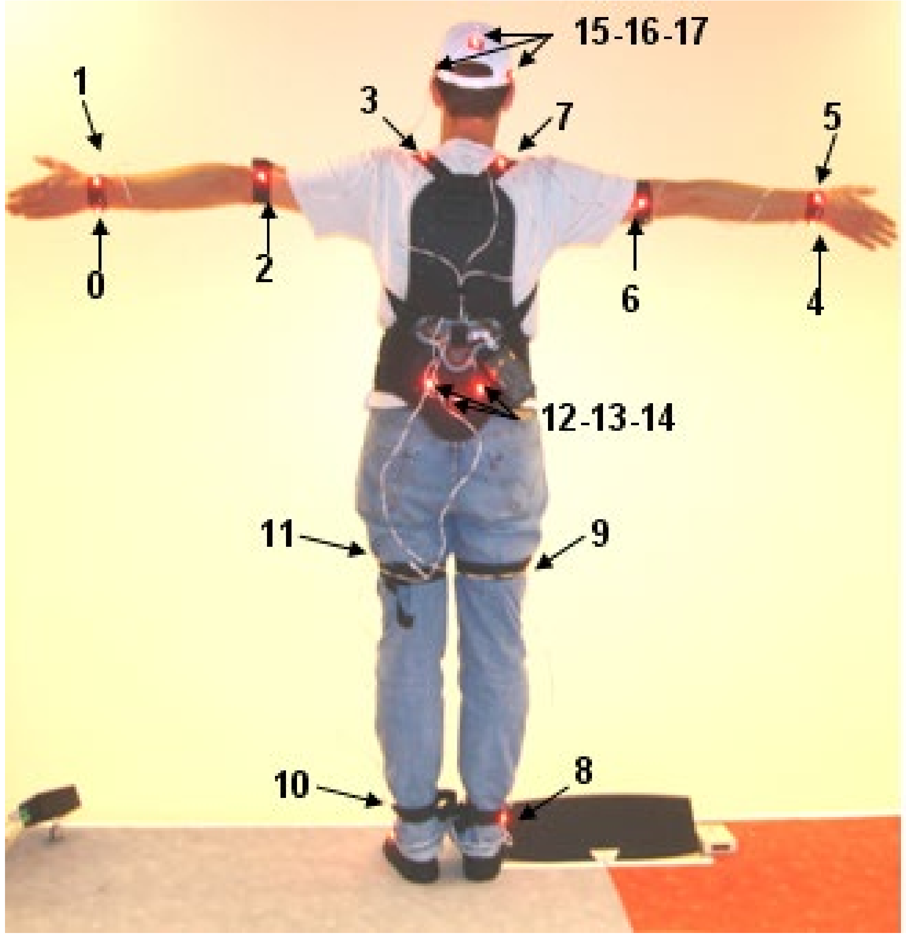
Motion Capture for full-body interaction

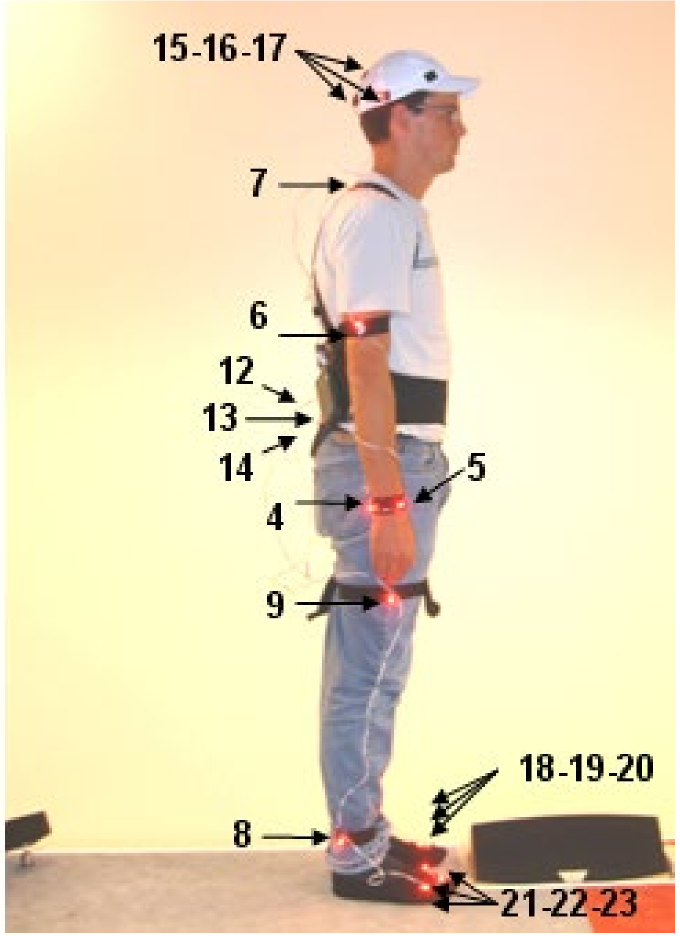
1. Background on full-body motion capture
   – Example of a film production
   – Example of real-time interaction
2. Posture reconstruction
   – Analytic IK
   – Jacobian-based IK
3. Collision avoidance
4. Other examples of full-body interaction

