Motion Capture for full-body interaction

1. Background on full-body motion capture
    - Example of a film production
    - Example of real-time interaction

2. Posture reconstruction

3. Collision avoidance

1. Background on full-body motion capture

Main motivation for using marker-based motion capture systems: **precision**

Application fields (on-line and off-line):

Industrial application: Orientation control/Navigation within marine/Ground and air application…

Entertainment: Visual effect/animation, theme park (e.g. Pharaoh tomb)

Training and Simulation: Real-time mock-up/evaluation stress

Movement science: measuring 3D human/subject’s performance.

Industrial Applications

Entertainment

Training & Simulation

Movement Science

1. Background on full-body motion capture

- **Motion Capture (mocap)**
  - Lee Harrison: first “data suit” for TV production in 1967 : the posture is measured with exoskeleton and potentiometers [S 1998]
  - Still some exoskeleton on the market to measure posture but rather invasive/cumbersome. Limited precision.

Scanimate system 1967

(Image courtesy of Lee Harrison, III)

Medialab Paris [S 1998]

1. Background on full-body motion capture

- **Occlusion-free technologies**:
  - **Magnetic** sensors do not suffer from occlusion but from field distorsions due to metallic elements in the environment (e.g. Floor)
    - 6D sensor providing position & orientation

- Datasuit with **accelerometers** (Xsense MVN): no occlusion but drift over time
  - *Acceleration*
  - *Angular velocity*
  - *to recover:*
    - *3D position*
    - *3D orientation*

1. Background on full-body motion capture

- **Optical technologies**:
  - **Passive** optical markers with IR cameras (VICON):
    - used both in film, game, VR, and orthopaedics. Precise but expensive. Weakness in real-time in case of occlusion: the system looses the markers IDs.

IR Camera

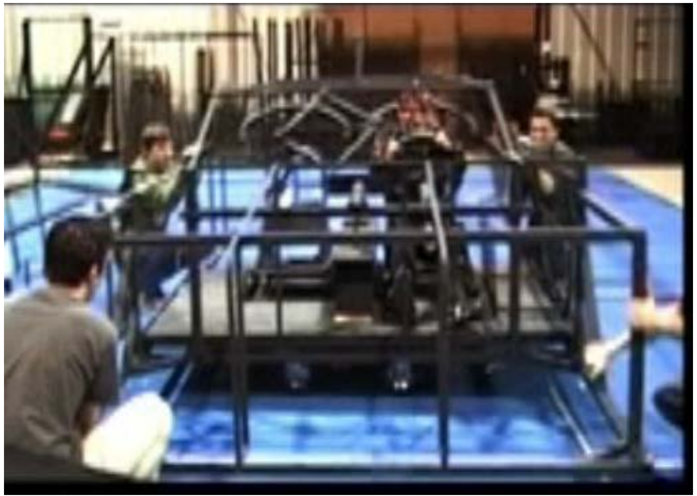
Suit with reflective markers

Markers on clothes
[Artanim Demo 2015]

Example of a film production (from Renaissance DVD)

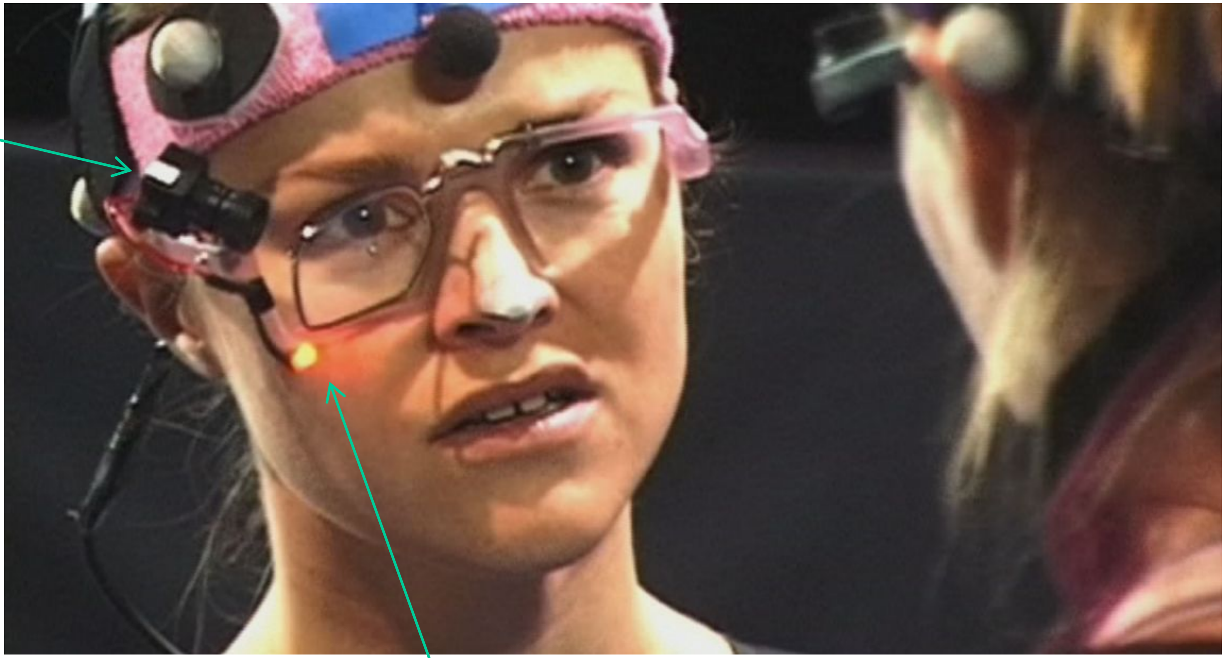
Simultaneous tracking of body posture and cloth movement

Need of minimal and hollow decor elements (called props) to minimize occlusion



Example of a film production (from Renaissance DVD)

Simultaneous body, head and eye direction (gaze) tracking



Camera filming the reflexion of the eye in the glass with IR filter

The eye direction can be expressed in the head Coordinate system

IR light

Example in ergonomics and training [software suite IMPROOV from CLARTE]

The user is practicing a task in the CAVE (right) while an ergonomist evaluates the movement through an additional screen with a third person viewpoint.


