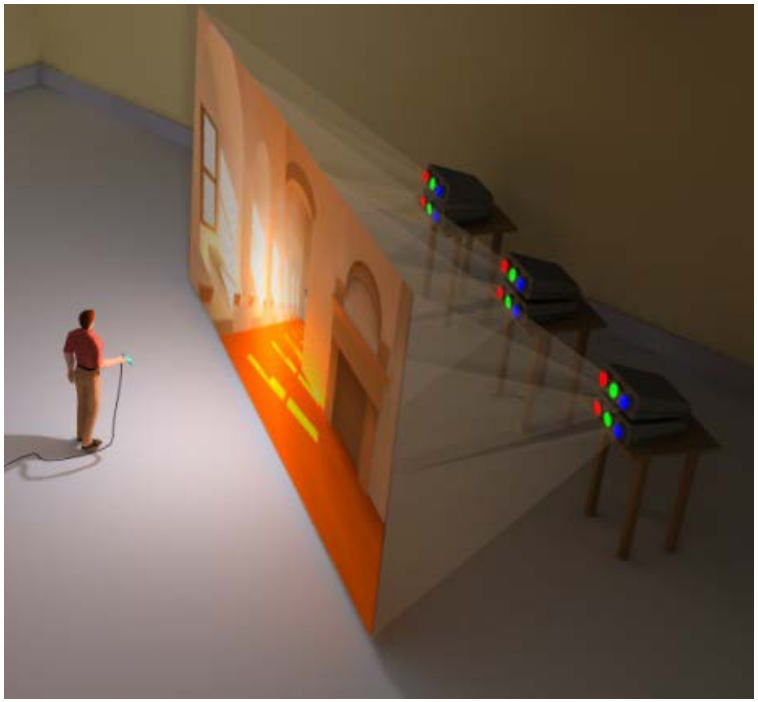
[image modified from CRVM CAVE]

- Field of regard (FOR):
  - ***Measured horizontally in % or in degrees:***

    amount of space of the virtual world currently surrounding the user

Different configurations (1:2)

- Difference between «Walls» and «CAVE»



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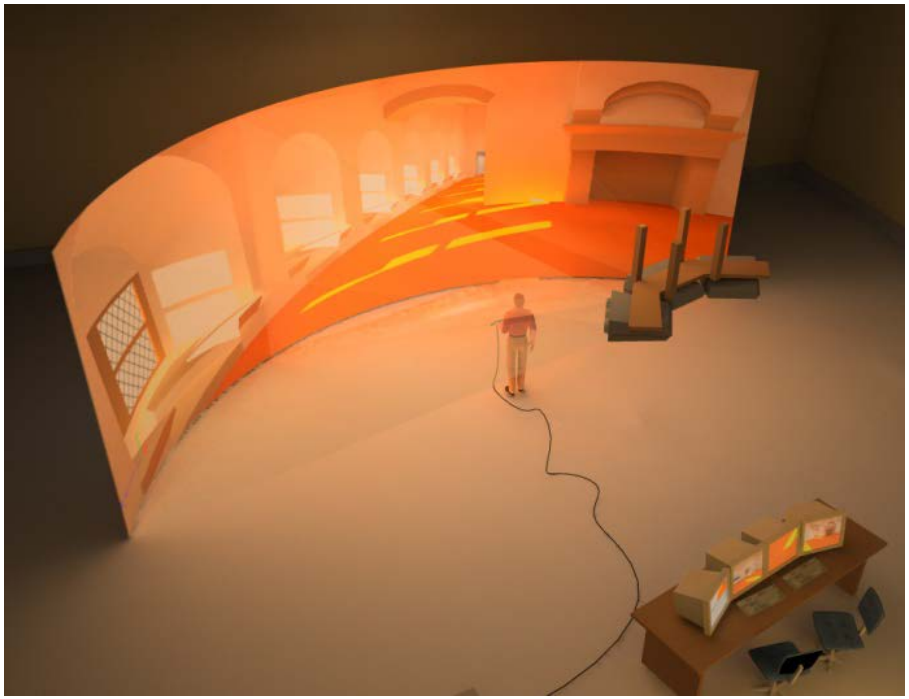
Wall virtual environment