video2 (brace spanning items 2: Posture reconstruction)

2. Posture reconstruction

- Minimal marker setup for full-body posture acquisition



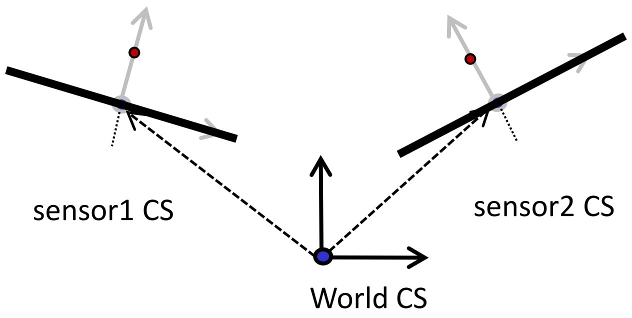


- *Head, spine and wrist orientations are recovered from multiple position markers (Phasespace LEDs)*

2. Posture reconstruction (2)

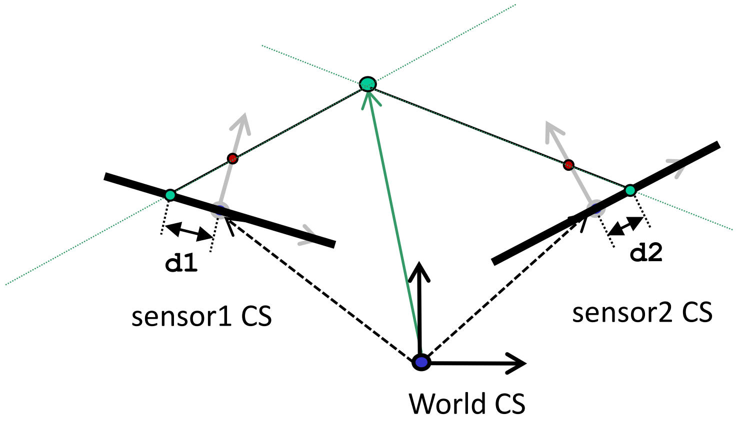
A two stages process :

- **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



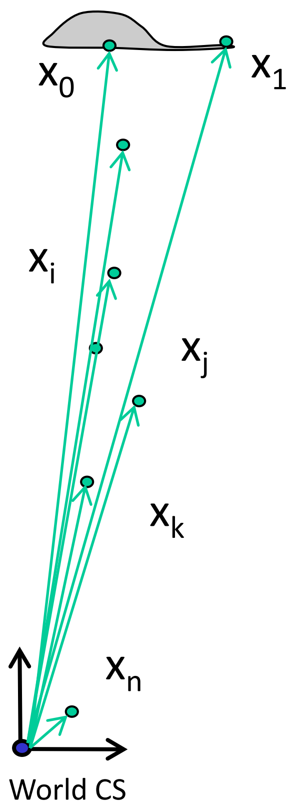
Output of calibration phase:
Known location of camera sensor
Coordinate Systems in the World CS

- **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)