MAINTENANCE

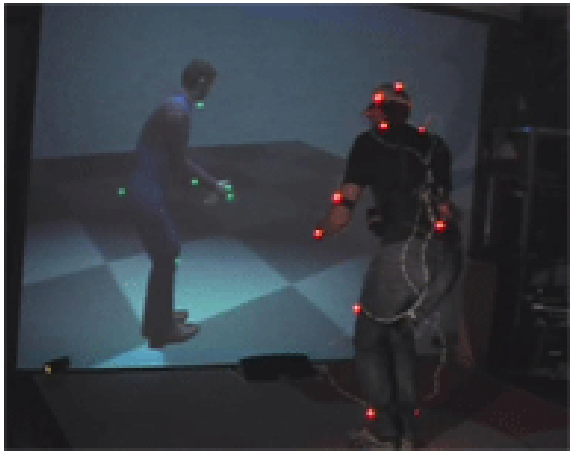
Utilisation de Props
Ecran déporté pour prendre du recul sur la scène

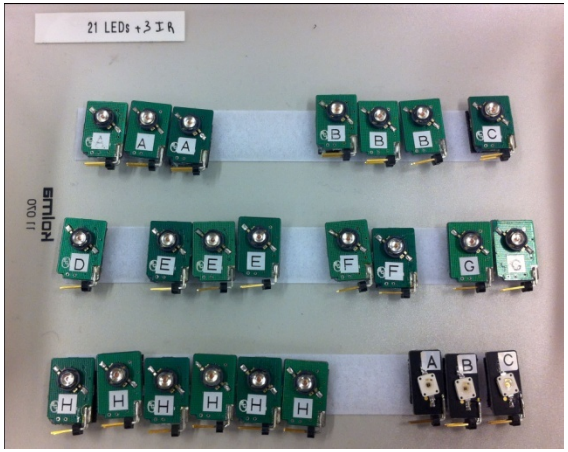

ERGONOMIE

Anticipation des problèmes de TMS
Meilleure appropriation des postes de travail par les équipes

1. Background on full-body motion capture

- **Optical technologies (cf T. Porssut course)**:
    - **Active** optical markers with IR camera (Phasespace), The system can recognize active markers even after occlusion





LEDs

Dimensions: 20 mm x 14 mm x 3.2 mm
Weight: 4.5 grams
Each LED modulates at a unique frequency resulting in a unique digital ID. LEDs are available in Red visible and Infra-red versions.

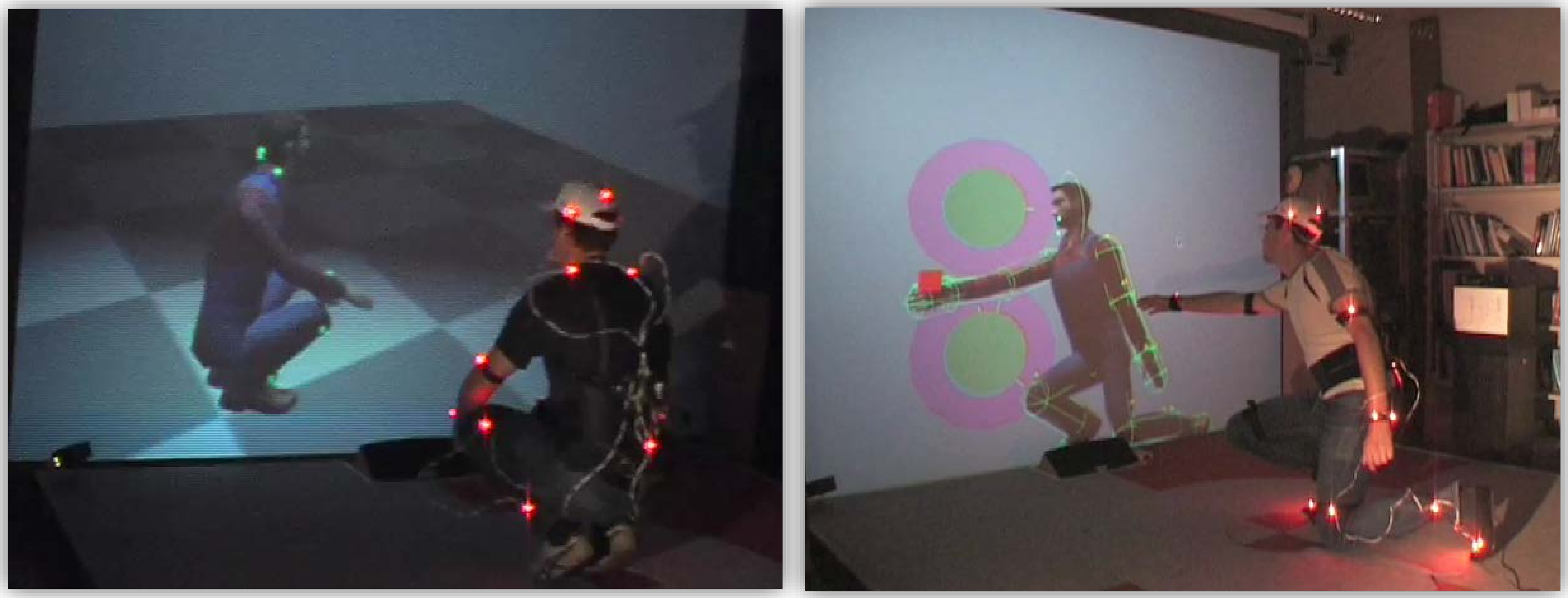
Cameras

Dimensions: 108 mm x 92 mm x 57 mm
Weight: 380 grams
Each camera achieves an Optical Resolution of 3600 x 3600 (12 Megapixel) using two linear detectors with 16-bit dynamic range. Onboard processors produce an impressive Subpixel Resolution of 30,000 x 30,000 at 480 Hz.

Example of interaction with active optical markers (LEDs)

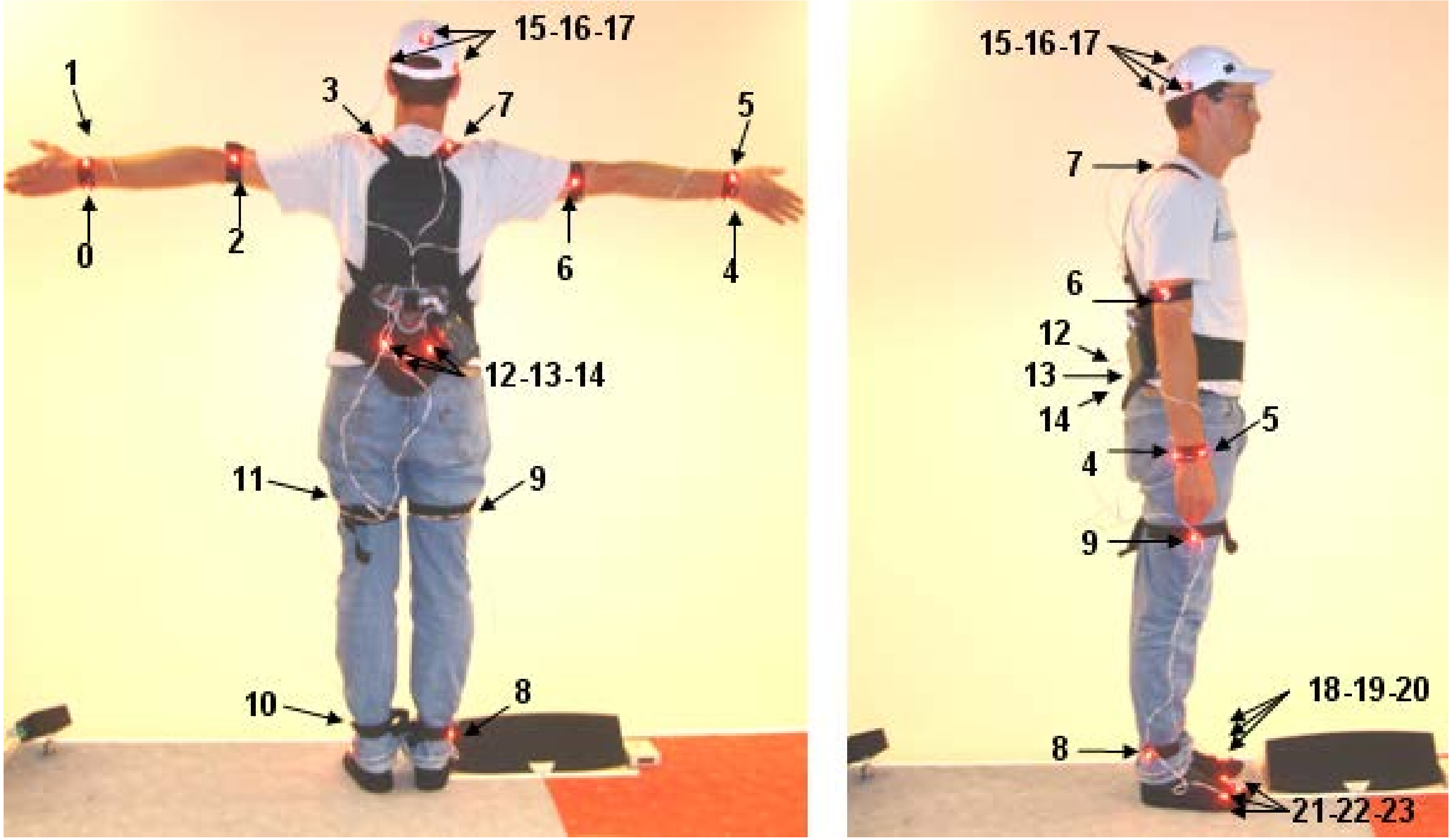
Keys tasks of a real-time full-body mocap system:

