Many-Camera Systems:

How They Started at CMU up to EyeVision at 2001 Superbowl

CVPR 2017 in Honolulu

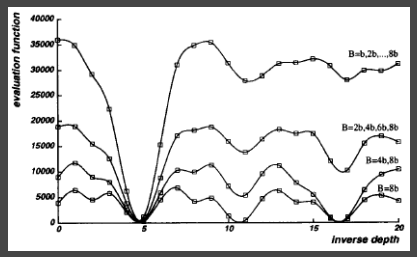
Takeo Kanade

Robotics Institute

Carnegie Mellon University

Video-Rate Multi-Camera Stereo Machine Project (1991-1996) for Real-time Range Mapping

Okutomi-Kanade Multi-baseline stereo theory 1990



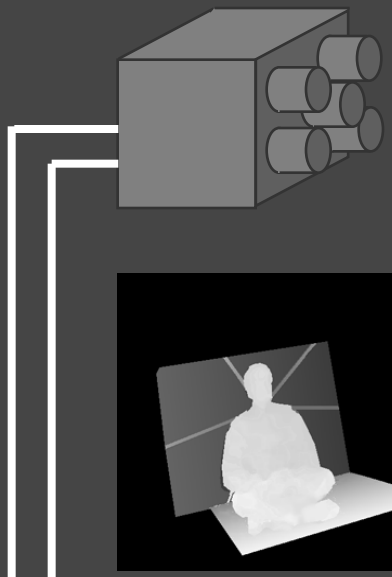
Multi-camera Stereo

v.1

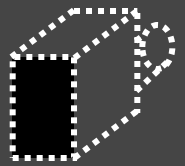
v.2

Outputs: **Color Image** 256 x 256 x 24 bits
Depth Image 200 x 200 x 8 bits at 30 fps

Soft Camera (aka Virtual Camera): Occlusion Problem



Range

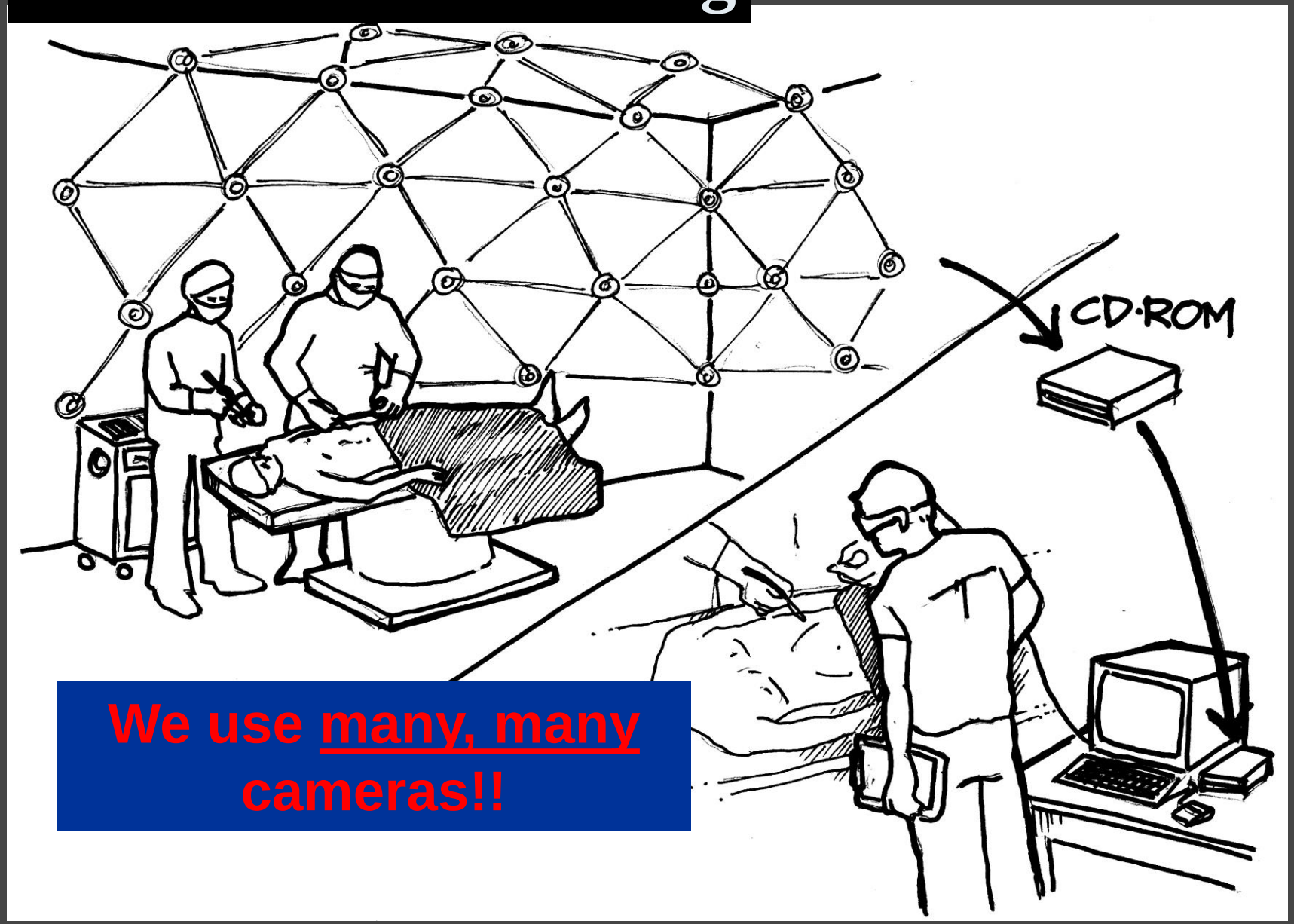


View Synthesis

Intensity/Color

Soft Camera Output

Whole-Scene Modeling

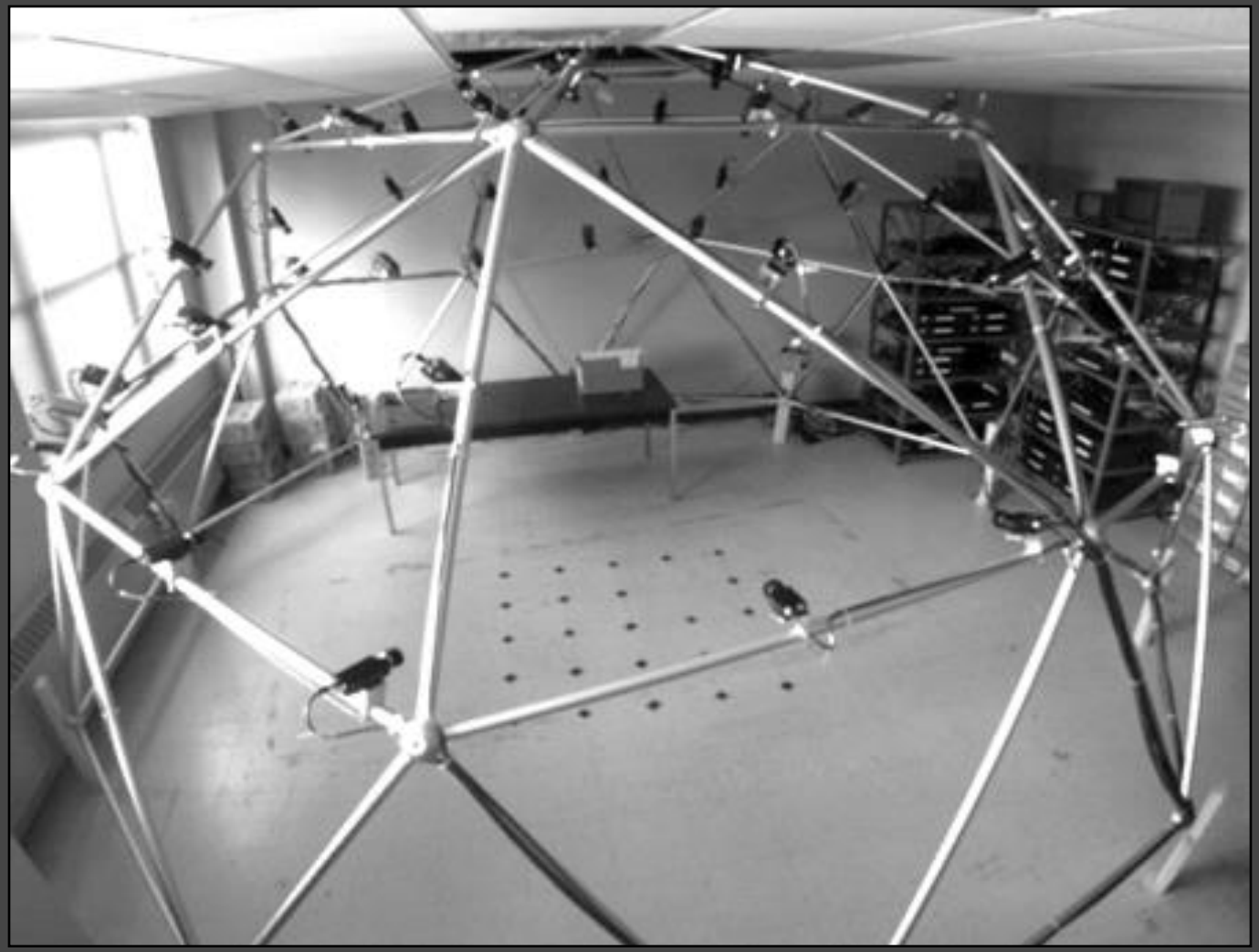


We use many, many cameras!!