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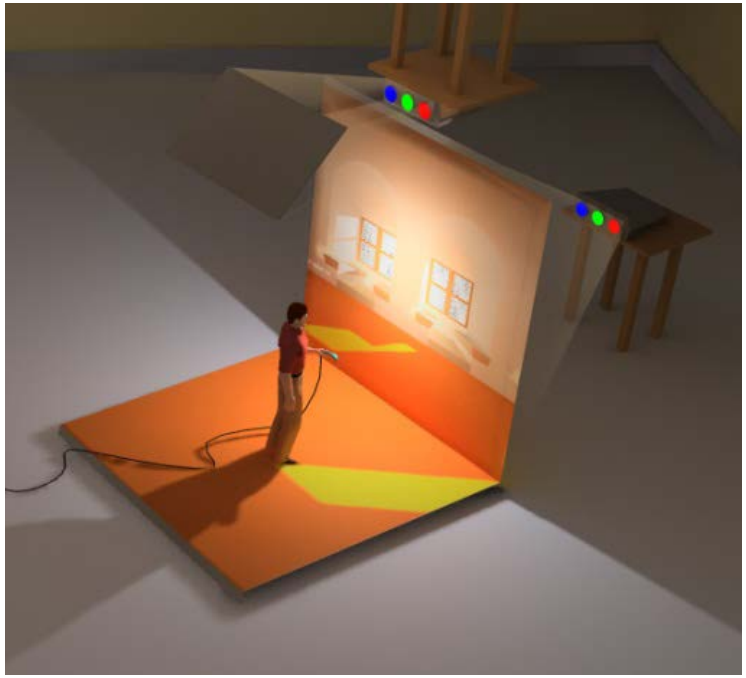
Curved wall virtual environment

Different configurations (2:2)

- Difference between «Walls» and «CAVE»



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2-screens CAVE virtual environment

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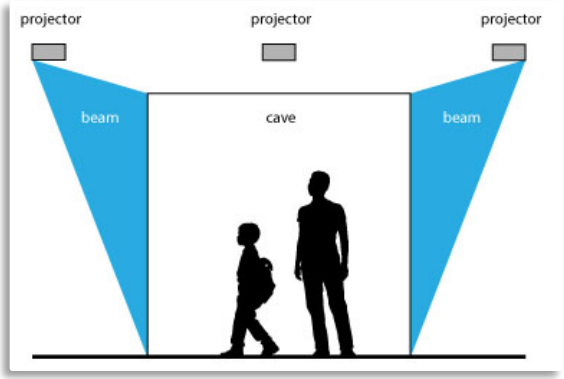
CAVE virtual environment

Different configurations

- Space issue:
  - Initially required a surface much larger than the VR working area due to the distance of projection
  - High cost (~1M$)

- Solutions:
  - 1. Using mirror
  - 2. Using short range projectors
    - Used for most modern solutions

      (cost within 10-50 K$)



CAVE computation

- **Perspective projection**

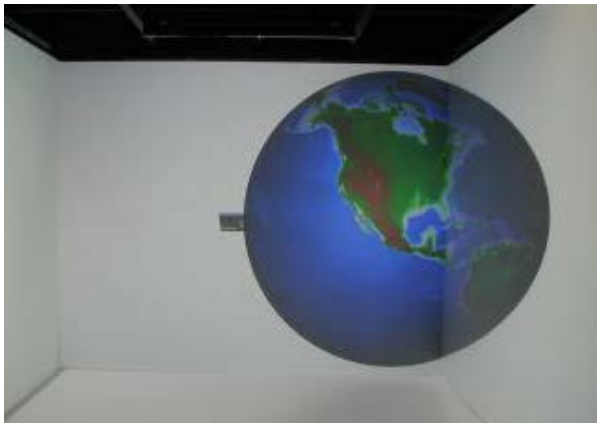
Unique "natural" viewpoint of this sidewalk painting