- Acquisition of the 3D location of the markers (device)
- Body posture reconstruction from the cloud of 3D points
- Need to combine posture reconstruction with collision avoidance



2. Posture reconstruction

- Minimal marker setup for full-body posture acquisition

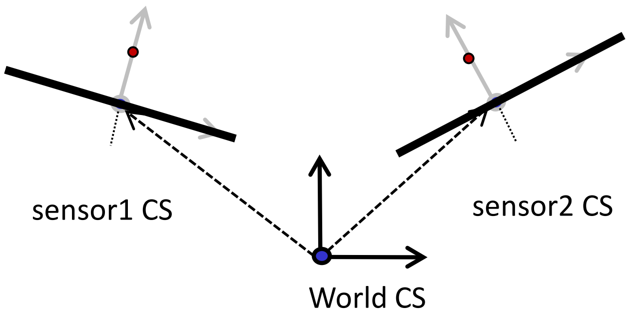


- *Head, spine and wrist orientations are recovered from multiple position markers (Phasespace LEDs)*

2. Posture reconstruction (2)

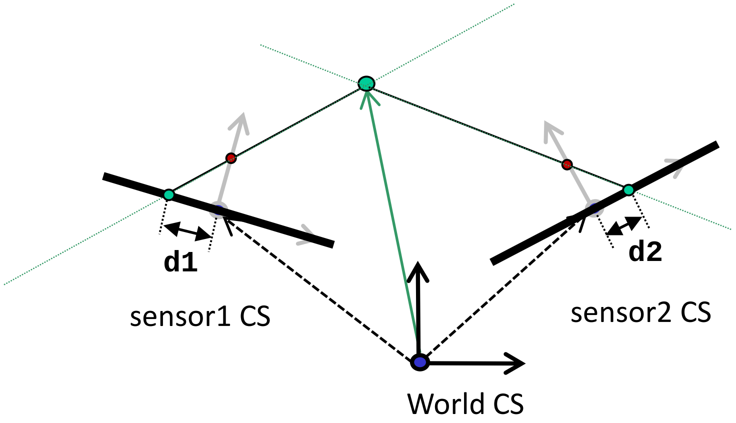
A two stages process :

- **System Calibration**
  - Install the cameras so that they overlap and cover the whole volume of acquisition
  - Register the cameras in a common world coordinate system with a calibration device



Output of calibration phase:
Known location of camera sensor
Coordinate Systems in the World CS

- **Triangulation** : a 3D marker position can be computed when it is
  - visible by 2 cameras with 2D sensor (ViCON)
  - visible by 3 cameras with 1D sensor (Phasespace)

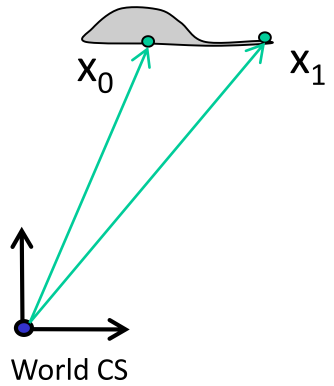


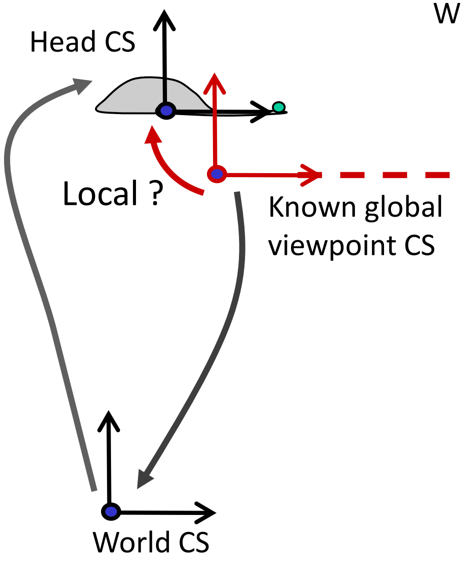
Triangulation :
The known locations of a marker
on the 2 sensors allow to build 2 lines that
intersect at the marker location in world CS

2. Posture reconstruction (3)

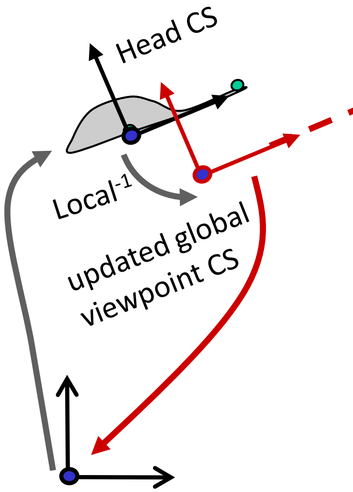
A simple case: head tracking for updating the line of sight

- Input:
  - The 3D positions $\{x_i\}$ of 3 markers mounted on a head cap
- Output:
  - At run time: global viewpoint Coordinate System (CS) for first person line of sight
- Method:
  - Global Head CS $\{w_1, w_2, w_3\}$
    - build vectors $v_1 = x_1 - x_0$, $v_2 = x_2 - x_0$
    - Normalize $v_1 \rightarrow w_1$
    - $v_3 = w_1 \times v_2$ and normalize it: $\rightarrow w_3$
    - $w_2 = w_3 \times w_1$
  - Head Calibration stage: get *local viewpoint CS in head CS* given a known global viewpoint CS
  - Run-time stage: get *global viewpoint CS* by composing Head CS with local viewpoint CS