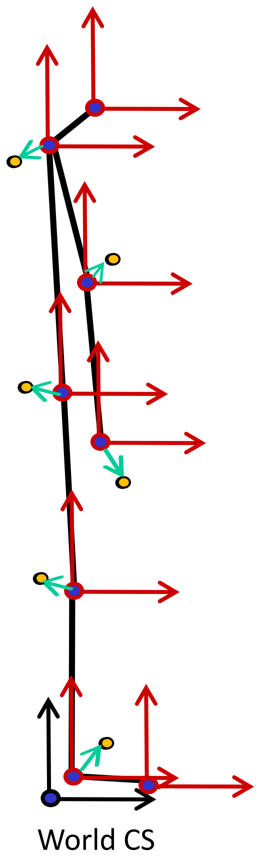


Triangulation :
The known locations of a marker
on the 2 sensors allow to build 2 lines that
intersect at the marker location in world CS

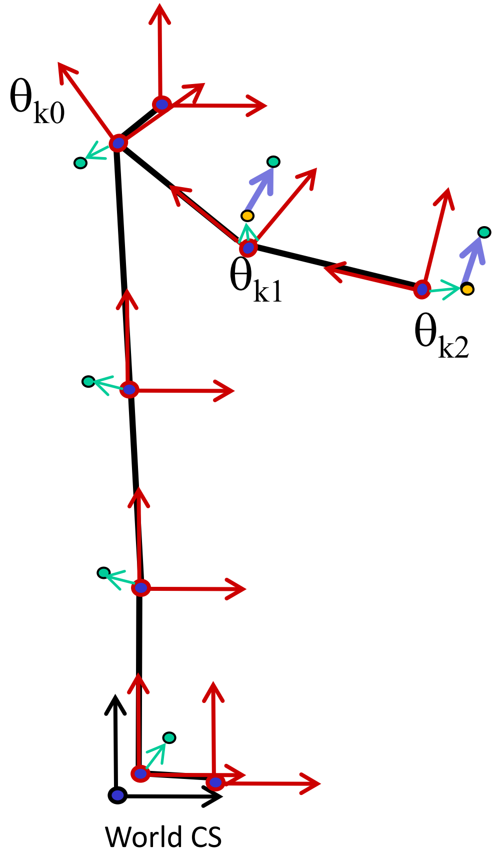
2. Posture reconstruction (3) *full body tracking*



INPUT: global location of all makers



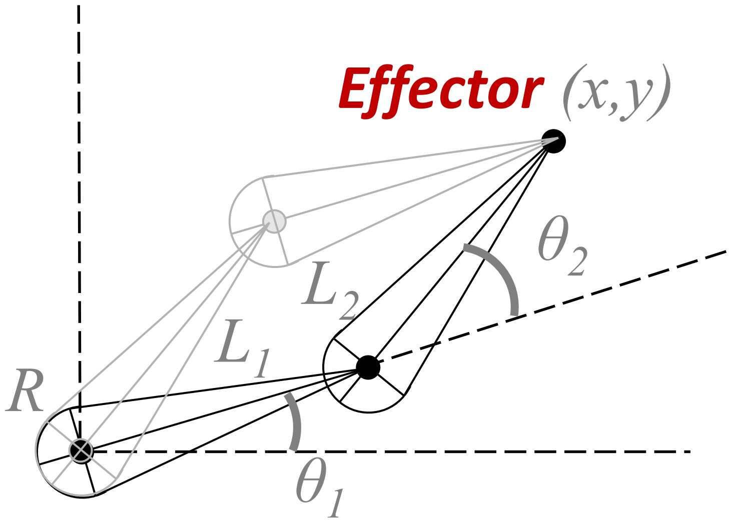
1) **CALIBRATION with a SKELETON model In the calibration posture**:
Determines the location of **the body point (called <u>effector</u>)**
that <u>should coincide with each sensor location</u>
The position of the effector is computed in the LOCAL coordinate system of its associated JOINT.
e.g. a wrist **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 (4)

- 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:

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

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

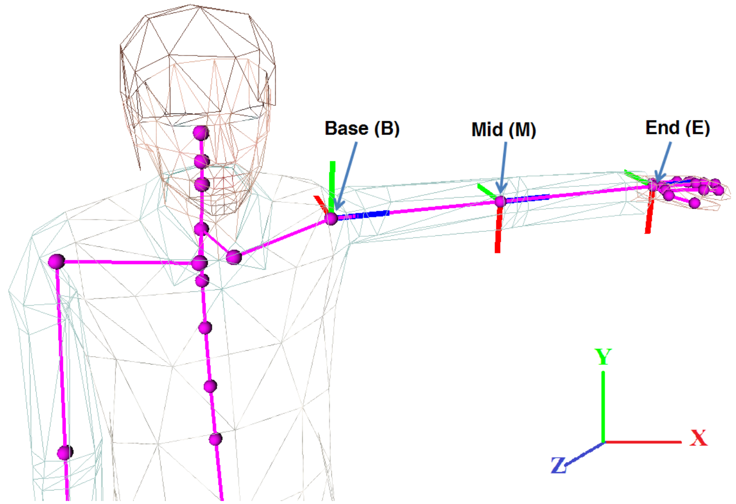
IK:

