

CAVE and Immersive spaces

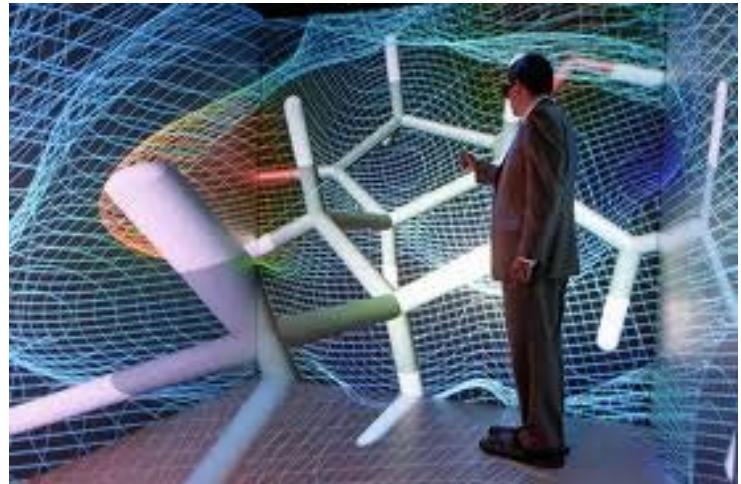
EPFL Immersive Interaction Group
N. Wang & R. Boulle

Outline

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

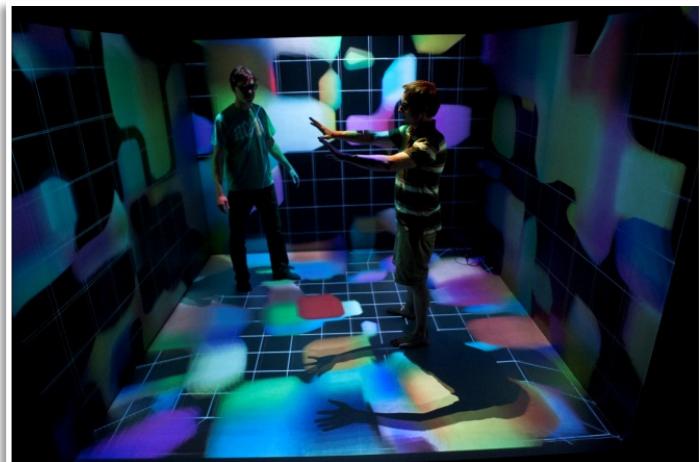
General concepts

- **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 complex 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).*