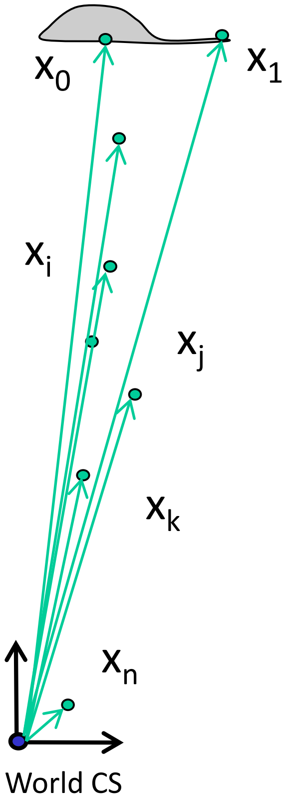
HEAD CALIBRATION



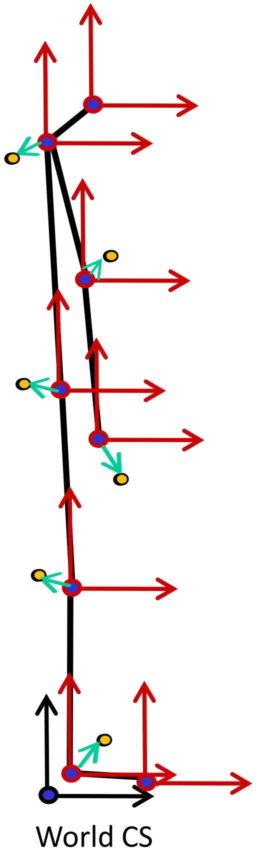
RUN-TIME

2. Posture reconstruction (4)

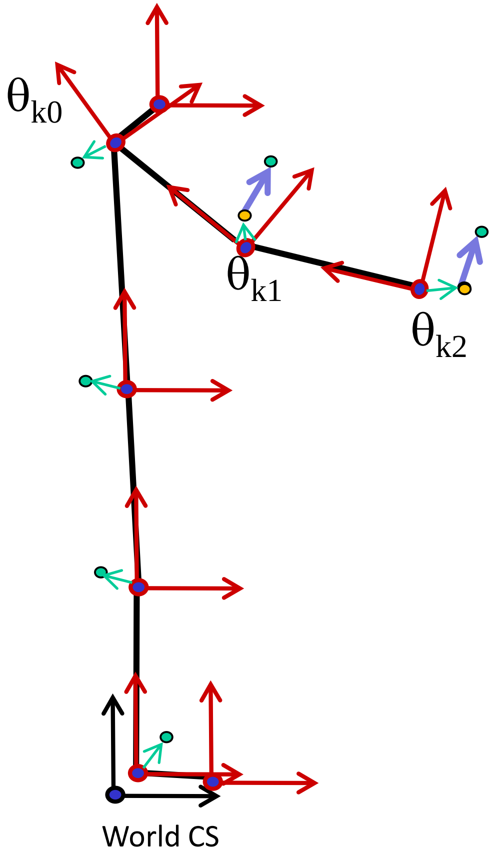
The complex case: full body tracking (1)



INPUT: global location
of all makers



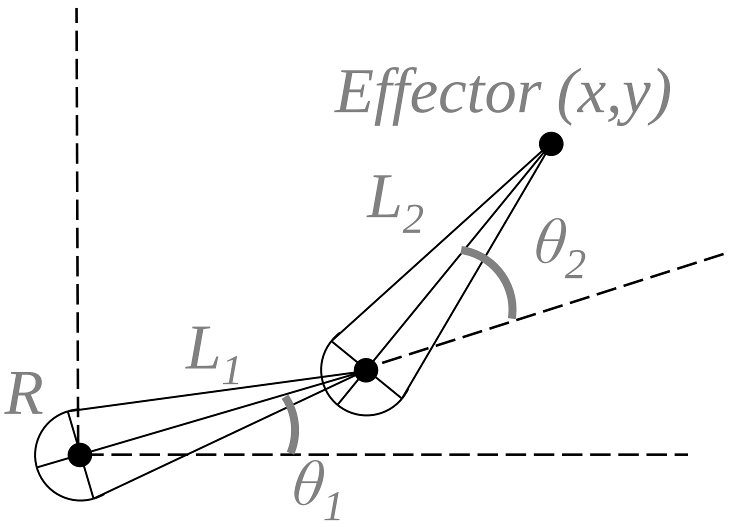
1) **CALIBRATION with a SKELETON model In the calibration posture**:
Determines the location of **the body point (called effector)** ●
that should coincide with each sensor location
The position of the effector is computed in the LOCAL coordinate
system of its associated JOINT.
e.g. a wrist **marker** determines the (constant) position of the wrist
effector in the **WRIST coordinate system**



2) RUN-TIME : attract each **effector** towards
Its associated **marker** position by optimizing
The state of the JOINT local transformations

2. Posture reconstruction (5)

- Input: cloud of 3D marker positions $\{x_i\}$ & body skeleton model
- Output: Body skeleton posture state expressed as a body global location and a set of joint values $\{\theta_k\}$
- Terminology:
  - **Forward Kinematics Problem (FK):** the position of an **effector** x_i as a function of θ_k is given by a set of highly non-linear equations: $x_i = F(\theta_k)$
  - **Inverse Kinematics Problem (IK):** finding a solution to $\theta_k = F^{-1}(x_i)$



FK:

$$x = f_1(\theta_1, \theta_2) = L_1 \cos\theta_1 + L_2 \cos(\theta_1 + \theta_2)$$

$$y = f_2(\theta_1, \theta_2) = L_1 \sin\theta_1 + L_2 \sin(\theta_1 + \theta_2)$$

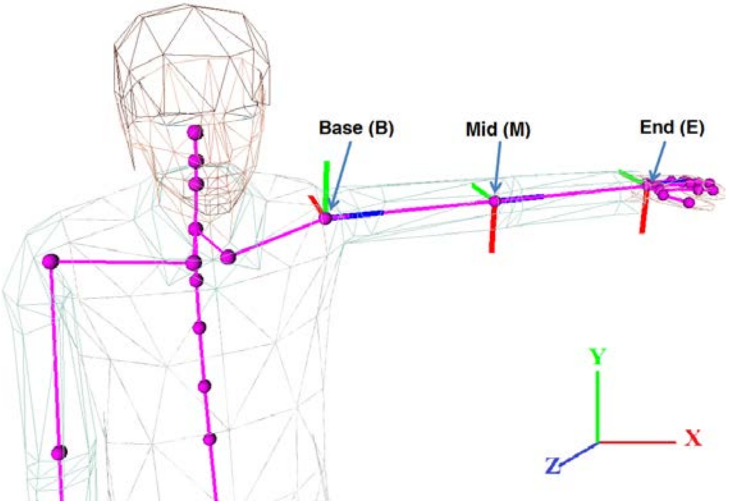
IK:

$$\theta_2 = \arccos\left(\frac{x^2 + y^2 - L_1^2 - L_2^2}{2L_1L_2}\right)$$

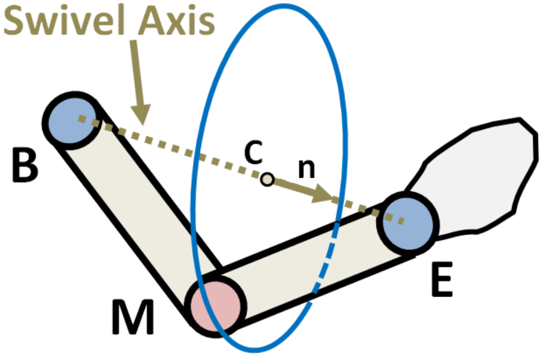
$$\theta_1 = \arctan\left(\frac{y}{x}\right) - \arctan\left(\frac{L_2 \sin\theta_2}{L_1 + L_2 \cos\theta_2}\right)$$