3D Dome Analog system

with 10 BW Cameras - circa 1994

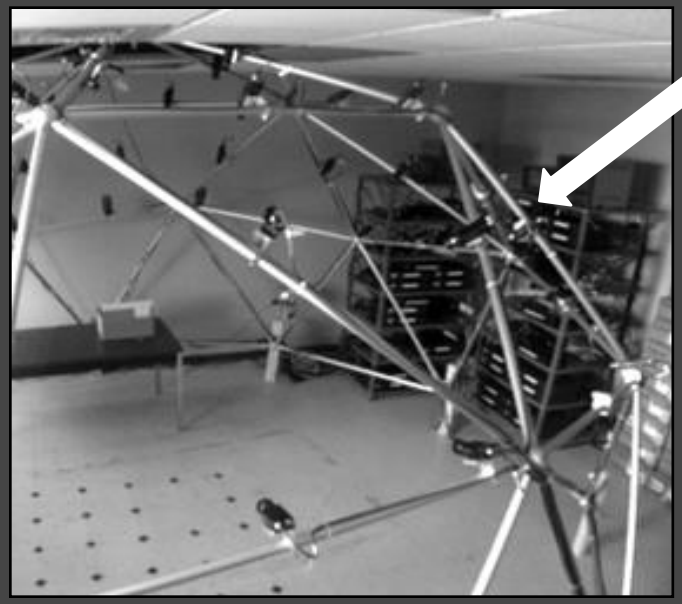
with 51 Color Cameras - circa 1995



Old and fun stories

Grad student vs. Robot

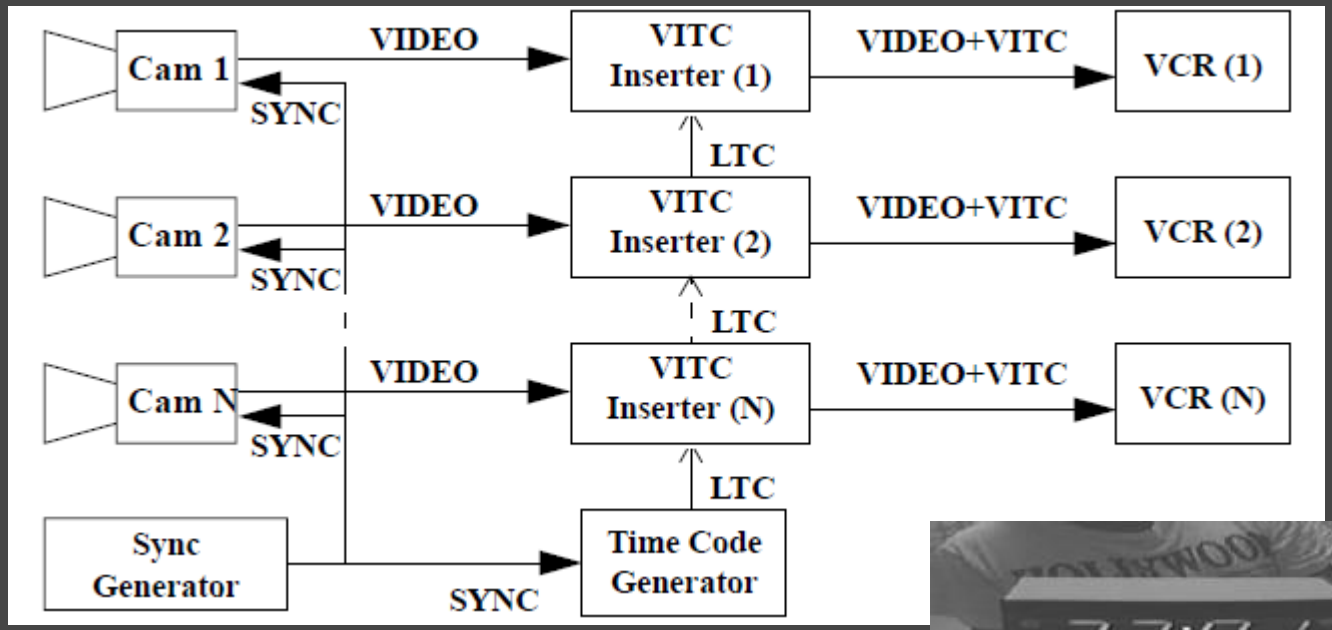
51 Analog
Video tape recorders

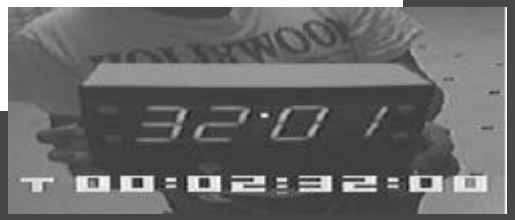


Old and fun stories

Grad student vs. Robot

Synchronization – nontrivial problem





Old and fun stories

Grad student vs. Robot

Synchronization – nontrivial problem

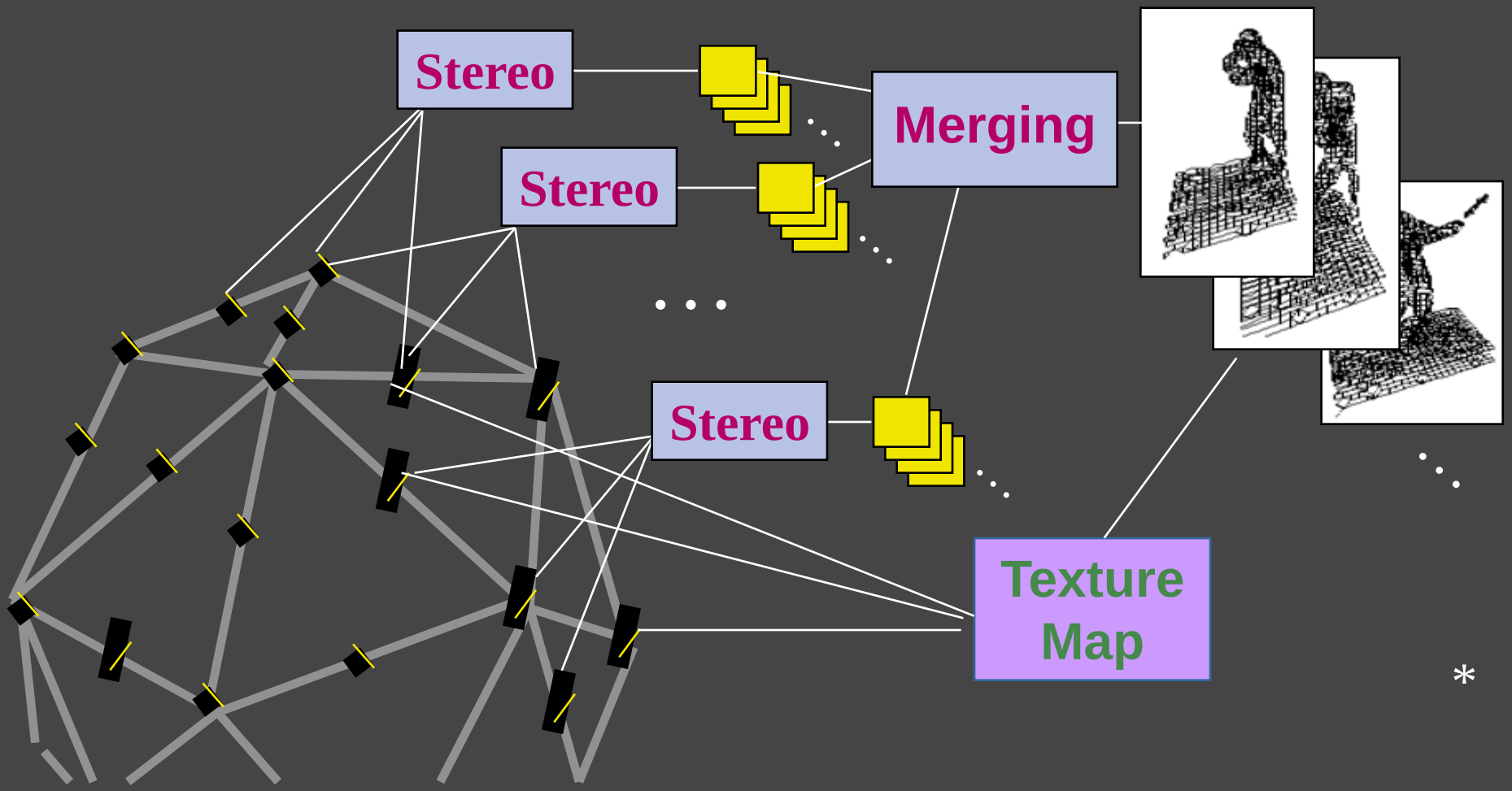
Our own digitizers

Figure 1: Vertical blanking portion of a frame containing VITC data

Old and fun stories

- Grad student vs. Robot
- Synchronization – nontrivial problem
- Our own digitizers
- Calibration pattern on special non-stretchable paper