One wrong viewpoint of this sidewalk painting from Julian Beever

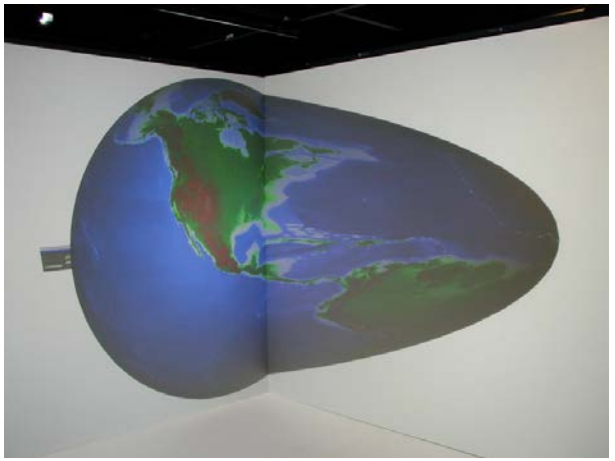
CAVE computation

- **Perspective projection**
  - graphically approximates on a 2D region the images of a 3D scene
  - approximate the actual visual perception

Head tracking viewpoint



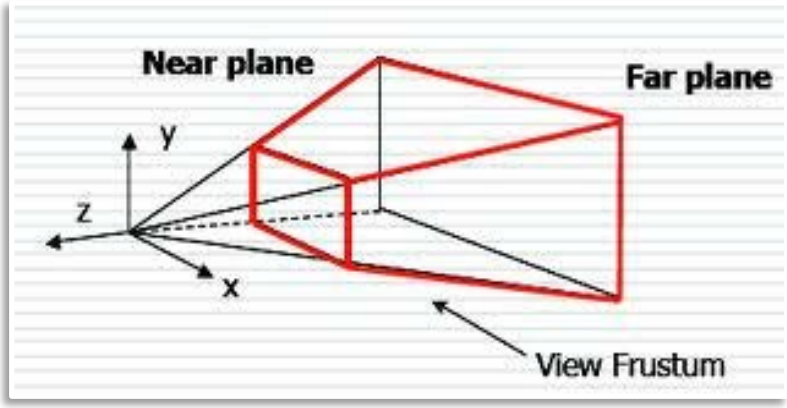
Consistent display projection from the subjective viewpoint



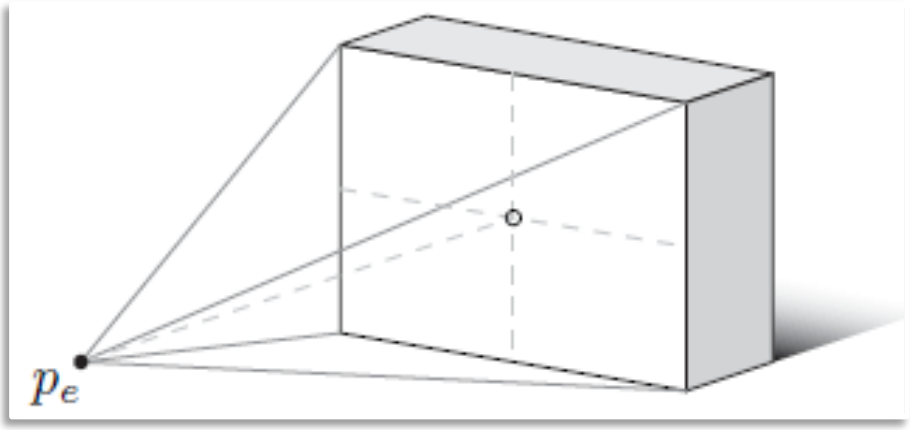
The same display viewed from a different location in the CAVE appears distorted