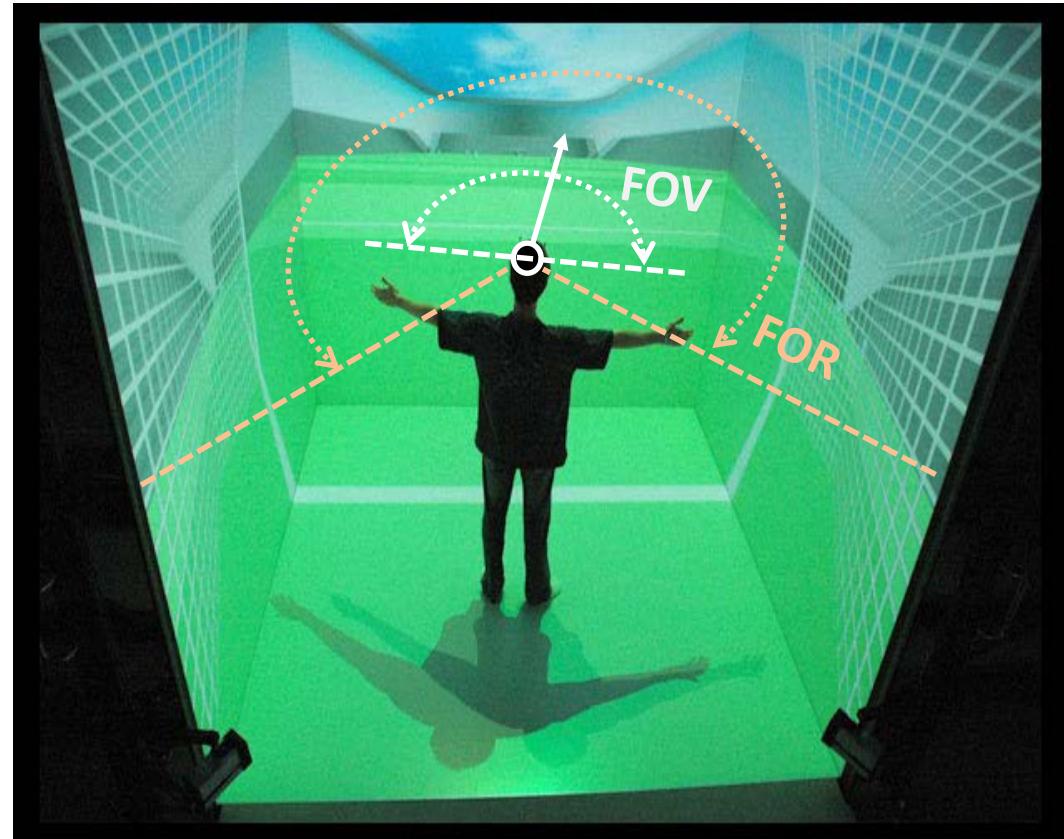


Two criteria for comparing CAVEs

- 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]

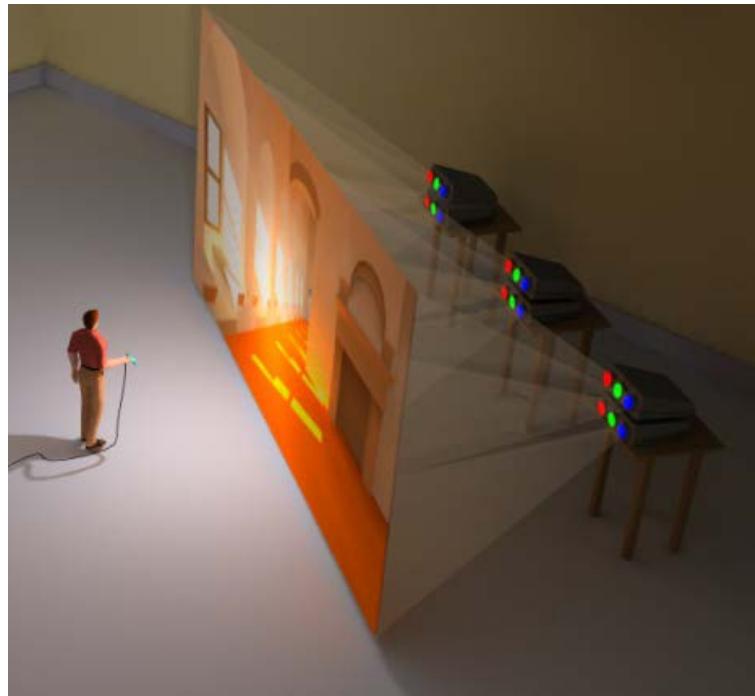
- Field of regard (FOR):