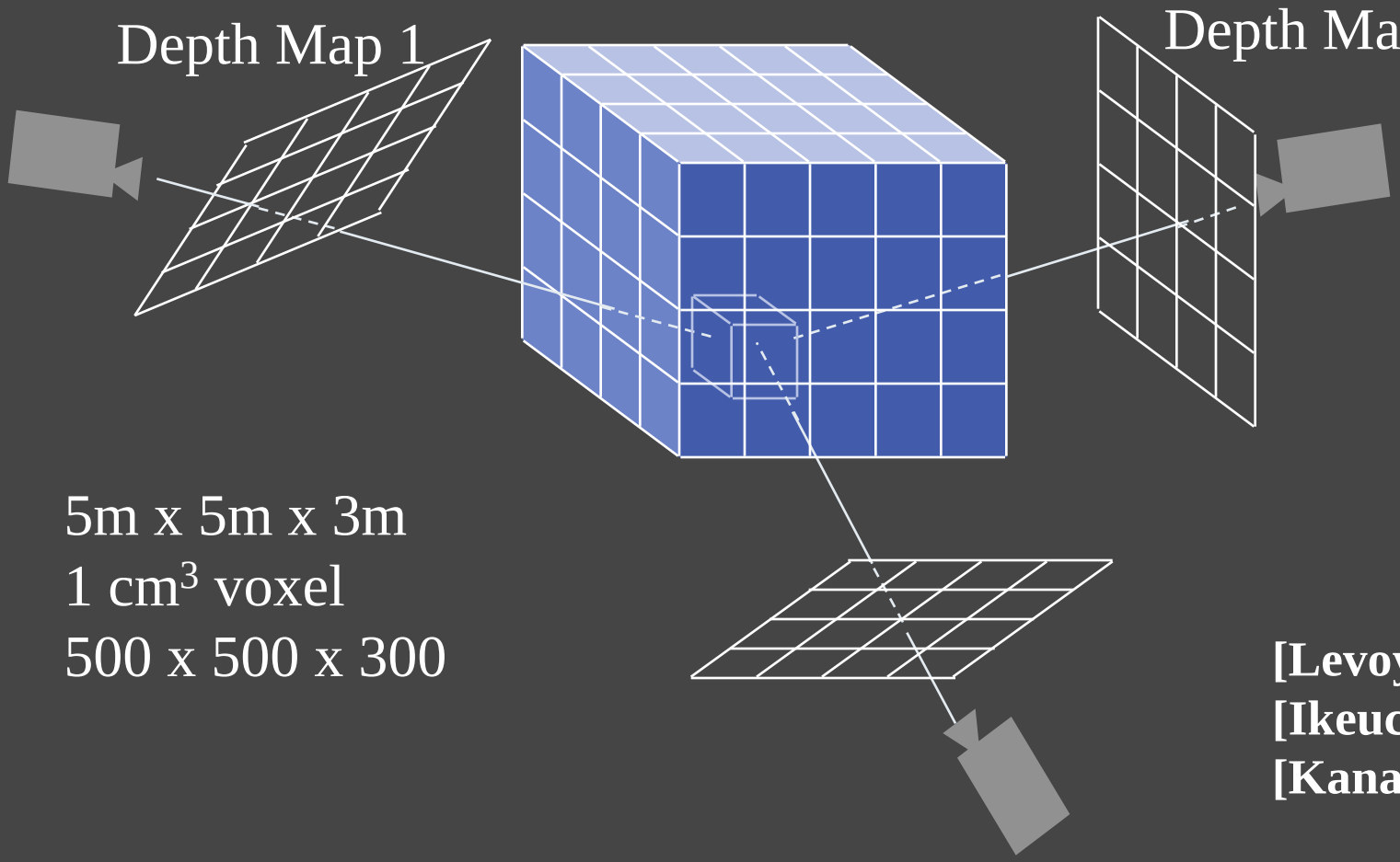
4D Full Body Surface Modeling



Voxel Merging

Implicit function:

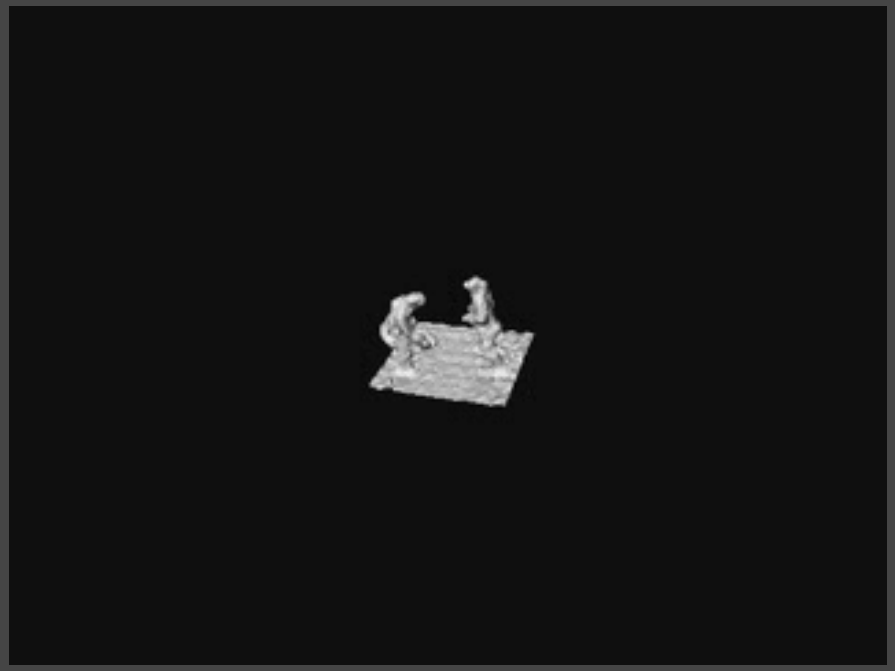
$$F(x,y,z) \begin{cases} > 0 & \text{outside} \\ = 0 & \text{on the surface} \\ < 0 & \text{inside} \end{cases}$$



5m x 5m x 3m
1 cm^3 voxel
500 x 500 x 300

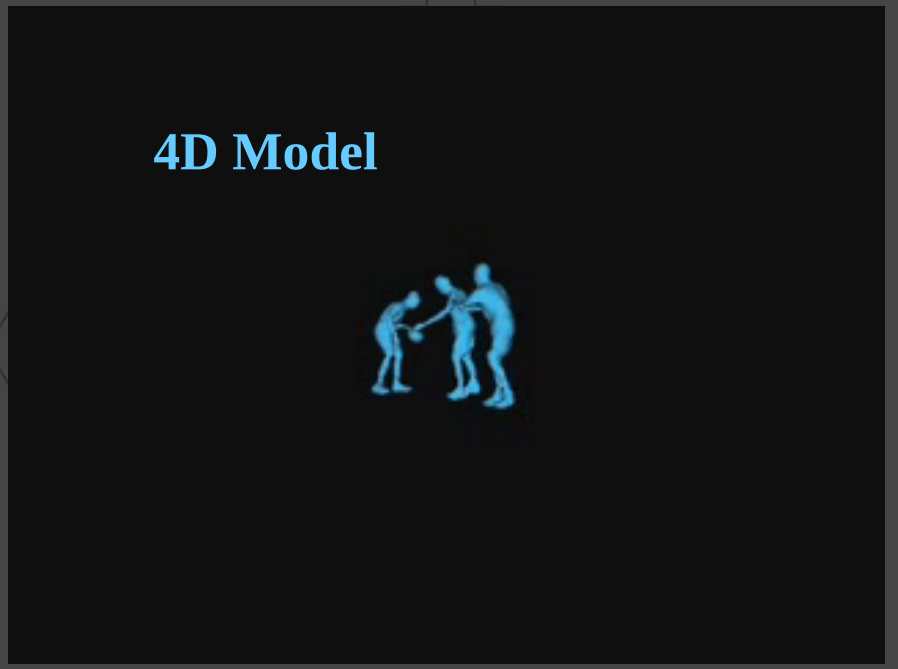
[Levoy, etal]
[Ikeuchi, etal]
[Kanade, etal]

4D Modeling
One on One – circa 1995

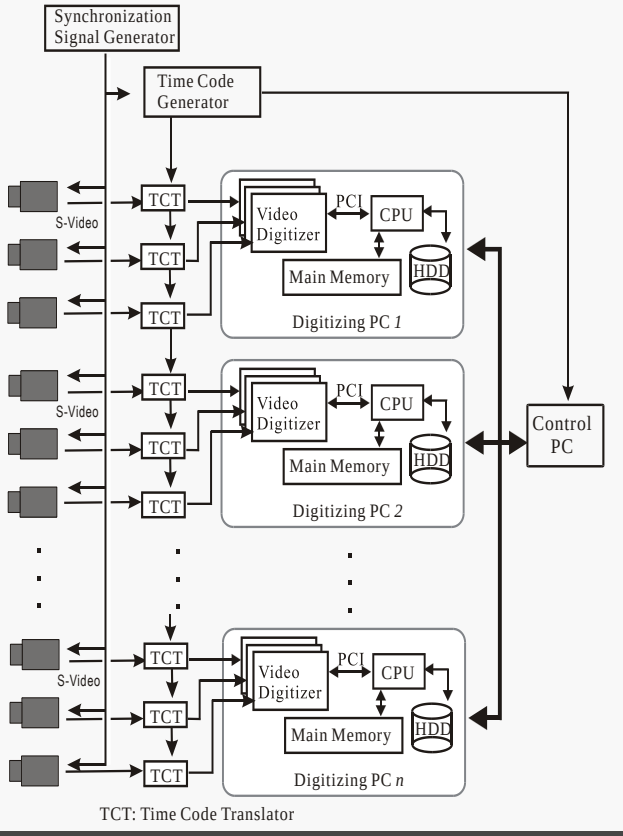


4D Digitization (1995)