CAVE computation

- **Let's define**



Specific frustum volume for CG

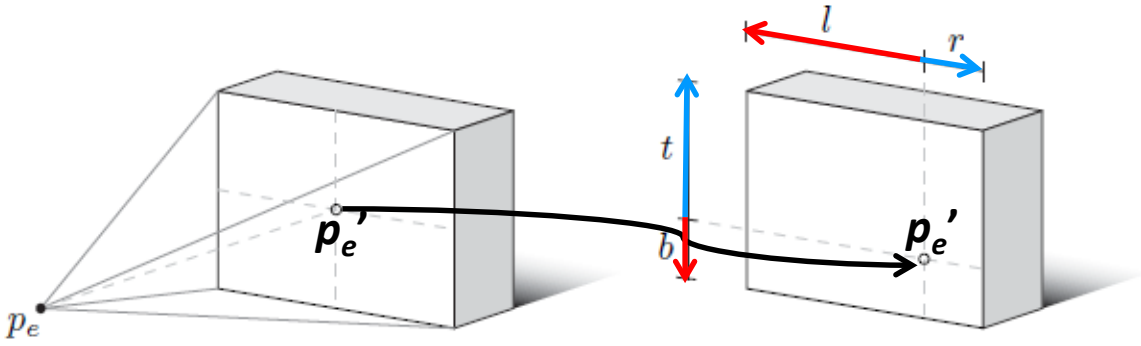


If $\mathbf{p_e}$ *projected on the center, a regular projection function can be used* (`gluPerspective`)

CAVE computation

- **CAVE general case :**
  - No more a standard ***central*** perspective

- ***p*$_e$'** viewpoint projection can be ***anywhere on the screen***



Apex of the frustum: the ***p*$_e$** *viewpoint*

Projection of ***p*$_e$** *and the 4 parameters of the frustum*

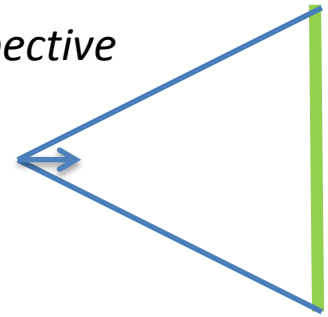
A frustum deformation function must be used (`glFrustum`)

CAVE computation

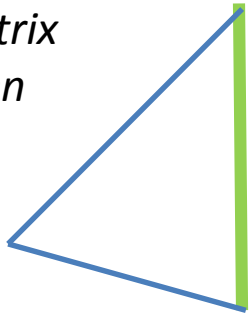
- **Symmetric vs. Asymmetric perspective**
  - **Symmetric frustum**, meaning that along their view direction, they have the same Field Of View (FOV) on the left side and on the right side
  - The **asymmetric frustum perspective** is not oriented (look through window)
  - The **Asymmetric perspective** can also be exploited for computing the **left and right stereo views** whose viewpoints are separated by the Inter-Pupillary Distance (**IPD**)