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

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

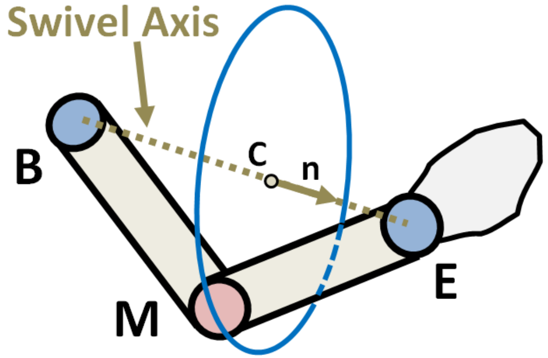
2.1 Two families of IK methods

- 2.1.1 Analytic IK:
  - Possible for simple non-redundant cases, e.g. dim(x,y) = dim(θ_1,θ_2)
  - The limb case [Korein, Badler, Tolani, Kallmann, Molla, Final-IK]:



- 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



Exemple of low-cost Analytic solution at full-body scale from three 6Dof effectors

VRIK [D-a-B] from Final-IK solution package [Final-IK]

- Input: position/orientation of the head (HMD) and the two controllers
- Output: real-time full-body poses including steps to maintain balance

- How to handle the underconstrained problem [D-a-B] ?

Two equally valid poses from the 3x6dof input [D-a-B]

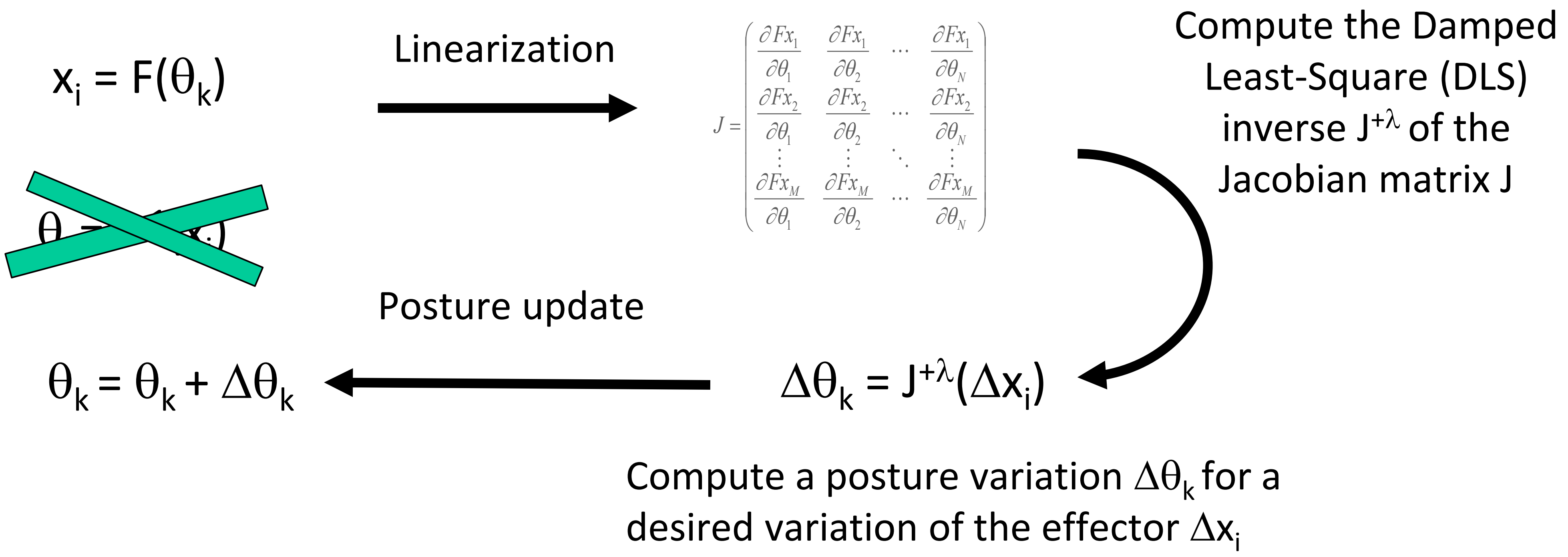
The input dimension is 3x6 = 18, far smaller than the body pose space