– *Measured horizontally in % or in degrees:*

amount of space of the virtual world currently surrounding the user

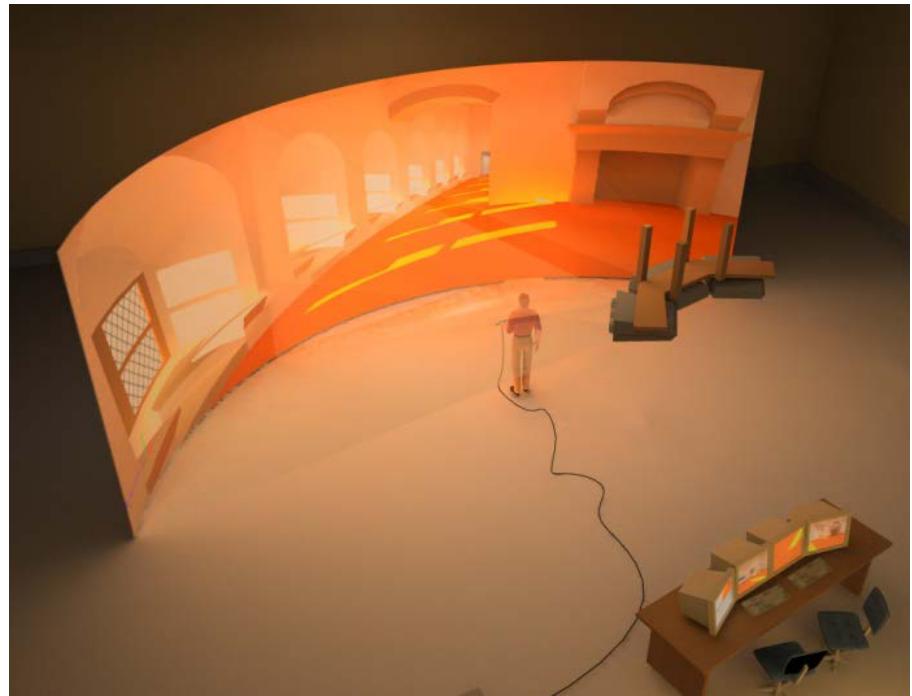
Different configurations (1:2)

- Difference between «Walls» and «CAVE»



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Wall virtual environment

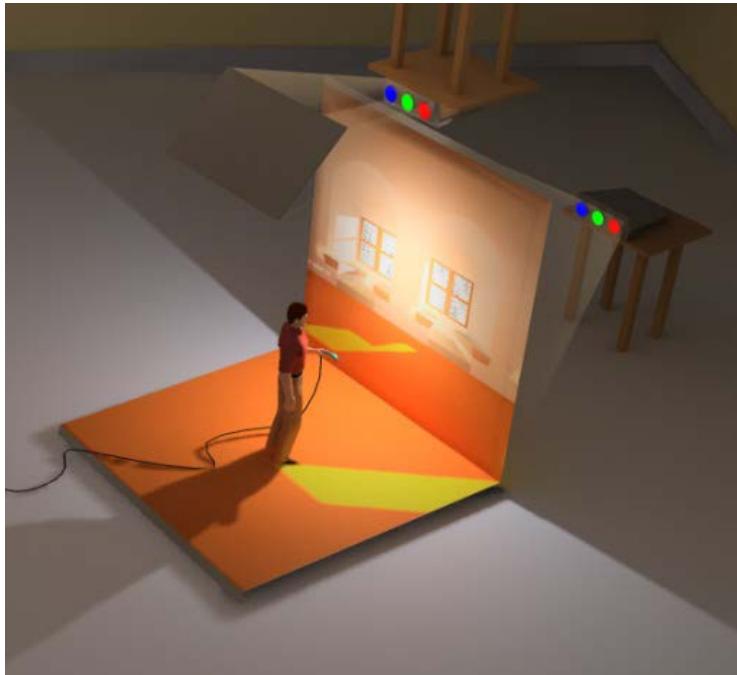


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Curved wall virtual environment

Different configurations (2:2)

- Difference between «Walls» and «CAVE»



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2-screens CAVE virtual environment