Example:
3-Man Basketball



Fully Digital "3D Room" ~2000

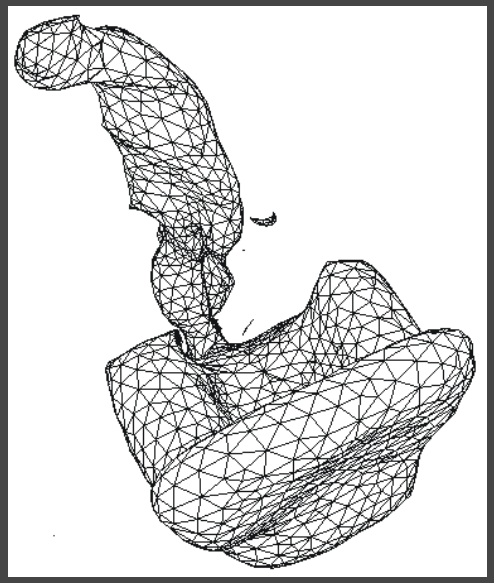


New 3D Room ~ 2003

4D Digitization (~2000):

Man-Sofa-Ball

Digital 3D Room: 39 High Quality Cameras

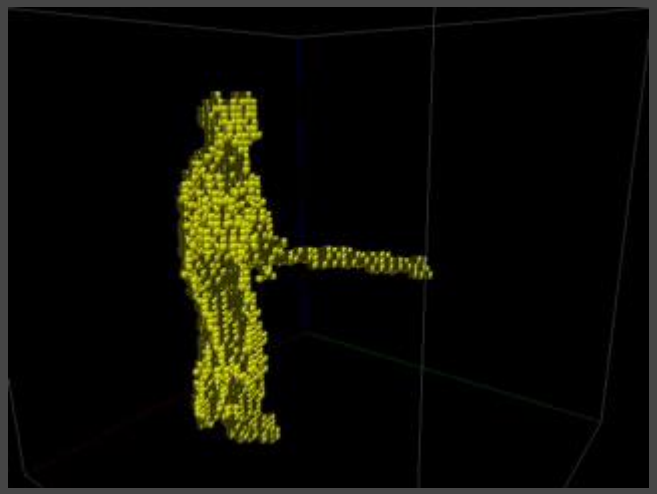


movies.)

sequence

Real Time 4D Digitization

- 64 x 64 x 64
- 10 frames/sec (with 5 PCs)
- Avatar creation

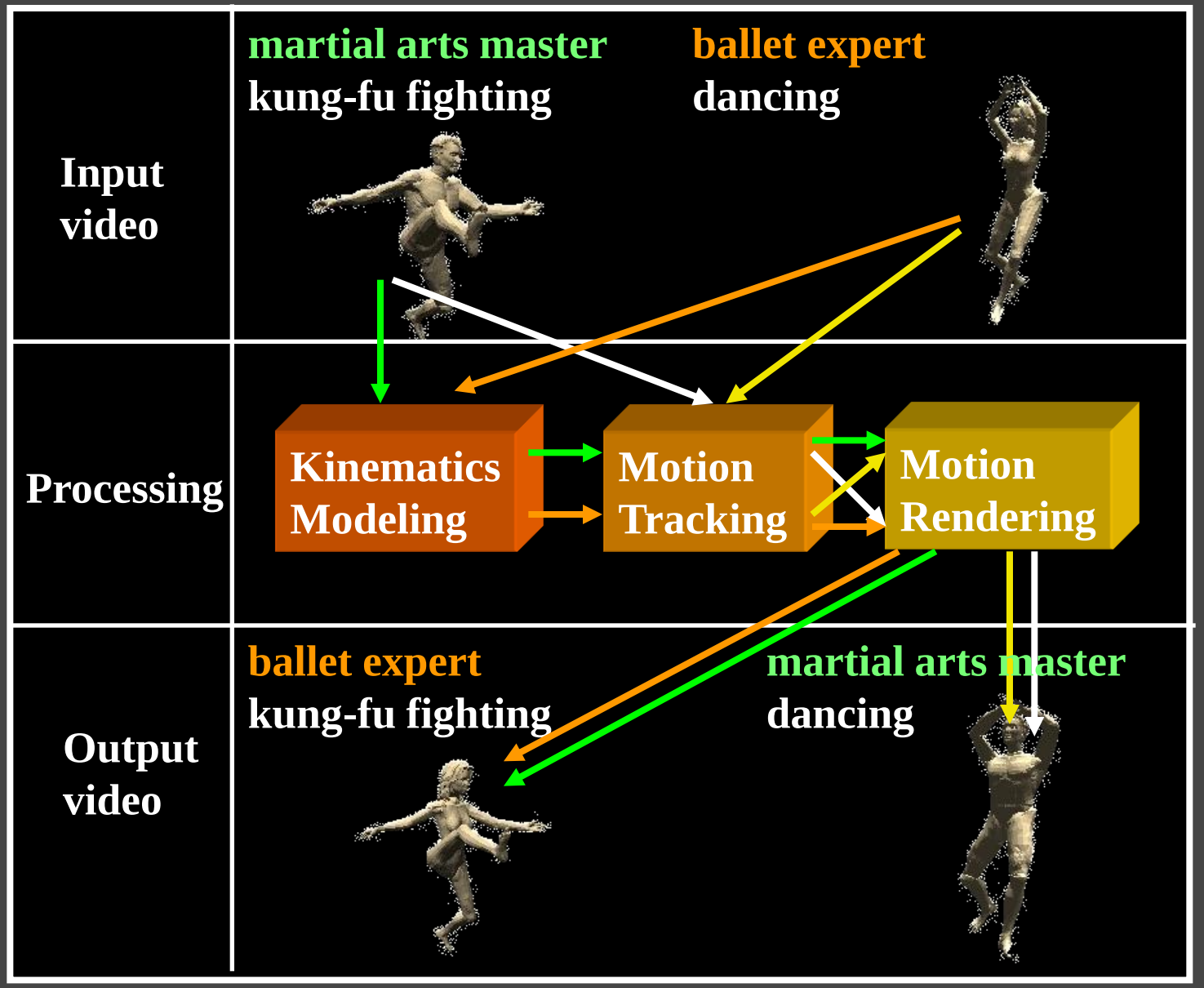


4D Digitization

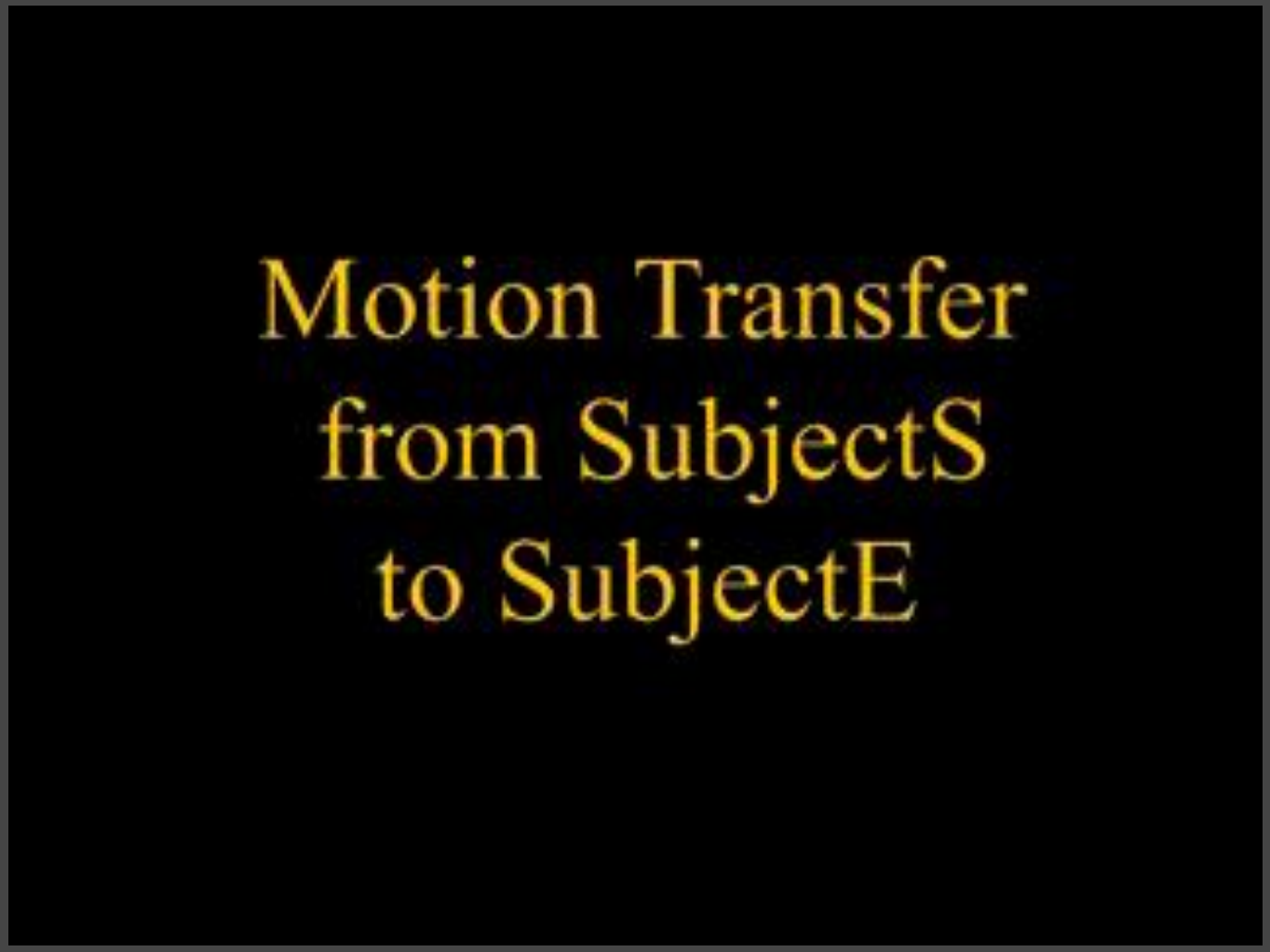
Example 5:
Dance
(Aug 2000)