top view

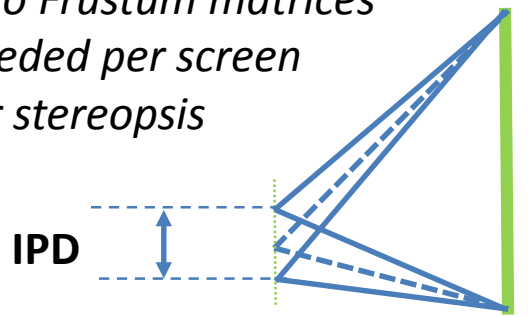
Regular perspective



One Frustum matrix needed per screen

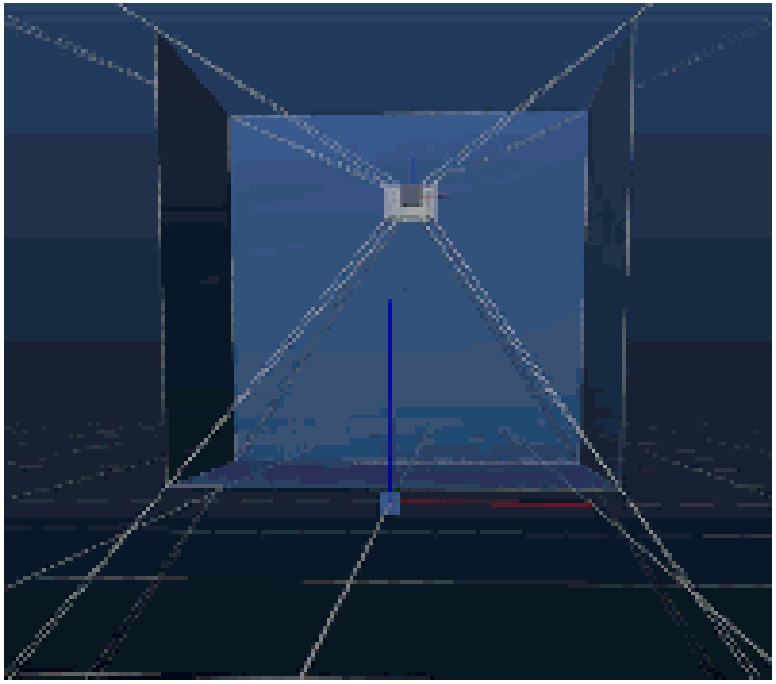


Two Frustum matrices needed per screen for stereopsis



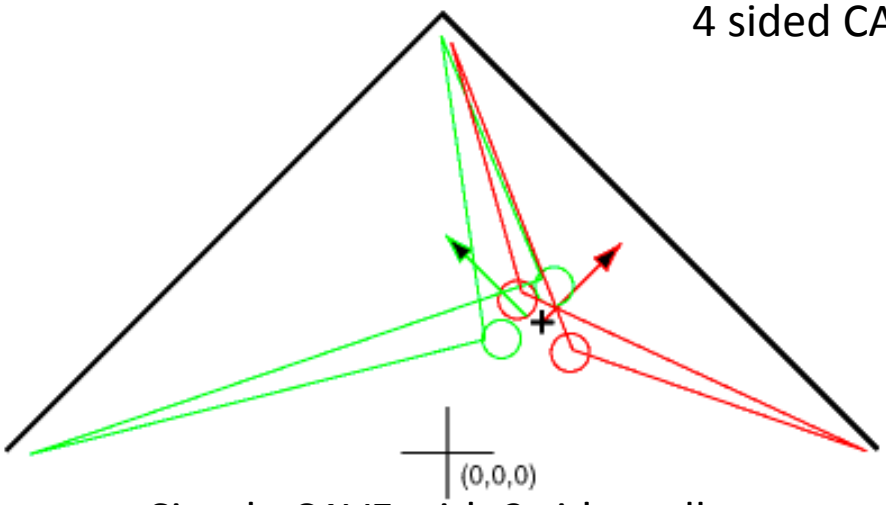
CAVE computation

- Only the head position is important for asymmetric frustum in CAVE (orientation has no more importance)