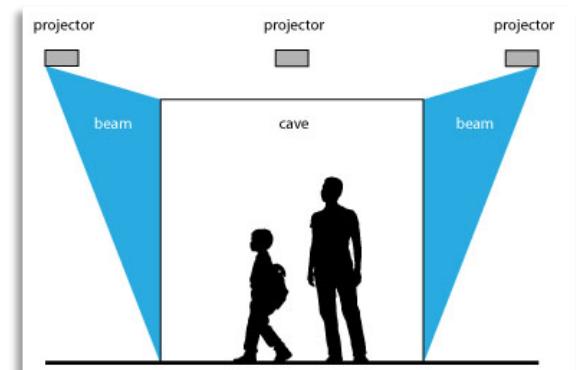


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CAVE virtual environment

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



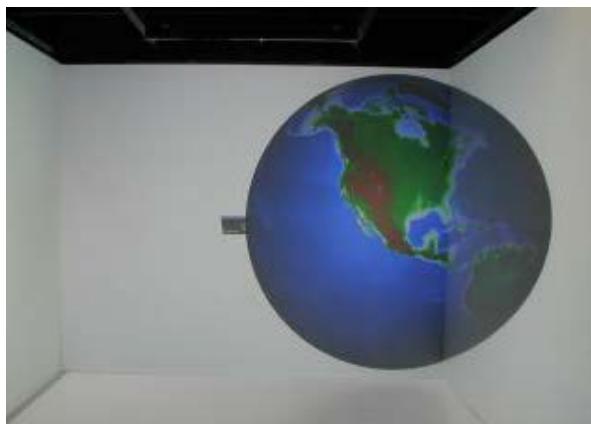
One wrong viewpoint of this sidewalk painting from Julian Beever

CAVE computation

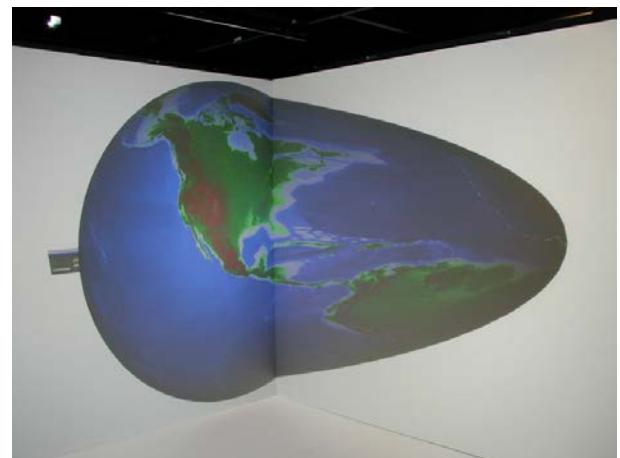
- **Perspective projection**
 - graphically approximates on a 2D region the images of a 3D scene
 - approximate the actual visual perception



Head tracking viewpoint



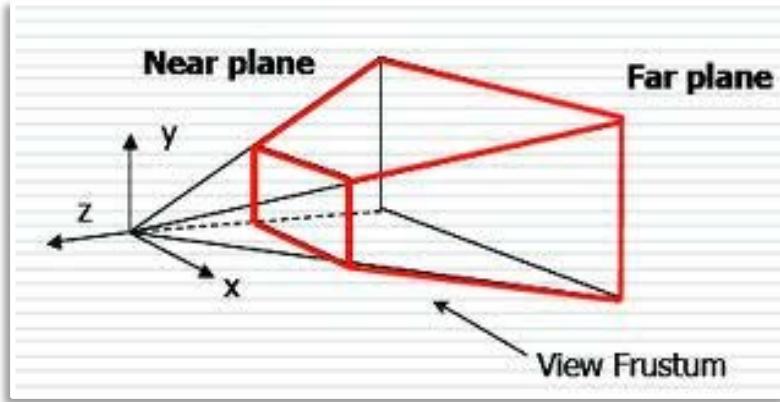
*Consistent display projection
from the subjective
viewpoint*