Click to play

Markerless Motion Transfer



SubjectE performs SubjectS's THROW motion



EyeVision

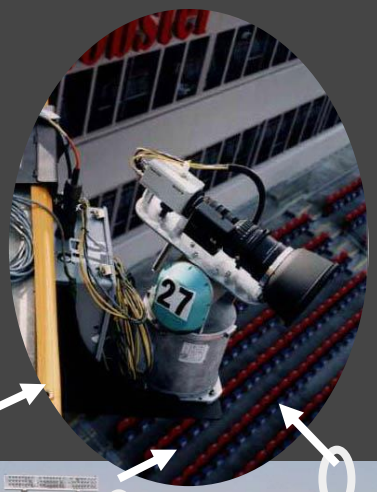
at

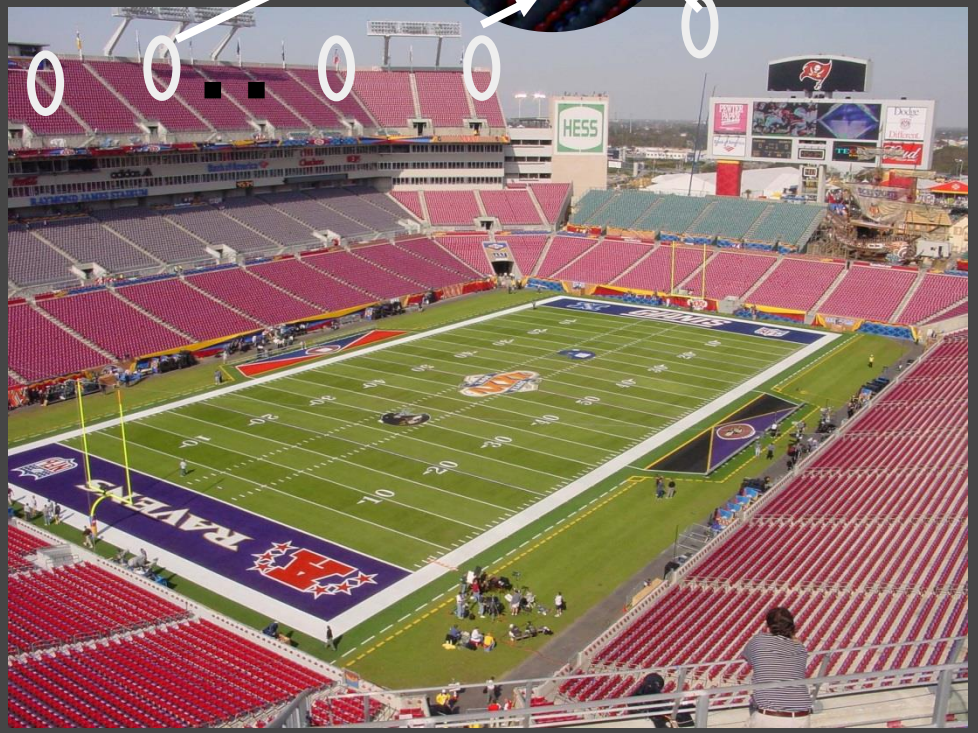
Super Bowl

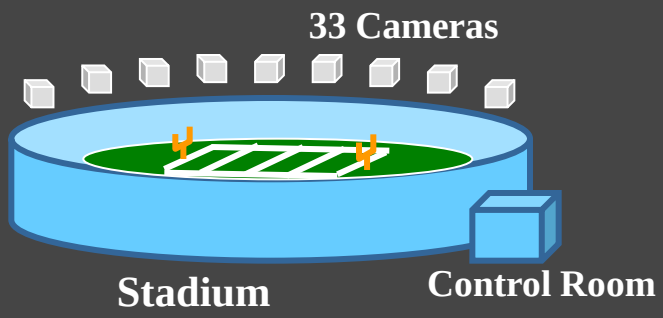
Movie "Matrix"-like replay
anywhere in the field

