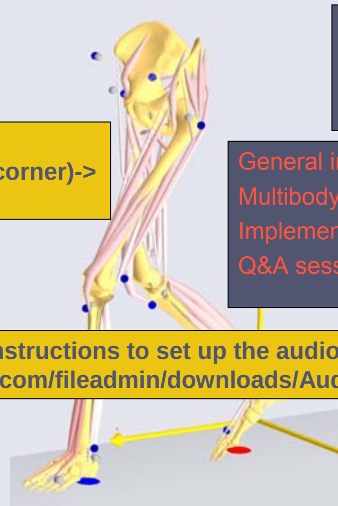
Kinematics
in musculoskeletal modeling



The web cast will start in a few minutes….

To fit your screen:
Sharing (upper right corner)->
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General intro (~5 min)
Multibody systems (~15 min)
Implementation and demo (~15 min)
Q&A session (~10 min)

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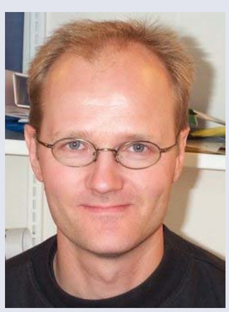
Presenters



John Rasmussen
(Presenter)

Arne Kiis
(Host)

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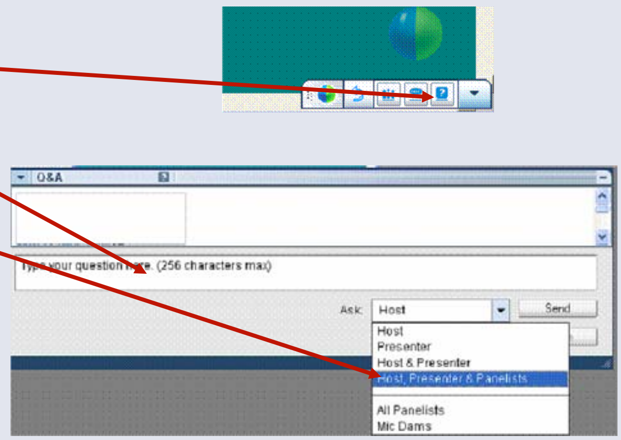
Q&A Panel

- Søren Tørholm and Michael Damsgaard.
- Launch the Q&A panel here.
- Type your questions in the Q&A panel.
- Send the question to ”Host, Presenter & Panelists”
- Notice the answer displays next to the question in the Q&A box. You may have to scroll up to see it.



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Kinematics is the foundation of inverse dynamic analysis

- Kinematics determines the accelerations and thereby forms input to the equilibrium equations.
- Kinematics often turns out to be the challenging part of a modeling project.
- Let us briefly review some properties of multibody dynamics systems.

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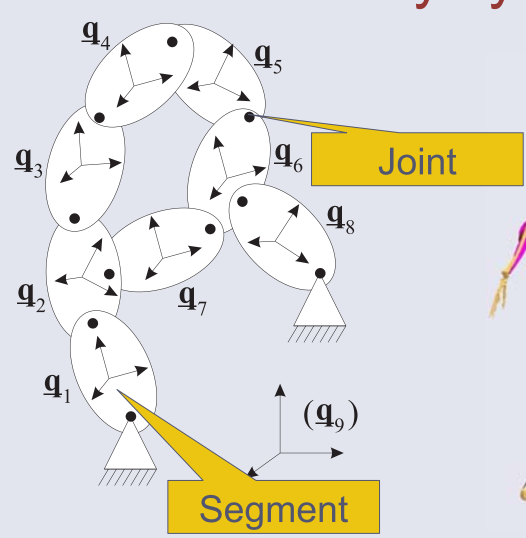
Multibody systems



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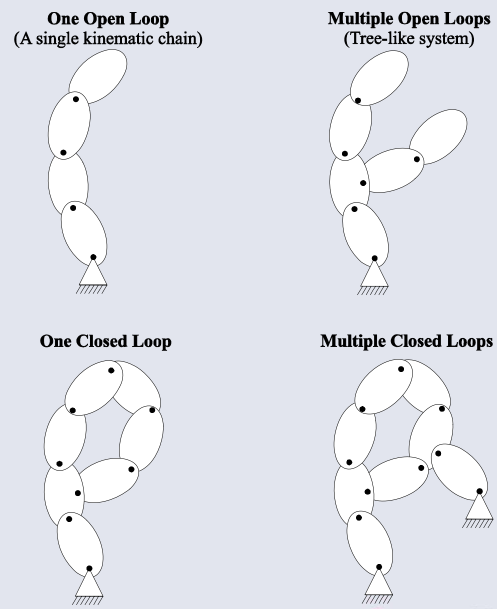
Topology

Human body models change topology depending on posture and the environment.