2.1 Two families of IK methods

- 2.1.1 Analytic IK:
  - Possible for simple non-redundant cases, e.g. $\dim(x,y) = \dim(\theta_1,\theta_2)$
  - The limb case [Korein, Badler, Tolani, Kallmann, Molla]:



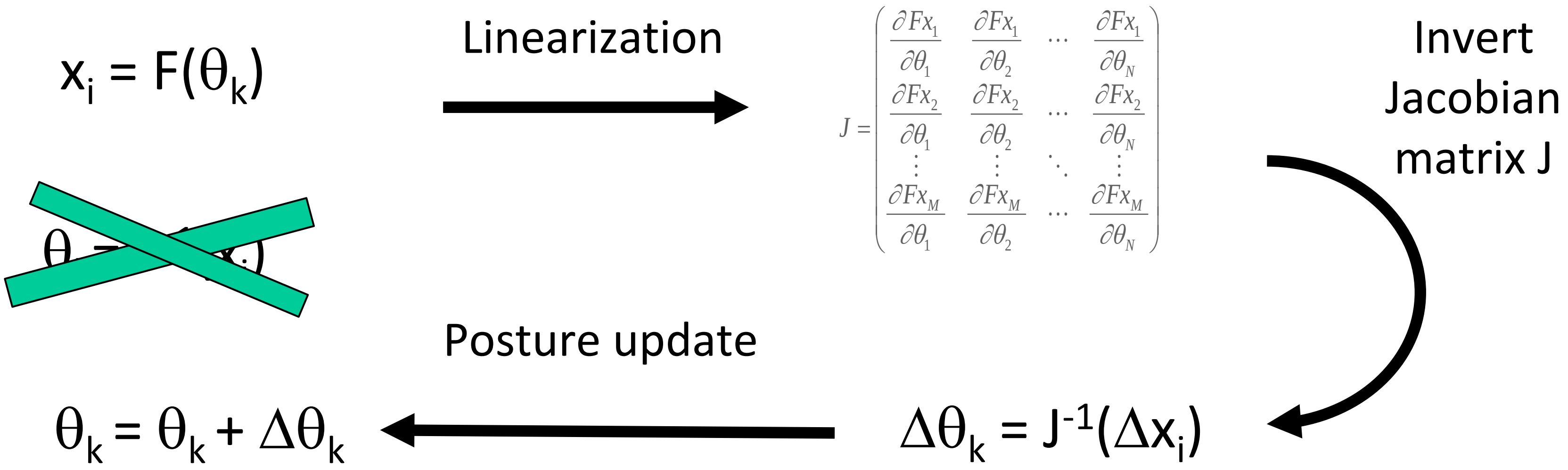
- Input: position/orientation of the end effector (e.g. hand)
  - 3 dof (position) + 3dof (orientation)
- Output: joint state for base/mid/end
  - 3 dof (base) + 2 dof (mid) + 2 dof (end)



- One degree of redundancy: swivel angle

2.1 Two families of IK methods

- 2.1.2 Numeric Jacobian-based IK:
  - Linearized equation -> build matrix of partial derivatives = Jacobian
  - Can handle redundant cases by computing the pseudo-inverse of the Jacobian
  - Valid near the current state of the articulated system



$x_i = F(\theta_k)$

Linearization

$$J = \begin{pmatrix} \frac{\partial Fx_1}{\partial \theta_1} & \frac{\partial Fx_1}{\partial \theta_2} & \cdots & \frac{\partial Fx_1}{\partial \theta_N} \\ \frac{\partial Fx_2}{\partial \theta_1} & \frac{\partial Fx_2}{\partial \theta_2} & \cdots & \frac{\partial Fx_2}{\partial \theta_N} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial Fx_M}{\partial \theta_1} & \frac{\partial Fx_M}{\partial \theta_2} & \cdots & \frac{\partial Fx_M}{\partial \theta_N} \end{pmatrix}$$

Invert Jacobian matrix J

$\Delta\theta_k = J^{-1}(\Delta x_i)$

Posture update

$\theta_k = \theta_k + \Delta\theta_k$

$\cancel{\theta_k = F^{-1}(x_i)}$

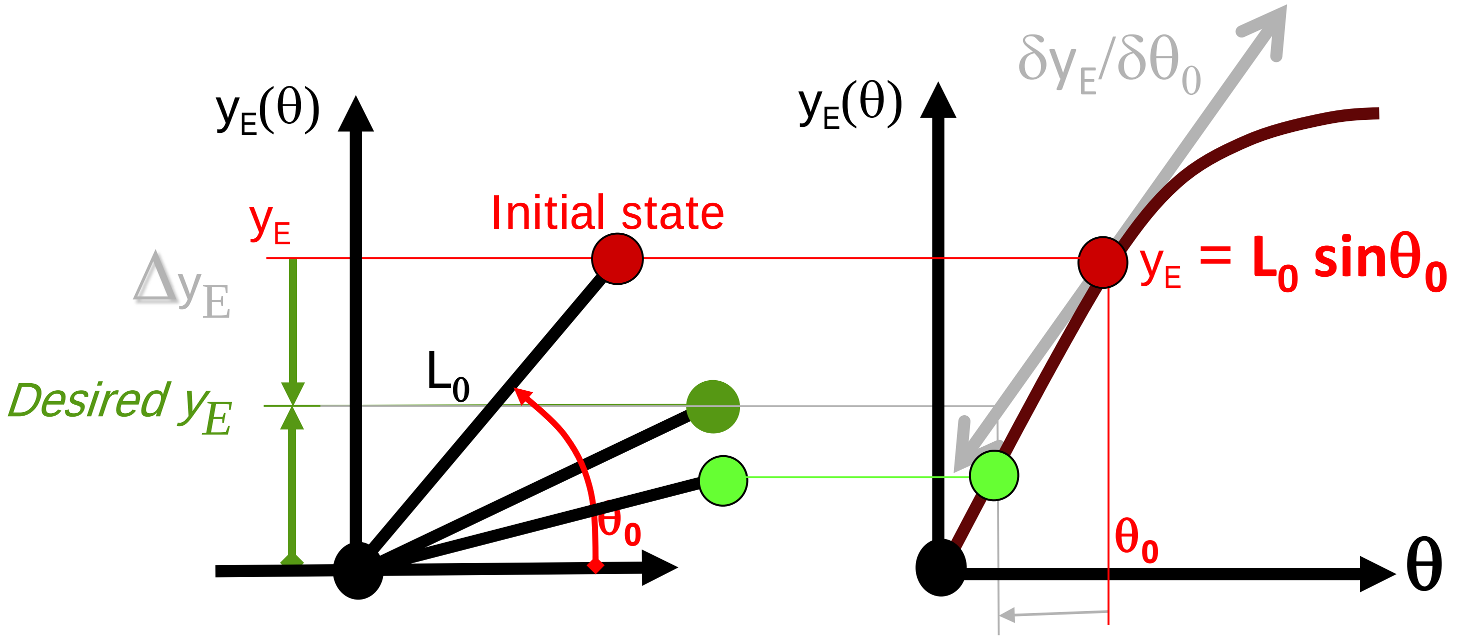
Compute a posture variation $\Delta\theta_k$ for a desired variation of the effector Δx_i