EyeVision at Super Bowl XXXV 2001

33 robot cameras

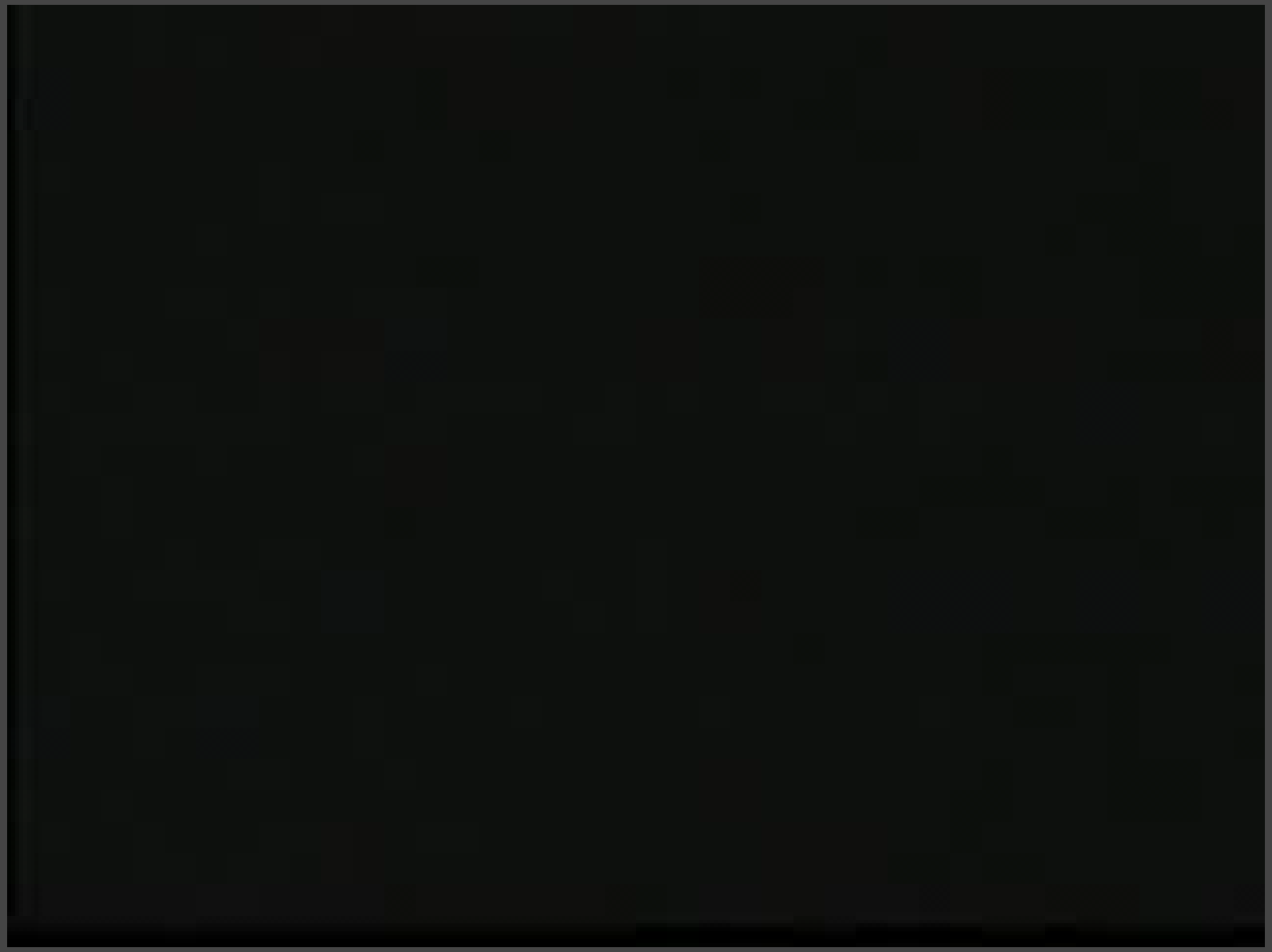






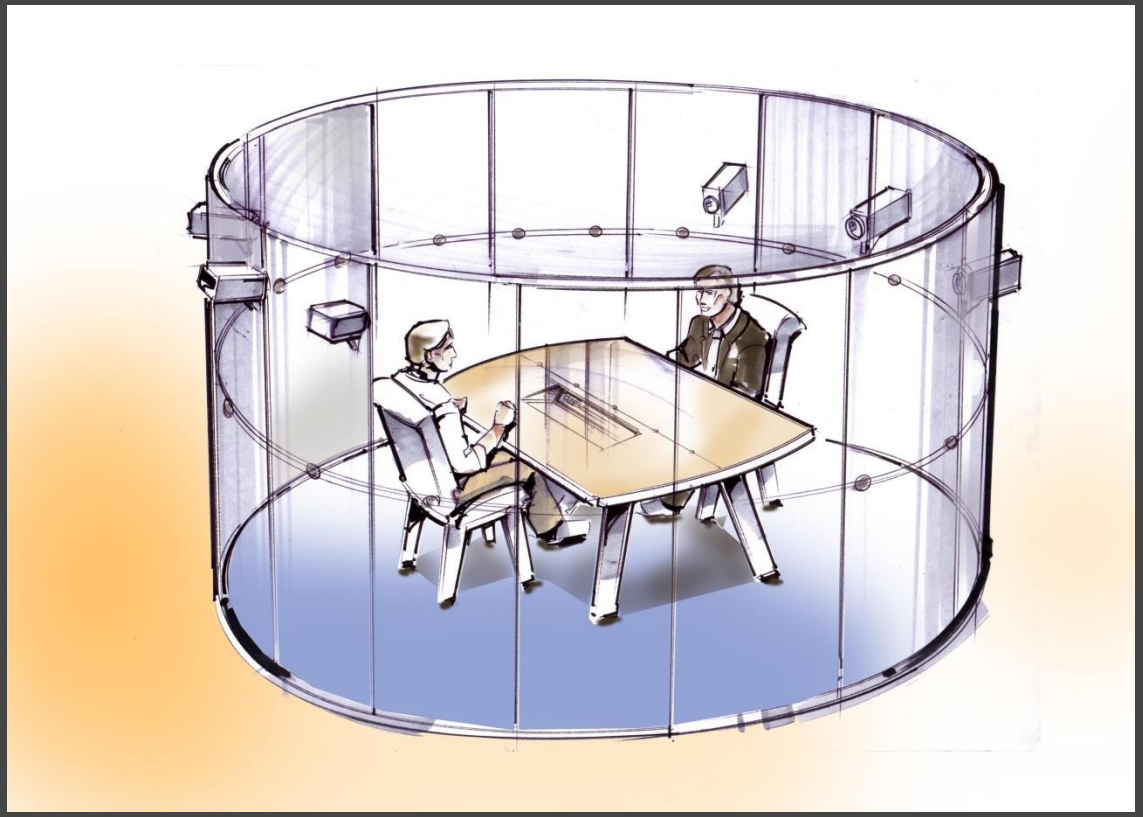
Trailer and wires

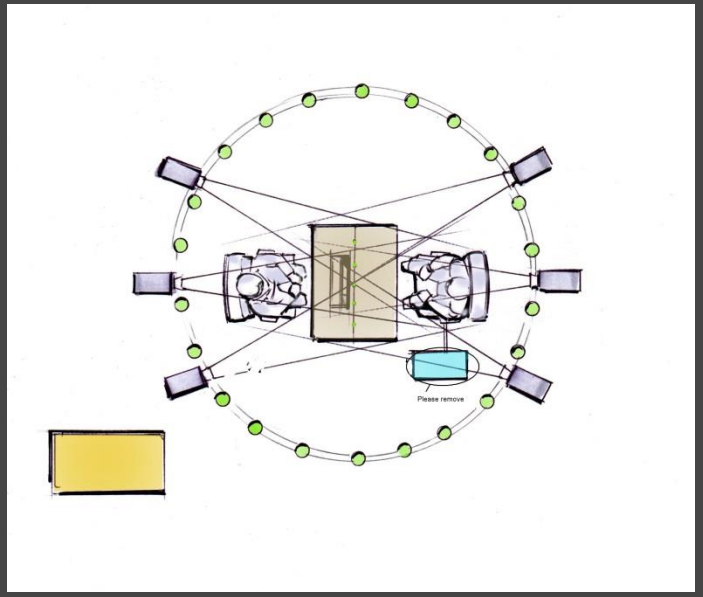
EyeVision “Best of”



Bigger ideas that didn’t happen?