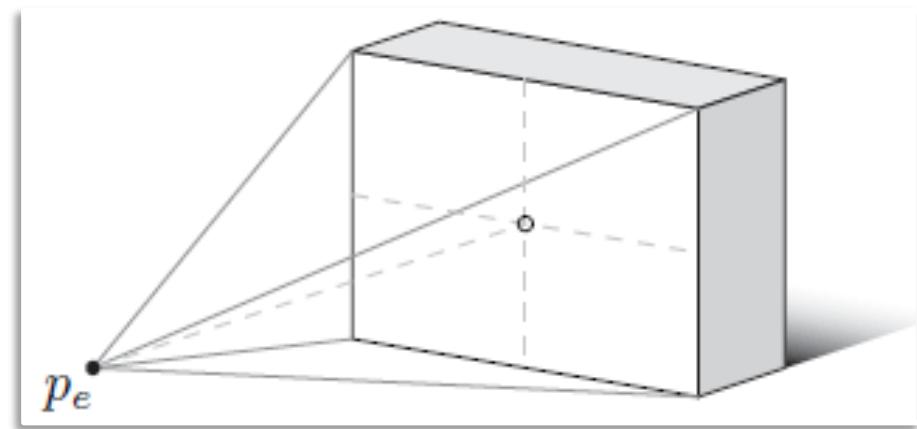
*The same display viewed from a
different location in the CAVE
appears distorted*

CAVE computation

- Let's define



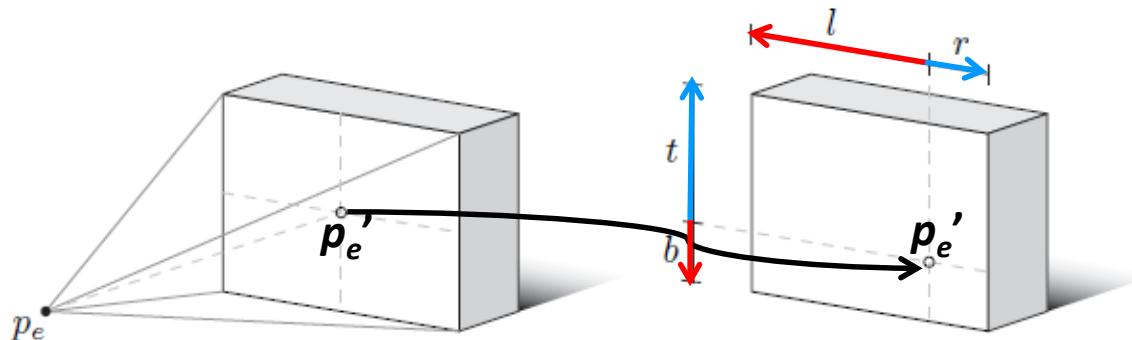
*Specific frustum
volume for CG*



*If 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**

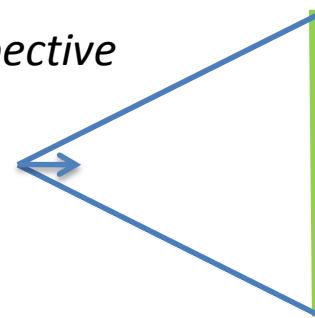
- **Symmetric frustum**, meaning that along their view direction, they have the same Field Of View (FOV) on the left side and on the right side

- The **asymmetric frustum perspective** is not oriented (look through window)

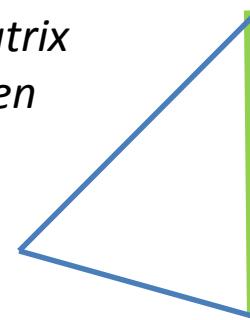
- The **Asymmetric perspective** can also be exploited for computing the **left and right stereo views** whose viewpoints are separated by the Inter-Pupillary Distance (**IPD**)