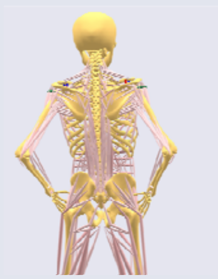


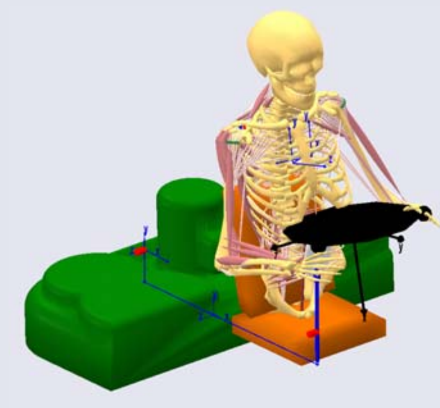
Closed chains are always present

- The human body has more close chains than most people think.
  – Forearms
  – The shoulder girdle
  – Shanks
  – The mandible

Closed chains appear and disappear

- Grabbing something with two hands
- Standing on both feet
- Grabbing one body part with another





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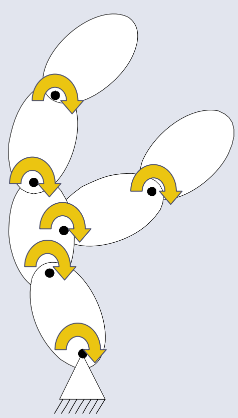
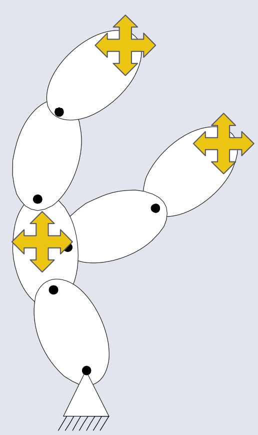
Forward and inverse kinematics



Forward kinematics



Inverse kinematics

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Musculoskeletal kinematics

- Must be very general to allow for all the kinds of movements humans can do.
- Must allow for coupling between the body and equipment.
- Must allow for inverse as well as forward kinematics.
- Must allow for closed loops.

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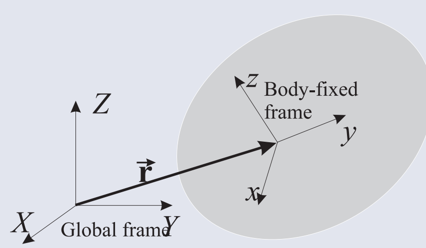
Cartesian Coordinates for a single segment

For the *i*'th segment:

- Positions $\mathbf{q}_i = [\mathbf{r}_i^T \ \mathbf{p}_i^T]^T$
- Velocities $\mathbf{v}_i = [\dot{\mathbf{r}}_i^T \ \omega_i^T]^T$
- Accelerations: $\dot{\mathbf{v}}_i$

where

- Vector **r** is position vector of the local origin.
- Vector **p** is the Euler parameters (special quaternions).
- Vector ω is angular velocity.



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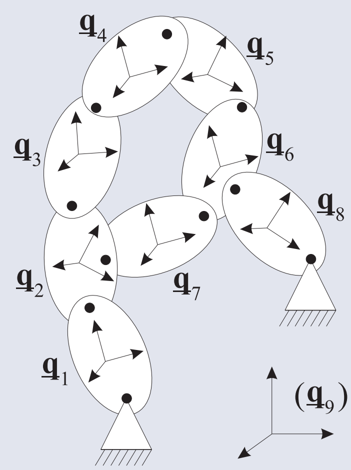
Cartesian Coordinates for a system of segments

For *n* bodies:

- Positions $\mathbf{q} = [\mathbf{q}_1^T \ldots \mathbf{q}_n^T]^T$ (7*n* coords:)
- Velocities $\mathbf{v} = [\mathbf{v}_1^T \ldots \mathbf{v}_n^T]^T$ (6*n* coords.)
- Accelerations: $\mathbf{v}_i$



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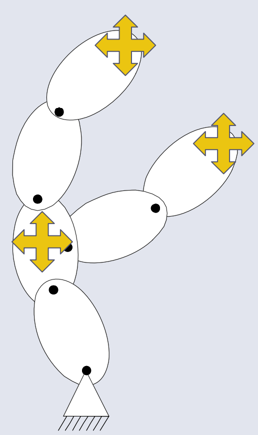
Constraints

- The constraints are relations between degrees of freedom, i.e. equations.
- Joints are one type of constraints.
- Drivers are another type of constraints.
- We need precisely enough constraints to determine the position of each segment in space.