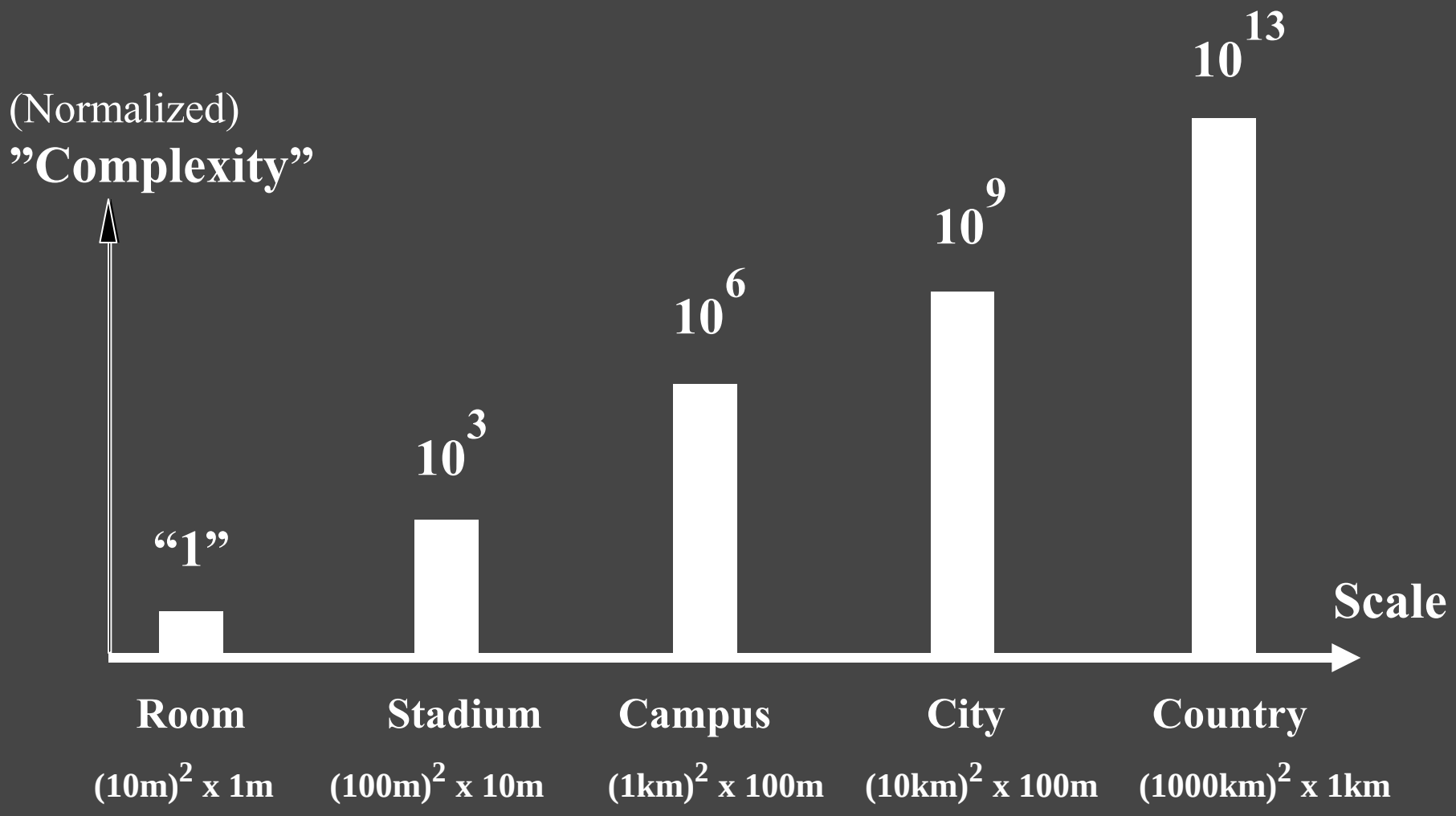
Interview Room of the Future



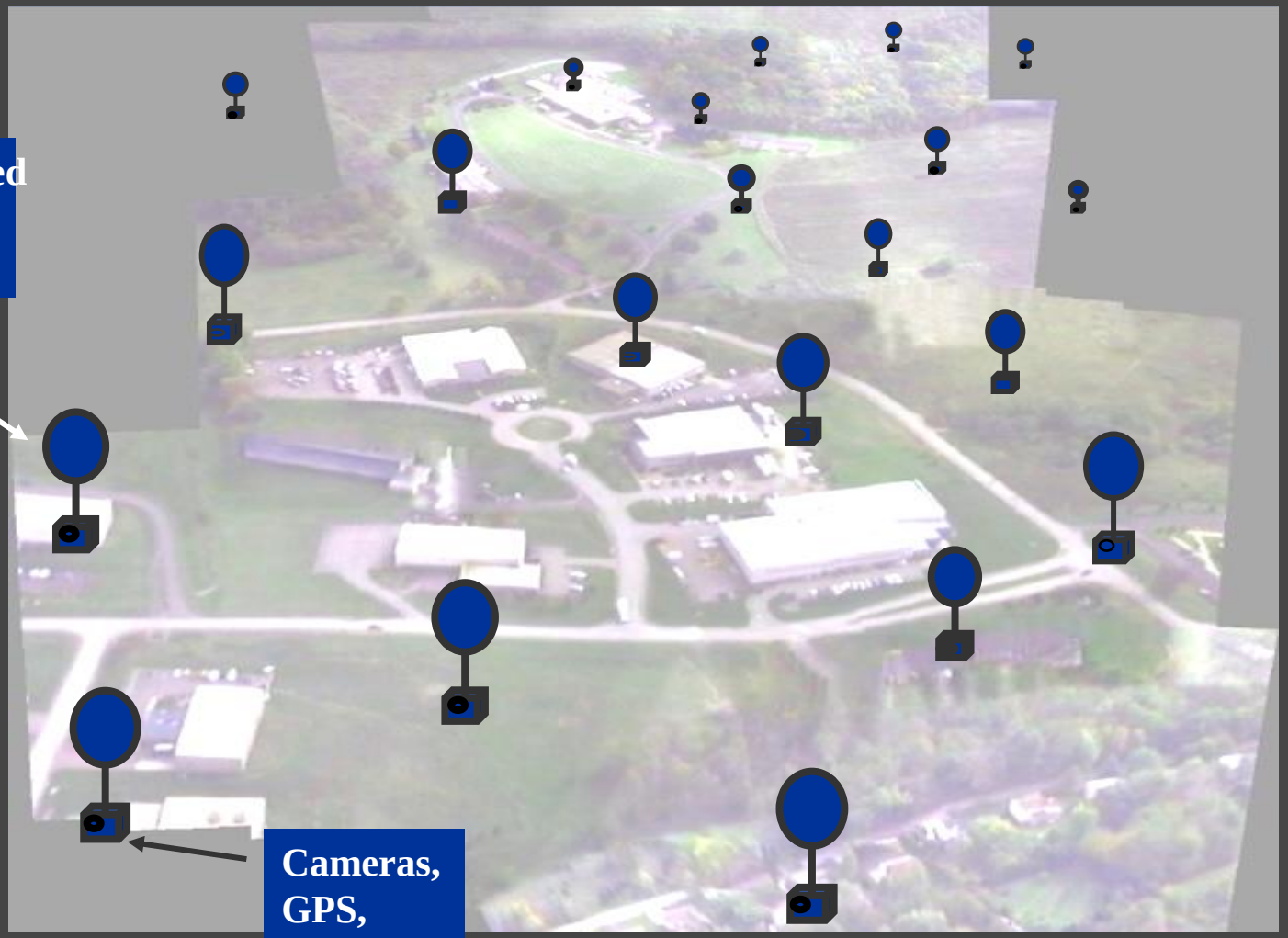


Multi-modal
Interactive
Real-time feedback

Scale ?

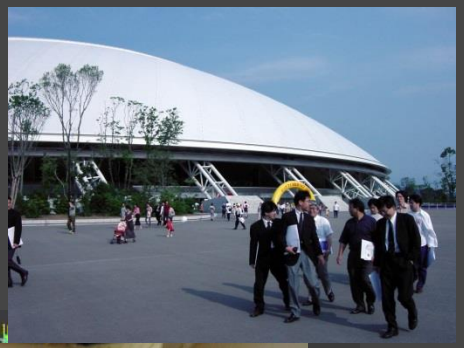

(Normalized)
"Complexity"
"1"
10^3
10^6
10^9
10^{13}
Scale
Room
$(10m)^2$ x 1m
Stadium
$(100m)^2$ x 10m
Campus
$(1km)^2$ x 100m
City
$(10km)^2$ x 100m
Country
$(1000km)^2$ x 1km