2.1 Two families of IK methods

- 2.1.3 comparison of IK methods on the simplest 1D case $y_E = L_0 \sin\theta$

The analytic solution is given by : $\theta = \arcsin(\textit{Desired } y_E / L_0)$

Jacobian-based approach: case with $\Delta y_E = \text{Desired } y_E - y_E$



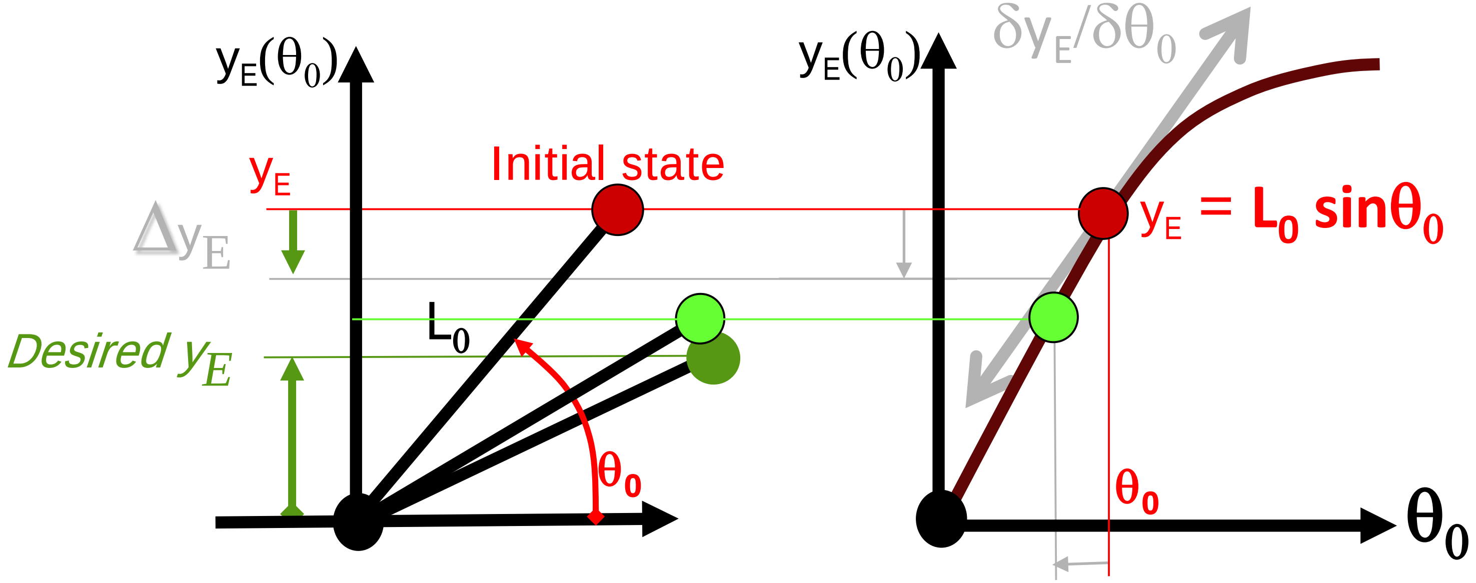
$$\Delta\theta_0 = \Delta y_E .\ 1/(\delta y_E/\delta\theta_0)$$

The linear approximation is only valid near the current state

2.1 Two families of IK methods

- 2.1.3 comparison of IK methods on the simplest 1D case $y_E = f(\theta)$

Jacobian-based approach: case with Δy_E = clamped(Desired $y_E - y_E$)



$$\Delta\theta_0 = \Delta y_E .\ 1/(\delta y_E/\delta\theta_0)$$

The jacobian-based with clamped Δy_E has to be iterated until $\Delta y_E < \varepsilon$

2.1 Two families of IK methods

2.1.3 Comparison:

IK method	**Advantages**	**Drawbacks**
Analytic IK	Fast Deterministic	Non-Linear equations request body decomposition into solvable equations, e.g. limbs, etc…
Jacobian-based IK	Handle redundancy Minimum norm posture variation Whole-body solution Priority concept	Linearized -> Iterative convergence due to local validity of the solution History-dependent, Rank-decrease singularity

Other hybrid techniques: CCD (Cyclic Coordinate Descent),
FABRIK (Forward And Backward Reaching IK)

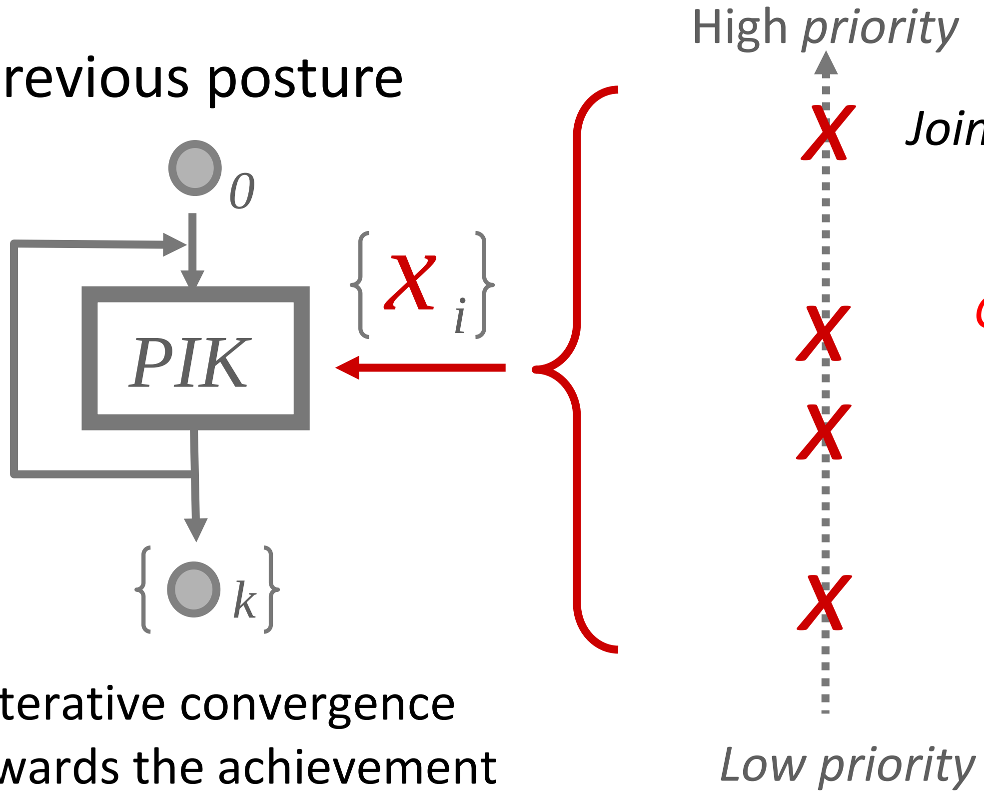
2.2 Jacobian-based IK with Priority levels