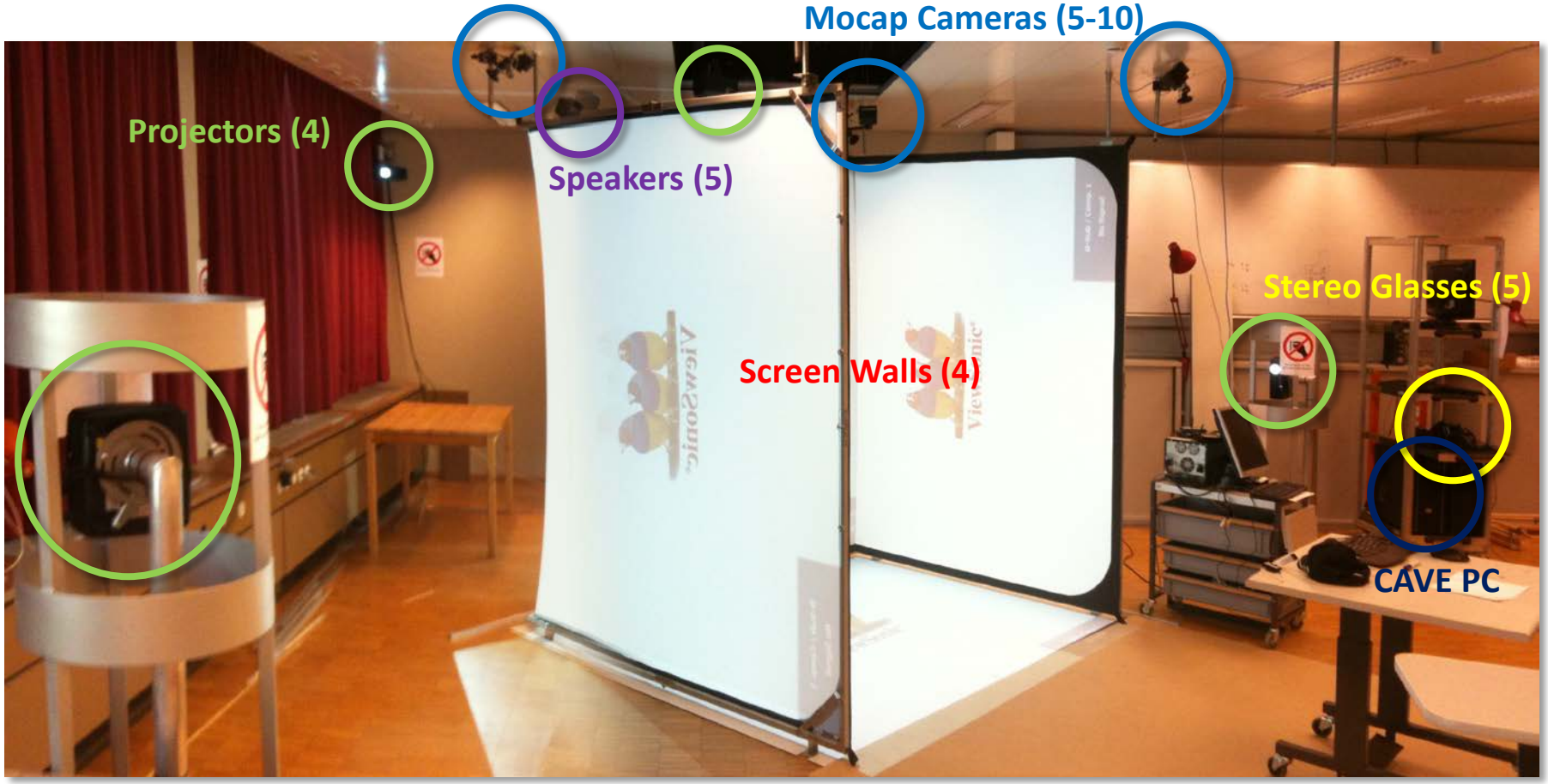
4 sided CAVE

- For implementing stereo, the left and right viewpoints are deduced from the unique user-provided 3D point