top view

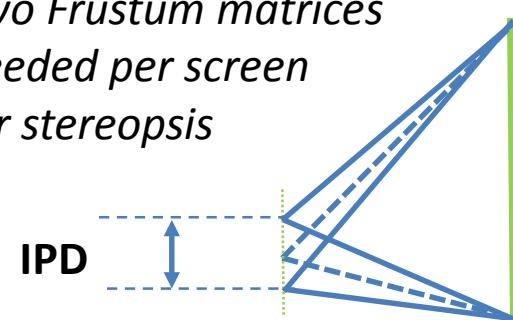
Regular perspective



One Frustum matrix needed per screen

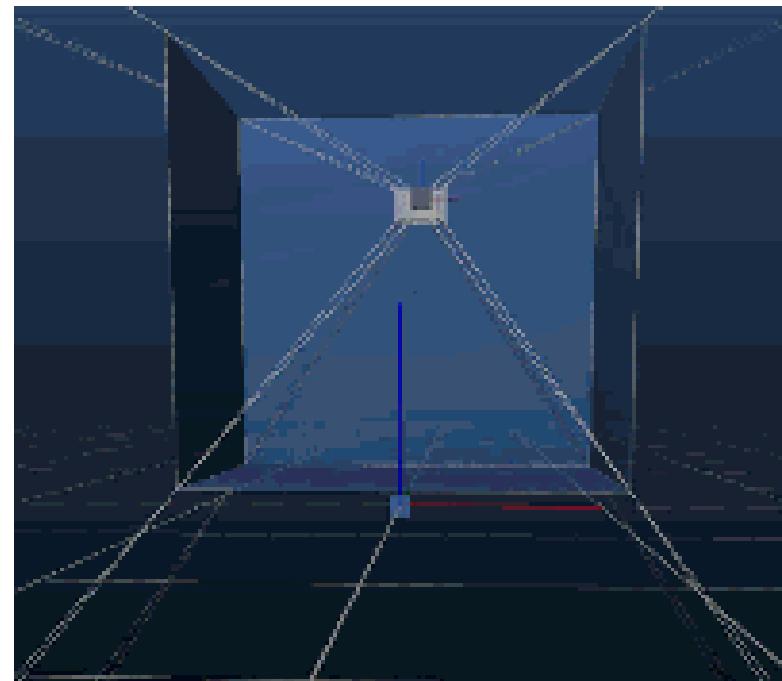


Two Frustum matrices needed per screen for stereopsis

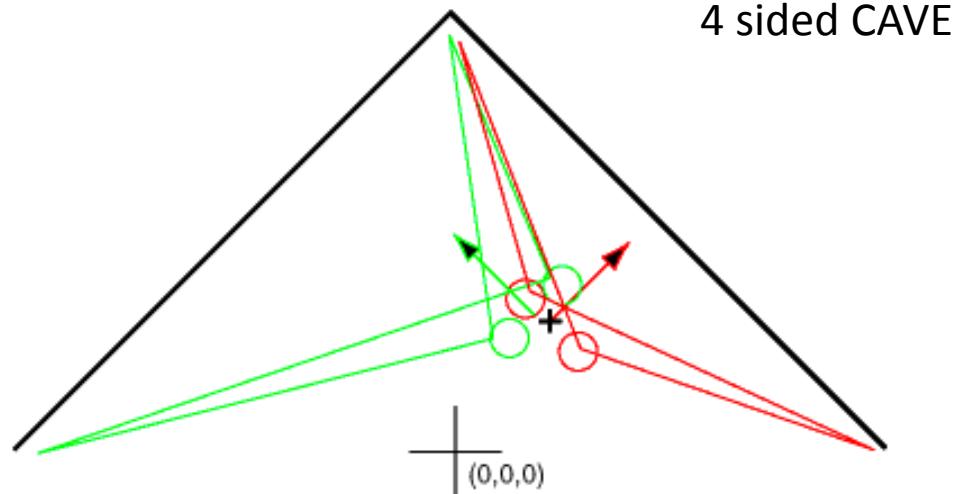