Make pose design decisions based on the observation of human movement (but this may reflect an application-dependent choice):

- The head height impacts the pelvis height
- The pelvis height determines the leg state
- The leg state ensures that the center of mass floor projection lies within the feet or trigger a foot relocation.
- Distribute the head orientation over the spine until the pelvis that is used as a reference frame (its vertical axis remains mostly constant)
- Modulate the spine distribution by taking into account the relative location of hands with respect to the torso
- The hands control the arm including the clavicle, if necessary.

2.1 Two families of IK methods

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

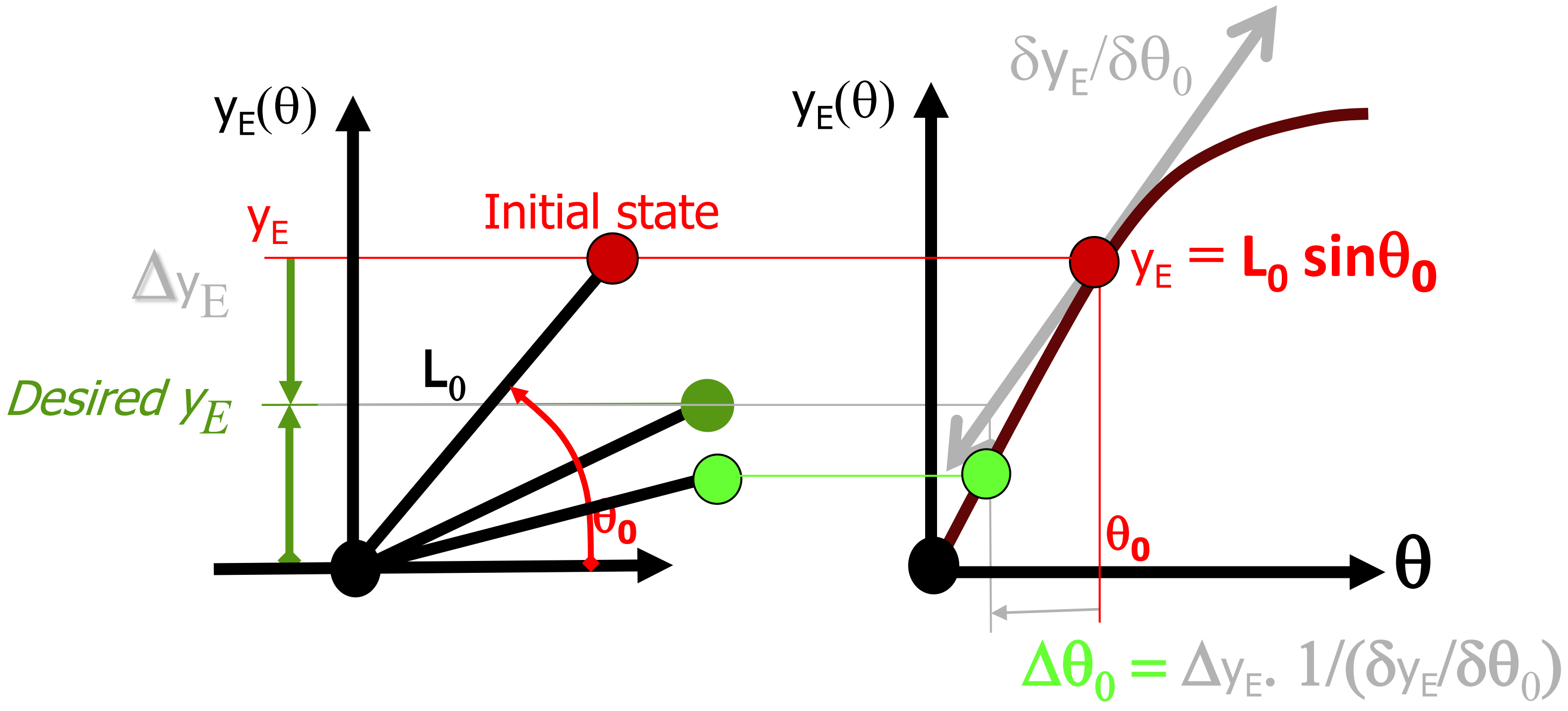


2.1 Two families of IK methods

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

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

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

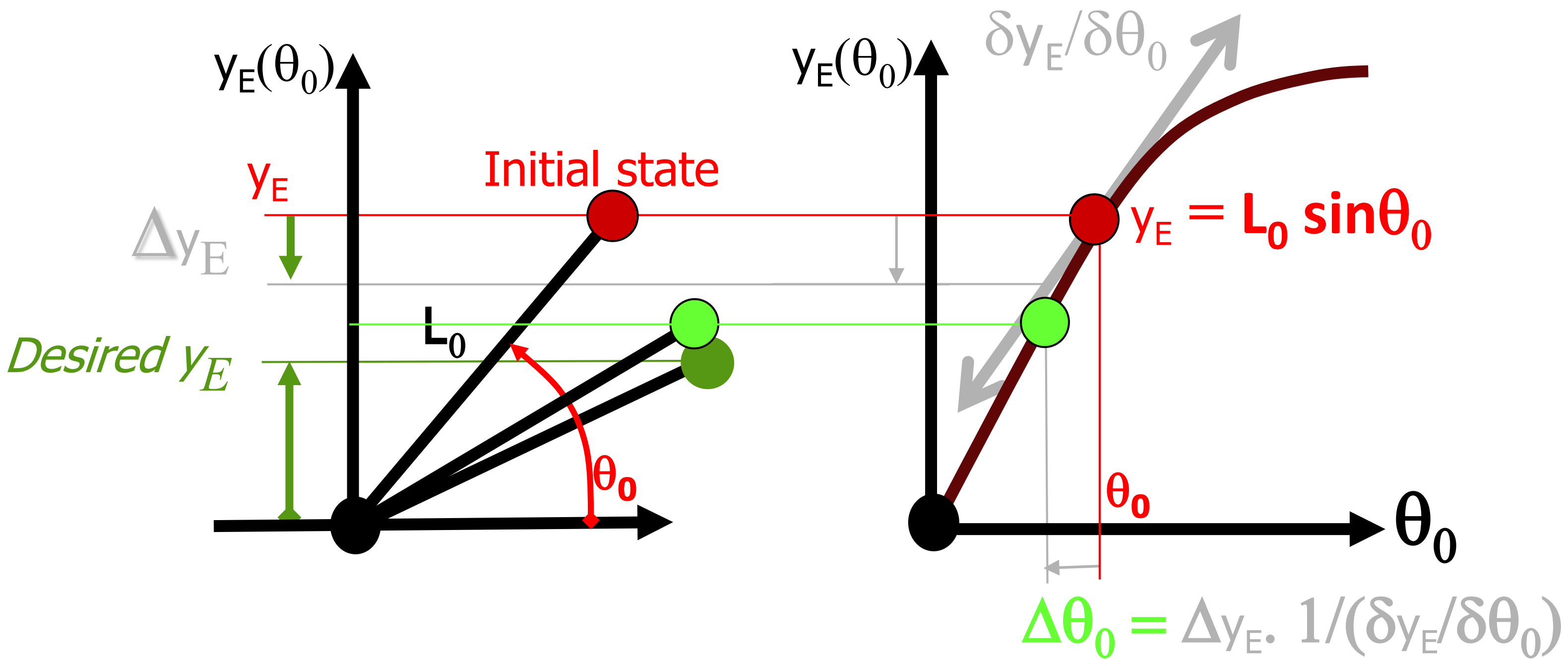


The linear approximation is only valid near the current state

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 $y_E - y_E$)



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 (Final-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)
Approaches leveraging on ML to map effector locations to a subset of poses