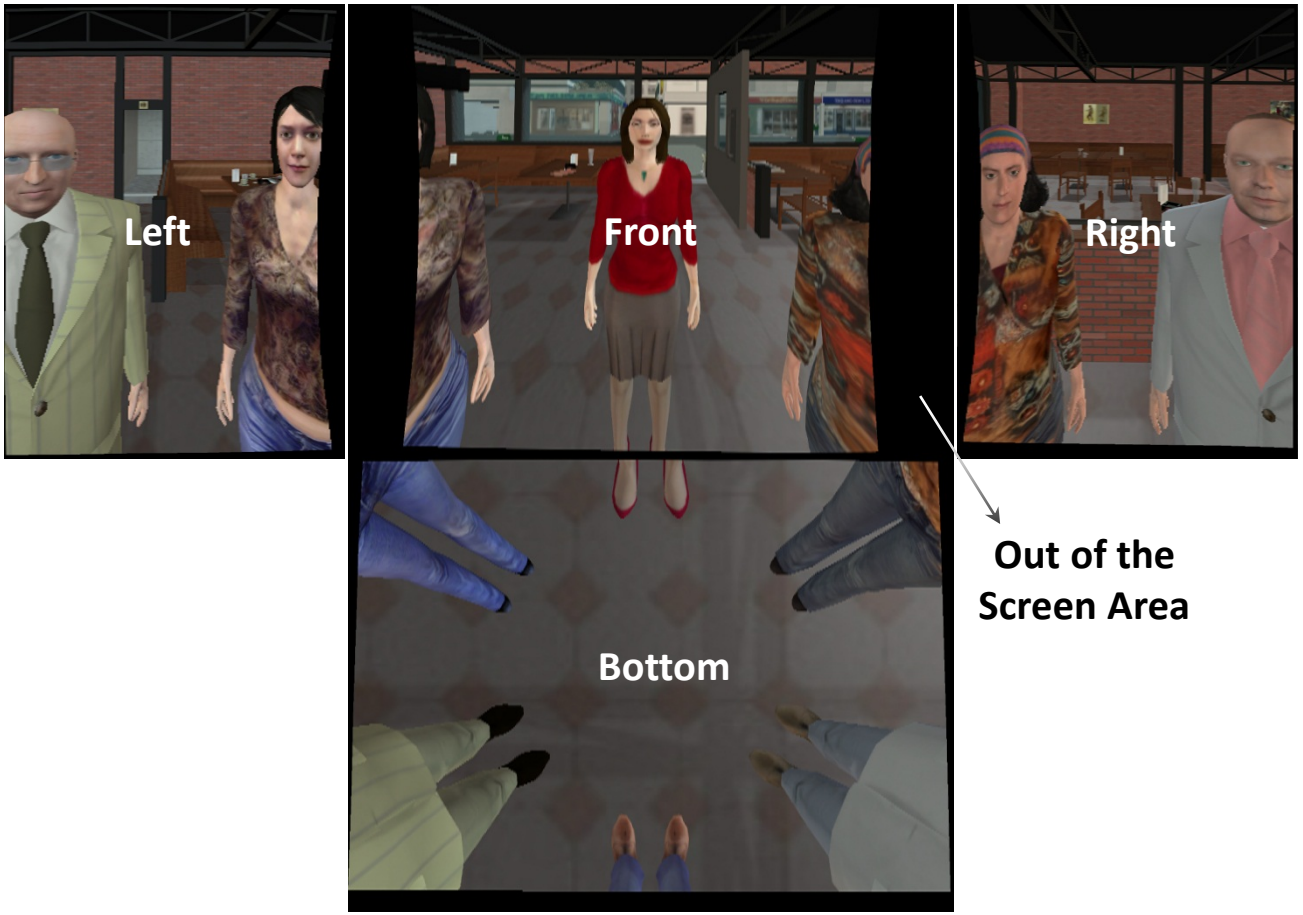


Simple CAVE with 2 side walls.
Note the 2 viewpoints parallel to
the screens for computing stereopsis