CAVE computation

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

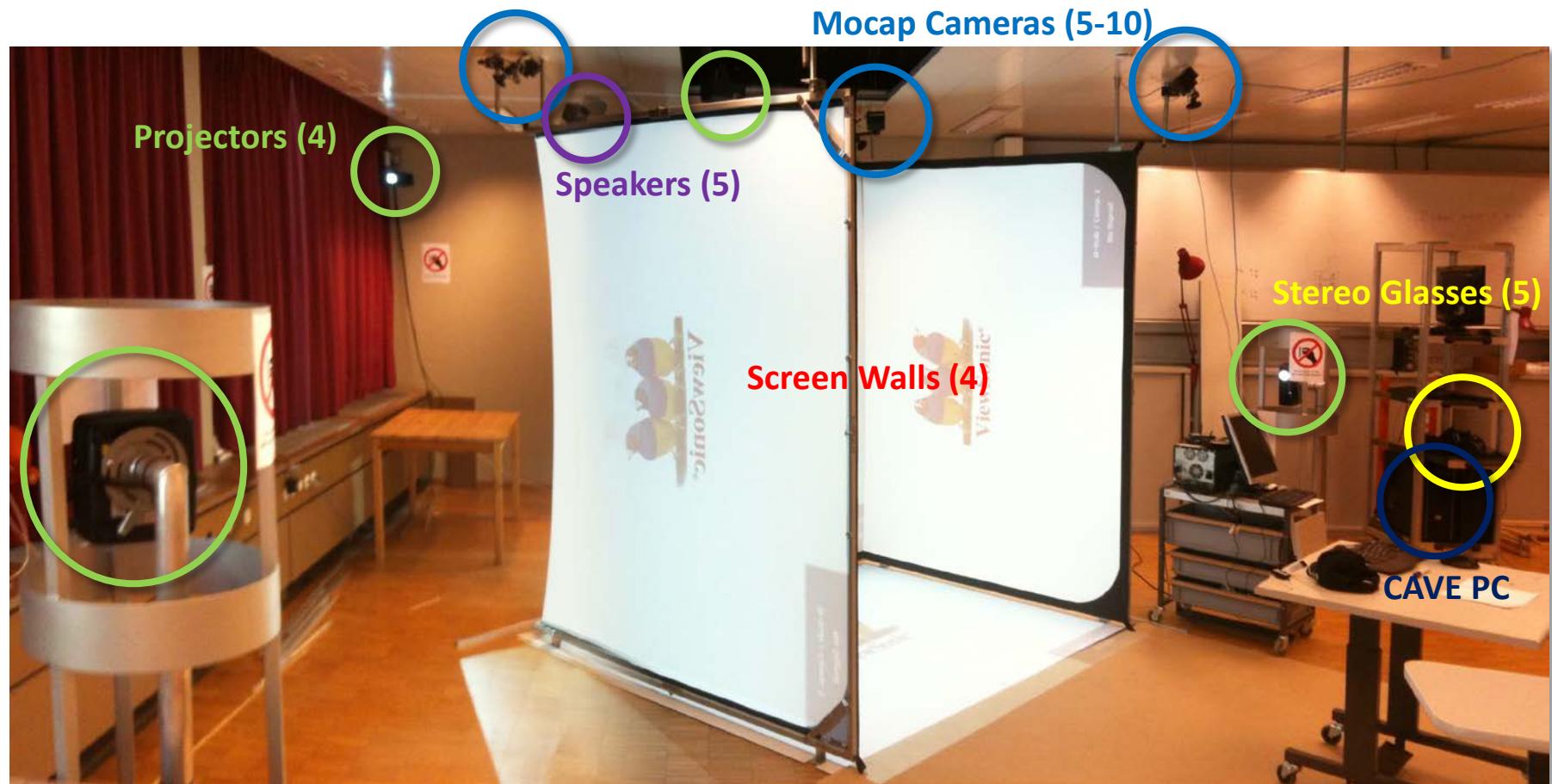


- For implementing stereo, the left and right viewpoints are deduced from the unique user-provided 3D point