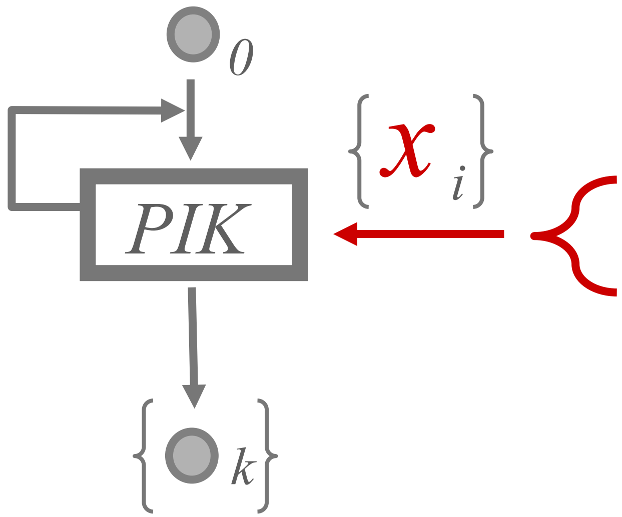
2.2 Jacobian-based IK with Priority levels

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

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

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

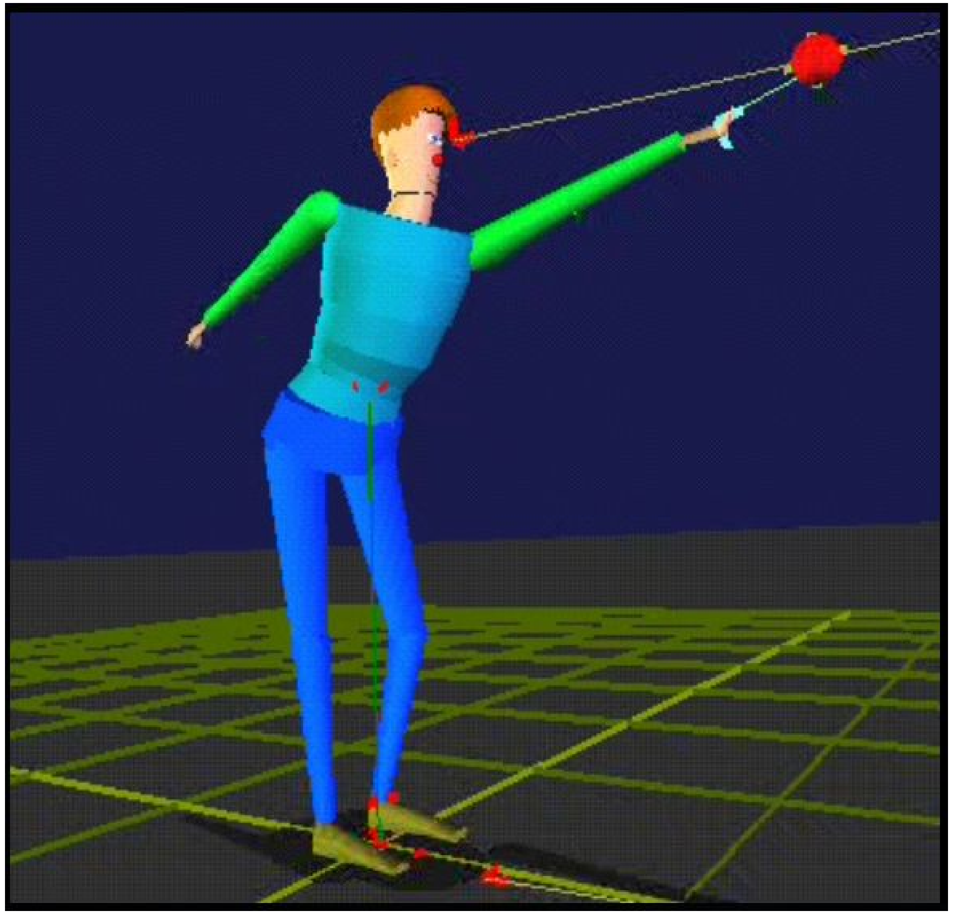
Goal oriented soft ***constraints*** *built from marker data and associated with a* ***priority*** *level*

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 [B04]:
interactively moving the reach goal



Priority levels :

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

5. attraction toward rest posture

[References]

[B04] P. Baerlocher, R. Boulic, « An Inverse Kinematic Architecture Enforcing an Arbitrary Number of Strict Priority Levels », The Visual Computer, Springer Verlag, 20(6), 2004, pp 402-417

[D-a-B] Dead-and-buried by Oculus Studio developer blog, http://root-motion.com/2016/06/inverse-kinematics-in-dead-and-buried/

[Final-IK] http://www.root-motion.com/finalikdox/html/index.html

[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