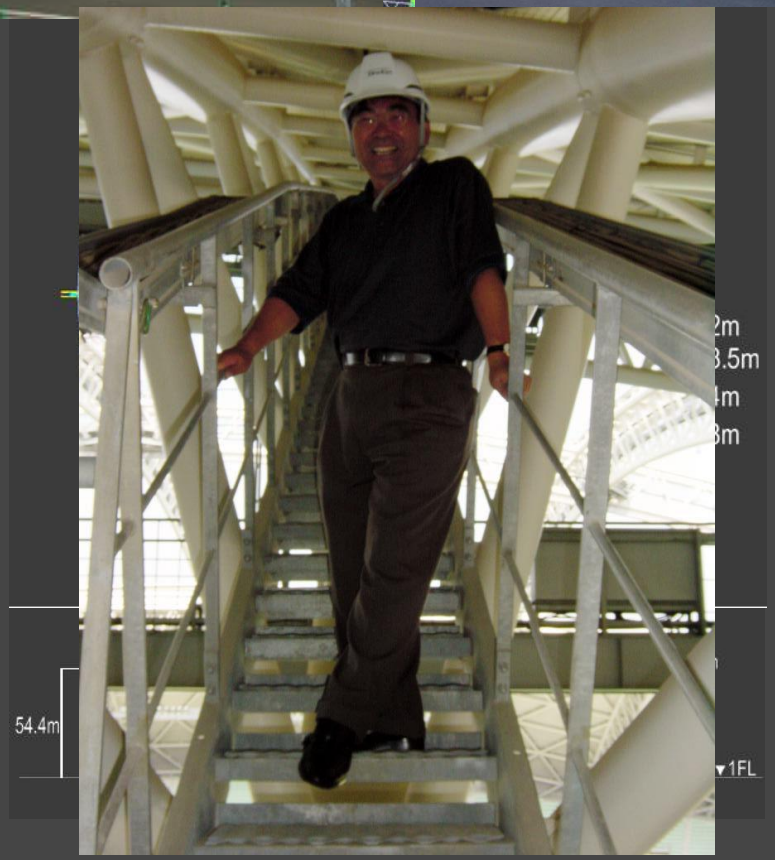
3D Country



O-ita Stadium

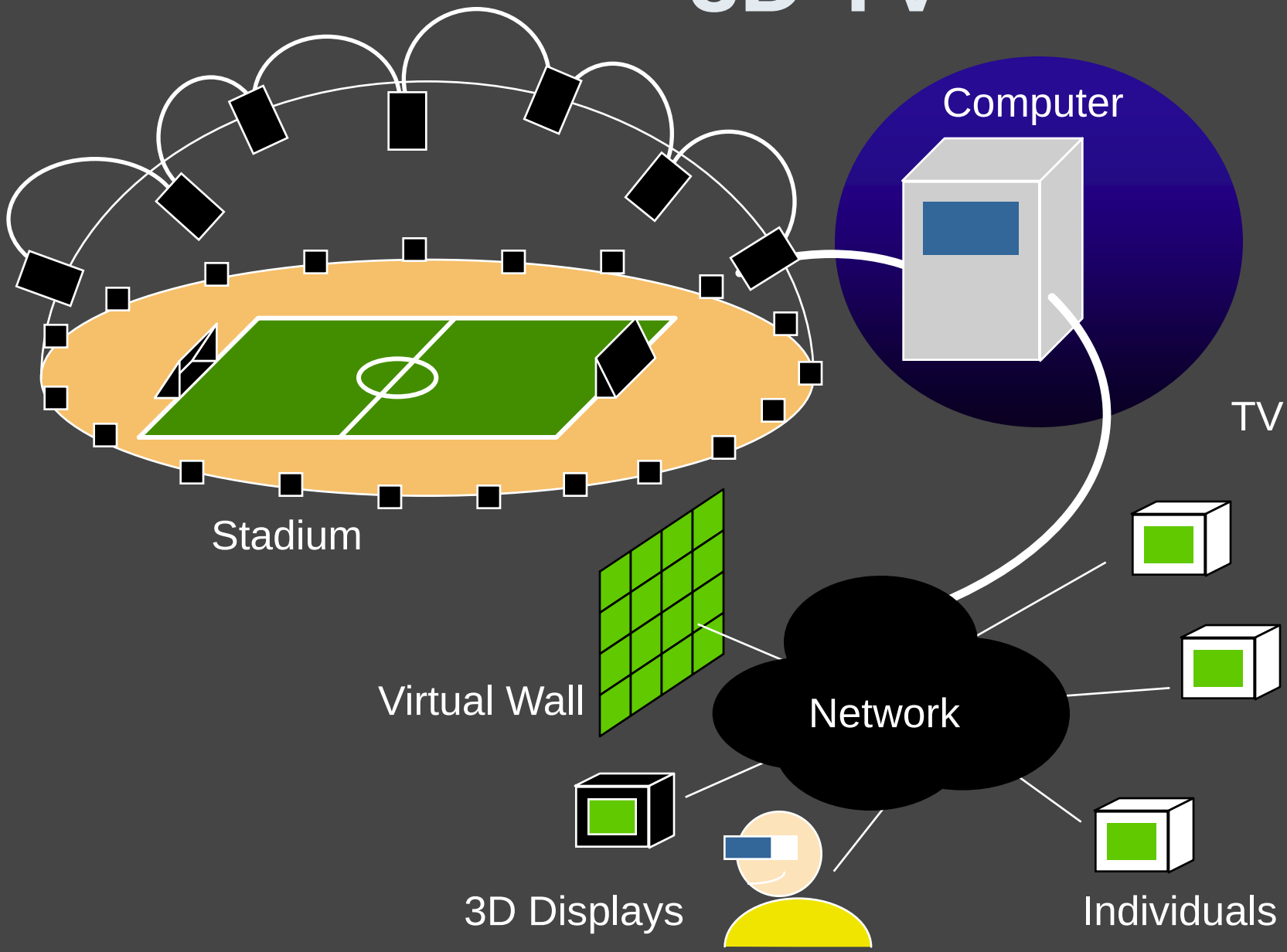
“Free View Point” Project



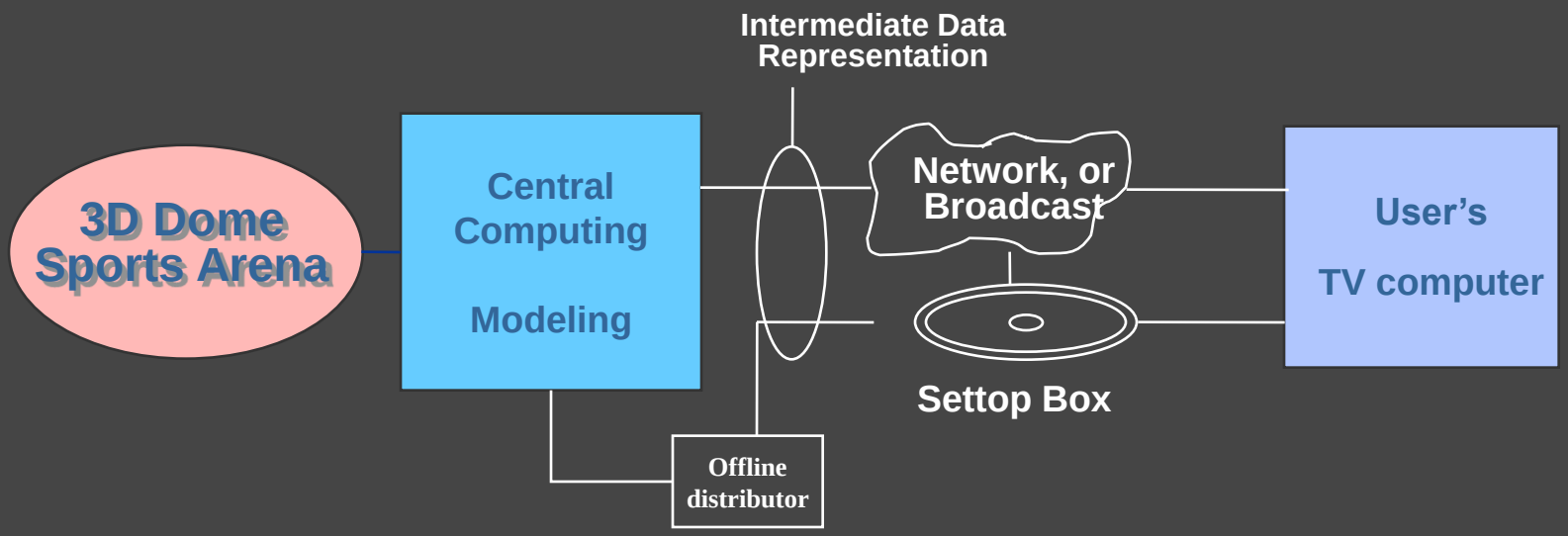


with Yuichi Ohta (Tsukuba)
Hideo Saito (Keio)
Akimichi (Takenaka)
Seiki Inoue (NHK)

3D TV


Computer
TV
Stadium
Virtual Wall
Network
3D Displays
Individuals

Computation vs. Bandwidth



- How much computation at the center or at the TV computer ?
- Where/how the storage at the user end?
- What the most efficient intermediate representation ?
- What interactions by users ?

Computation?

Estimate:

500 x 500 x 500, 50 NTSC Cam, 30 f/s ⇨ 100 Gflop

Progress:

Jan 1998: 10,000 x Realtime with a few SGIs
(14 days elapse time)

Feb 1999: 1,000 x Realtime with 20 PCs
(4 days elapse time)

Jan 2002: Modeling: < 50 x Realtime
Display: Realtime

Computation?

Estimate:

500 x 500 x 500, ~~50 NTSC~~ Cam, ~~30~~ f/s ⇨ ~~100 Gflop~~

0 0 0 1000 HDTV 60 20 Pflop

Progress:

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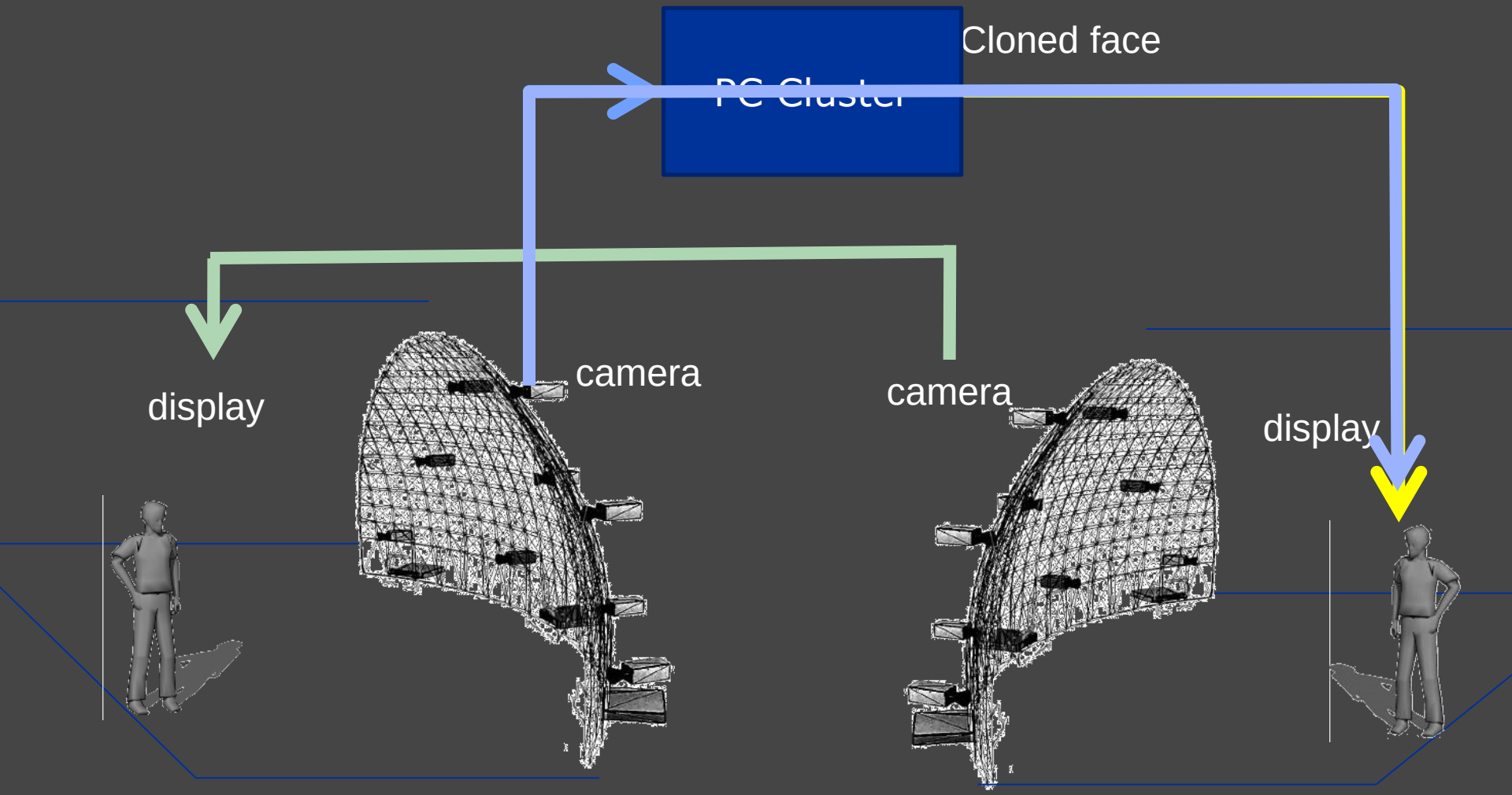
Visual Communication Lab



Many-Camera Systems

"Numerosity is power."

Early efforts:

Primitives and Pretty good

Fun and useful

Challenges in devices, algorithms, computation, communication AND application scenarios