Redundancy allows to associate *priority levels* among effectors A and B as long as

$$\mathrm{Dim}(\theta) \geq \mathrm{Dim}(\text{effector A}) + \mathrm{Dim}(\text{effector B})$$

If the effector tasks conflict with each other, we have the guarantee of best possible achievement of the effector task with highest priority.

previous posture



Iterative convergence towards the achievement of the marker constraints

High *priority*

Coupled joints (e.g. spine)

Joint limits management with hard inequality constraints

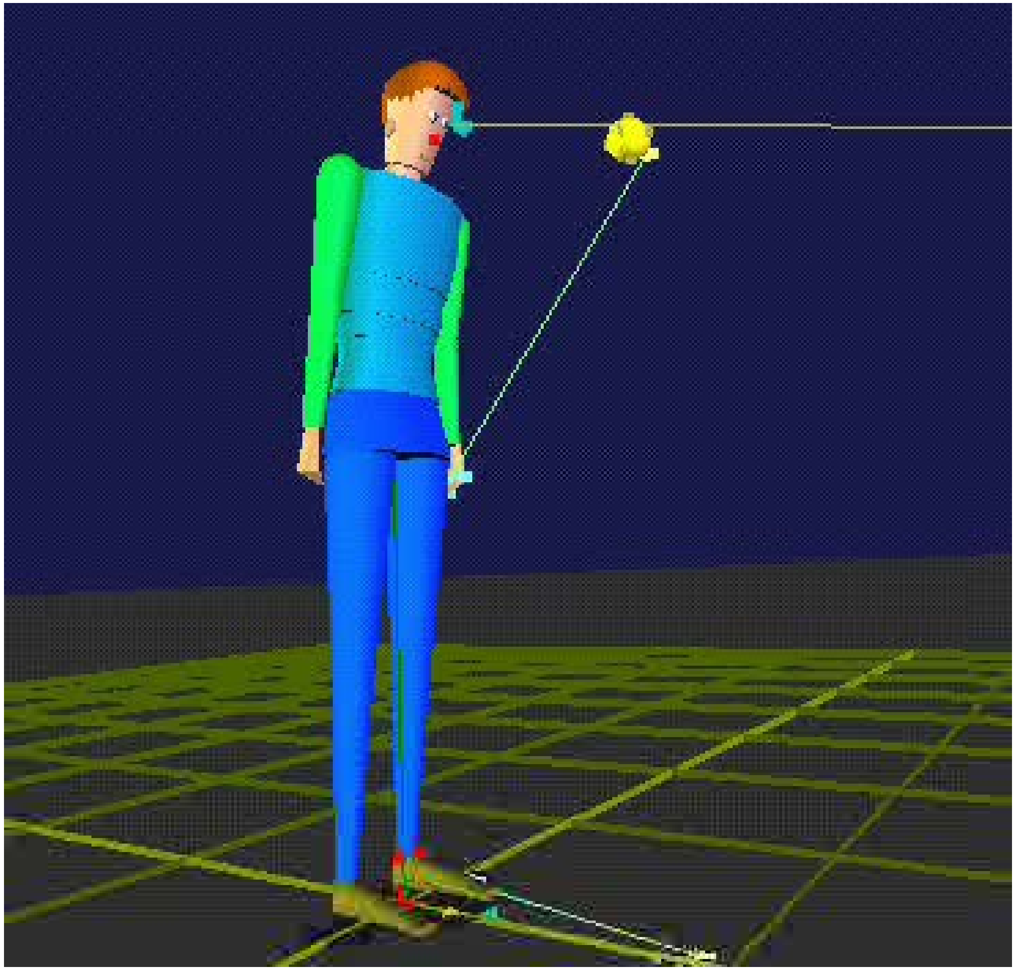
Goal oriented soft ***constraints*** *built from marker data and associated with a* ***priority*** *level*

Minimizing a cost function expressed in the joint space

Low priority

2.2 Jacobian-based IK with Priority levels (2)

Demonstrating the concept of priority enforcement: interactively moving the reach goal



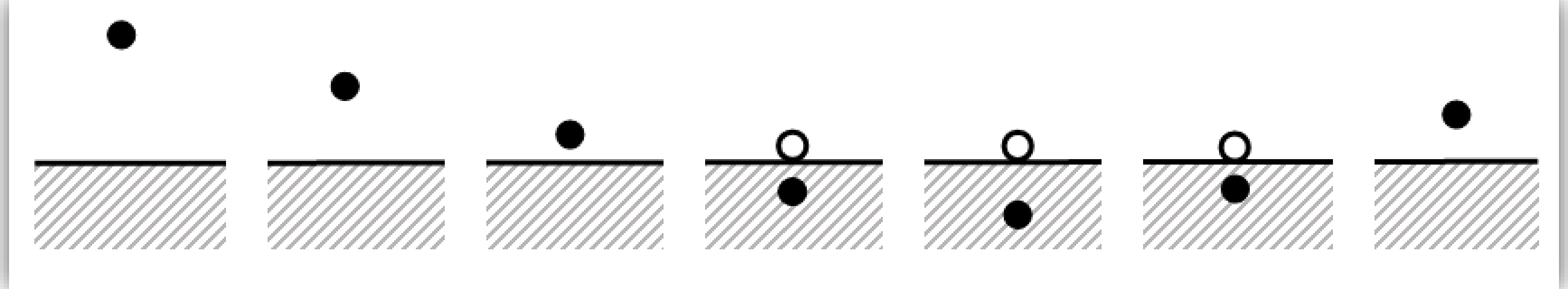
Priority levels :

1. balance
2. feet
3. gaze
4. left hand reach

5. attraction toward
   rest posture

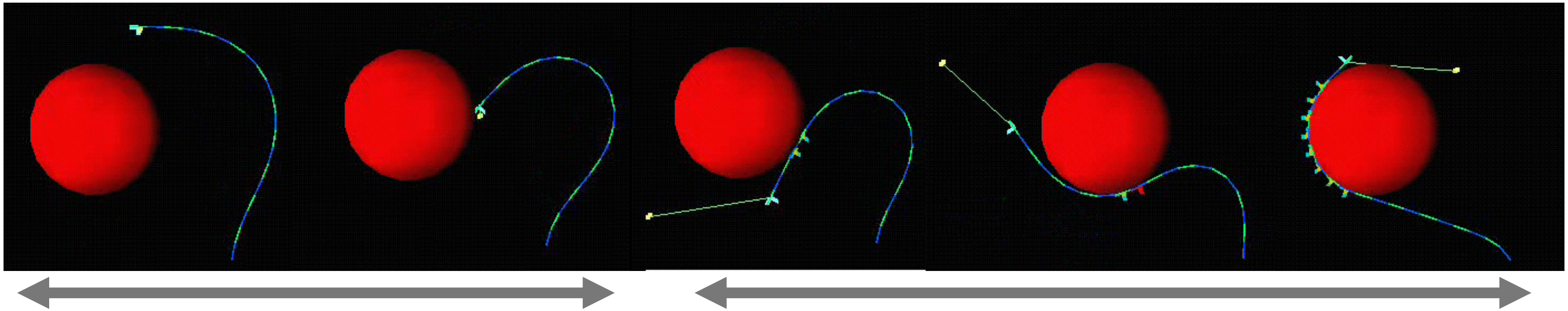
3. Collision avoidance

- Usual approach with proxy / god-object:
  - Rubber-band method (cf Haptic interfaces)