EPFL IIG CAVE



EPFL IIG CAVE

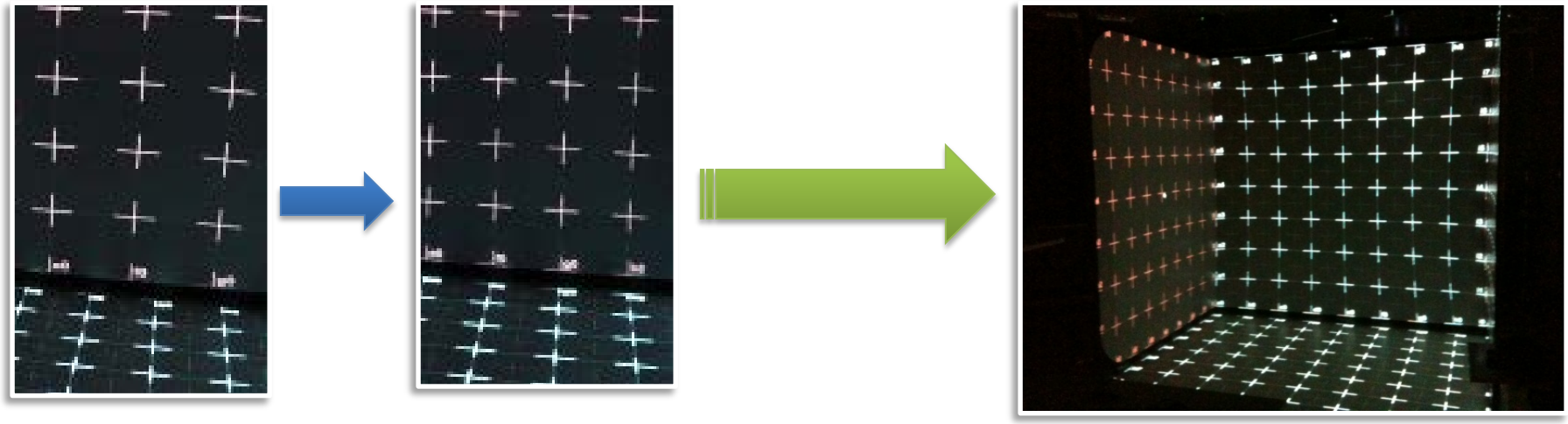


Projected Images from Each Projector:
Rendered images on the ideal projection planes are deformed to adjust to the slightly curved screens

CAVE computation

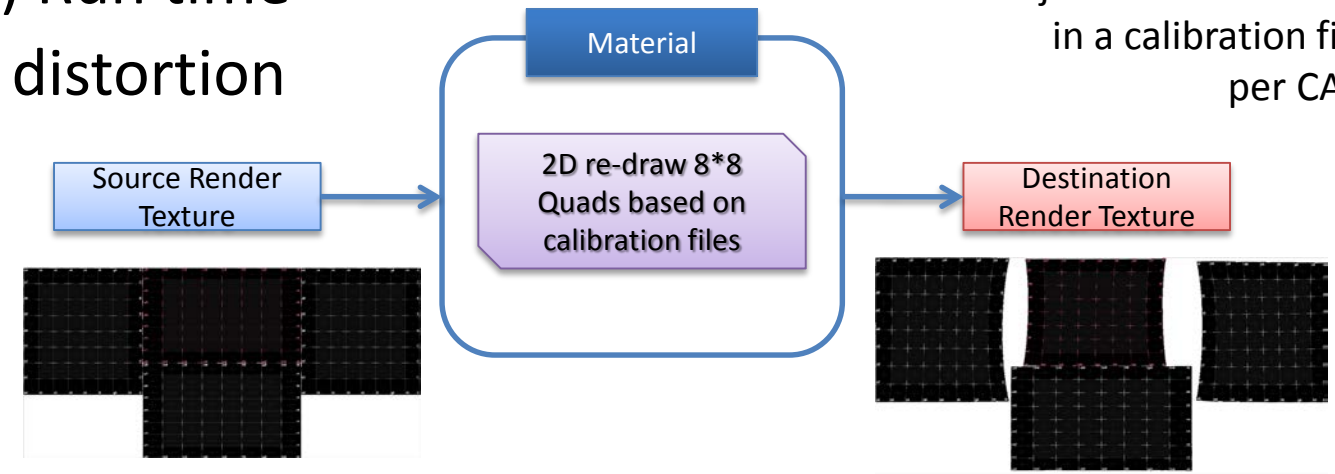
- **Mapping to Walls**

  1) Use of a regular 8x8 grid =>texture for calibration



Align textures at the screens junctions and record the results in a calibration file (done once per CAVE)

2) Run time distortion



Comparing CAVE and Head-Mounted Display

	4 walls CAVE	**HMD**
FOV (degrees)	180°-200°	~100°
FOR (degrees)	270°	360%
invasiveness	Low (stereo glasses)	High (+wire)
Minimal tracking	Only a 3D viewpoint	Requires head orientation too
Sharable Virtual environment	Easier for team discussion	cut from the real world
Computing cost	HMD_cost x nb_walls	CAVE_cost / nb_walls
Total cost	Still very high	Becomes affordable

Recent evolution in Experimental Museology

(EPFL EMPLUS Lab from Prof. sarah Kenderdine)

- Purposes:
  - preserving archeological sites from visitors
  - Providing at least a copy at scale 1
  - Enriching it with more content (information, 3D models and animation)
  - Visit can be shared by groups
  - stereo may not be necessary for large immersive installations

Recent evolution in Experimental Museology

(EPFL EMPLUS Lab from Prof. sarah Kenderdine)