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

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EPFL IIG CAVE



Out of the
Screen Area

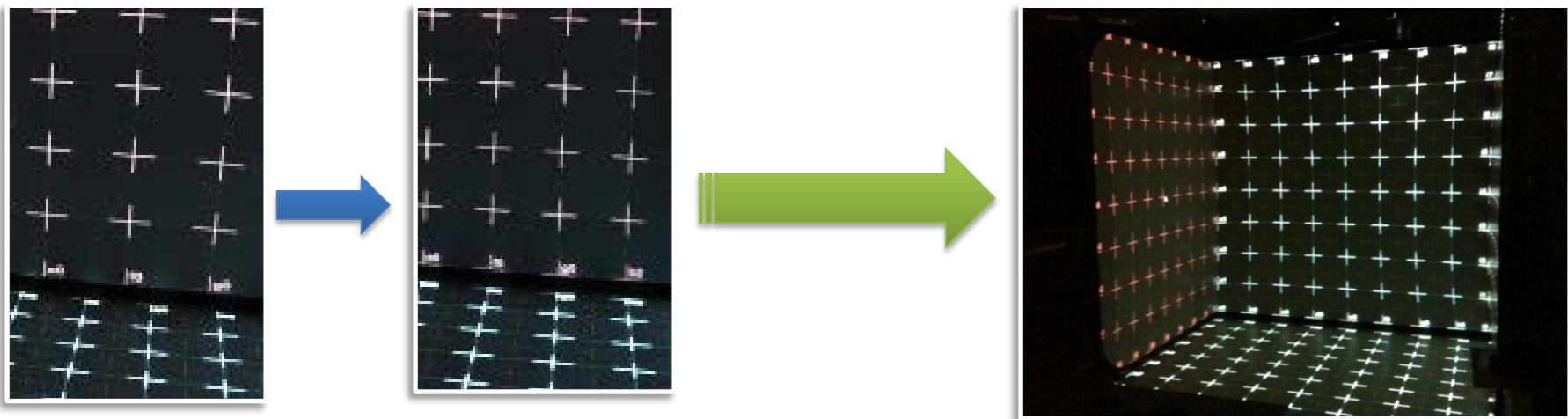


Projected Images from Each Projector:
Rendered images on the ideal projection planes
are deformed to adjust to the slightly curved screens

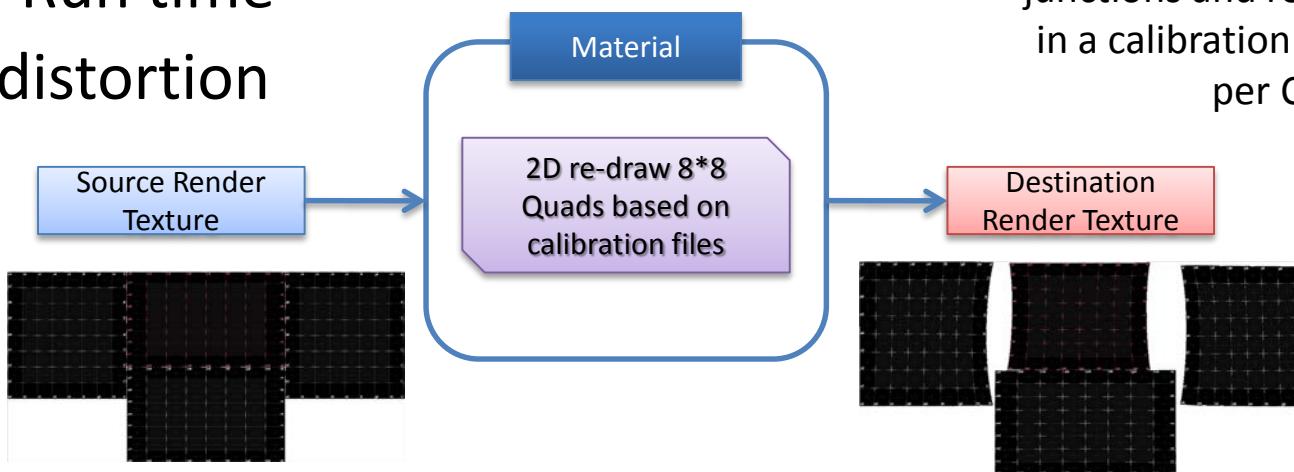
CAVE computation

- **Mapping to Walls**

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



- 2) Run time distortion



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

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

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