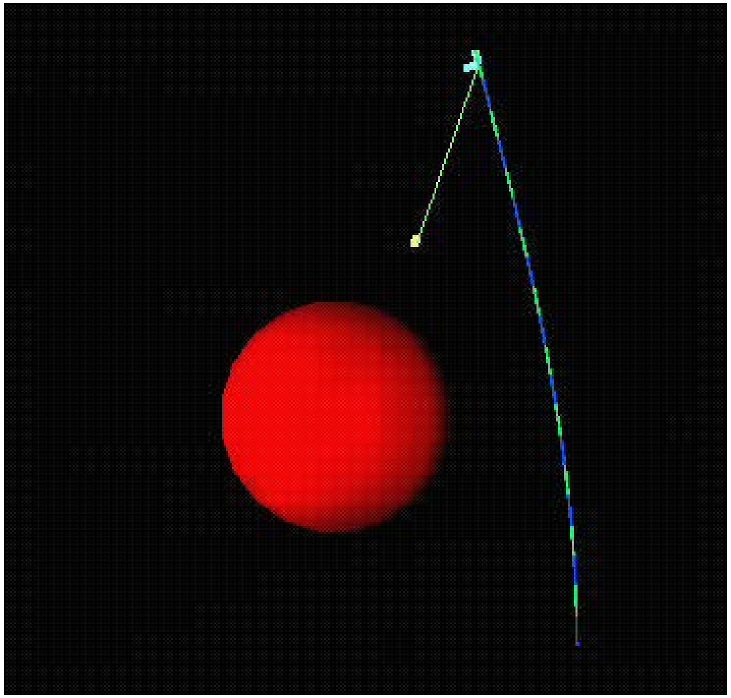


- Downside: visual-proprioceptive discrepancy
  - But worthy anyway [B 2006]

Concept of proxy for an articulated chain



- *Single effector*
  - *Chain tip*



- *Dynamically created 1D repulsion effectors with higher priority*
  - *may prevent the chain tip effector to reach its goal*

2.3 Posture reconstruction with Jacobian-based IK

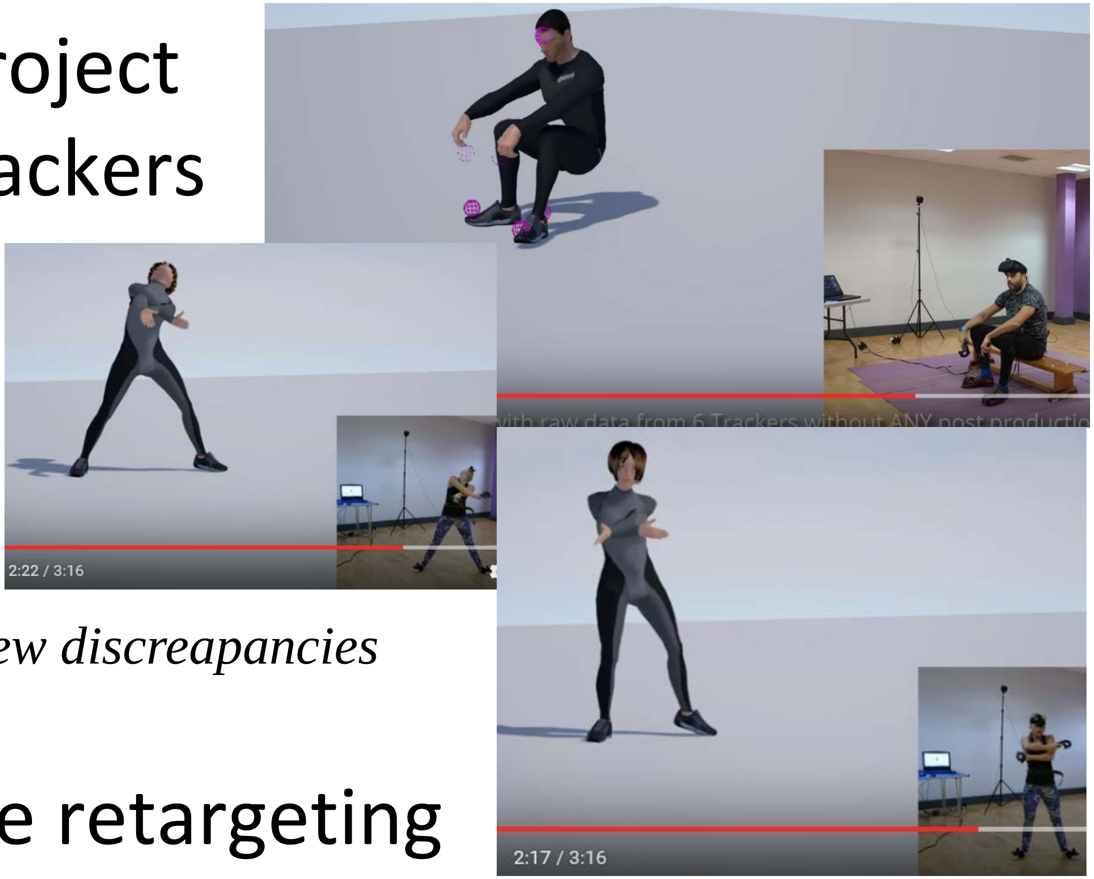
Set of constraints built from marker positions

Controlled body part	Constraint type
Toes	Position, orientation
Spine base	Position
Spine base	Orientation
Wrists	Position
Wrists	Orientation
Shoulders	Position
Clavicles	Position
Knees	Position
Ankles	Position
Head	Orientation

Example: situated interactions

Future of full-body interaction

- Ikinema Orion project with HTV Vive trackers



Fluid movements but still a few discreapancies

- Eray Molla online retargeting

Requires a skeleton and body surface calibration
[Eray Molla PhD thesis]

Future of full-body interaction

- Speed-up convergence of numeric method
  - [Harish et al SIGGRAPH 2016]
- Handle more cluttered virtual environments
- Consider collaborating with virtual human on complex tasks
- Overcome discontinuties of non-invasive mocap technology (such as Kinect)

[References]

[Harish et al 2016] Pawan Harish, Mentar Mahmudi, Benoît Le Callennec, and Ronan Boulic. 2016. Parallel Inverse Kinematics for Multithreaded Architectures. ACM Trans. Graph. 35, 2, Article 19 (February 2016), 13 pages. DOI=http://dx.doi.org/10.1145/2887740

[S 1998] Sturman D., Computer Puppetry, IEEE CGA Jan-Fe 1998

[AL2011] Andreas Aristidou and Joan Lasenby. 2011. FABRIK: A fast, iterative solver for the Inverse Kinematics problem. Graph. Models 73, 5 (September 2011), 243-260. DOI=http://dx.doi.org/10.1016/j.gmod.2011.05.003

[Eray Molla PhD thesis] https://infoscience.epfl.ch/record/215314

Web refs:

http://en.wikipedia.org/wiki/Motion_capture

Artanim Pharao Tomb demo: https://www.youtube.com/watch?v=iAacQLEFF_Q