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Examples of constraint equations

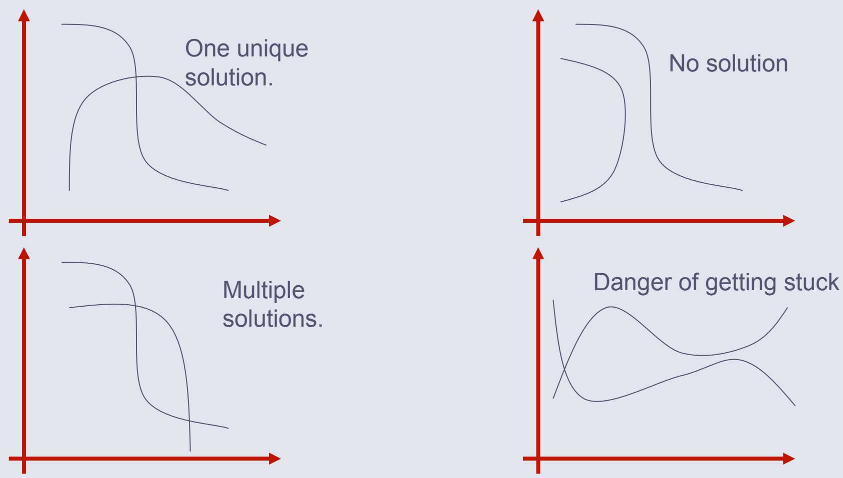
- Connections between segments at joints.
- Joint angles.
- Positions in space of given points in the system (for instance an optical marker position).
- Some relationships between joint angles (for instance rhythms).
- The position of the collective CoM of many segments.
- Other conditions on multiple elements and their relationships.

Constraint equations

$$\mathbf{\Phi}(\mathbf{q}, t) = \mathbf{0}$$

- The equations are generally nonlinear.
- The vector function, Φ, measures the violation of the constraints, i.e., when it is zero there is no violation.
- Number of equations:
  - 6*n* independent constraint equations for the system to be kinematically determinate.
  - 1*n* Euler parameter constraints, that must be included to find the 7*n* unknowns in **q**.
- The implicit form allows us to include any (holonomic) constraint equations.
- Can be solved by Newton-Raphson iteration.

Nonlinear equations



A good initial solution guess is essential!

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Some intermediate conclusions

- Kinematics is difficult because it is highly nonlinear.
- We have chosen a very general (Cartesian) formulation that simply allows us to add constraints.
- The constraints can have almost any form.

<u>How can this be implemented in practice?</u>

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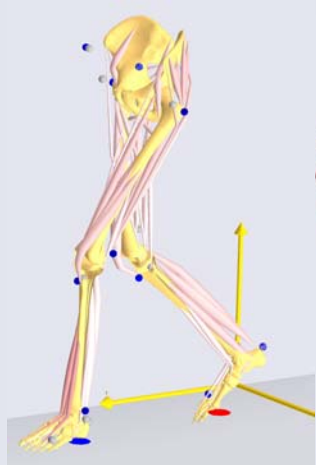
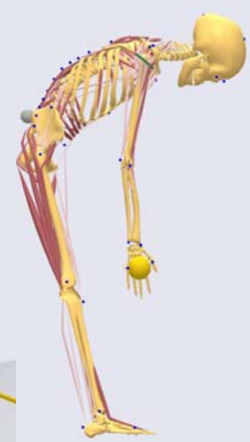
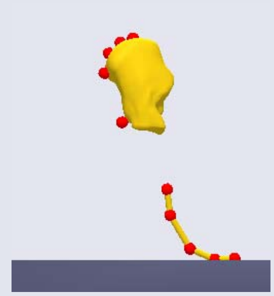
Three examples



Inverse kinematics



Balance



Contact condition

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Practical implementation:

Kinematic measures

(We skip simple and obvious examples)

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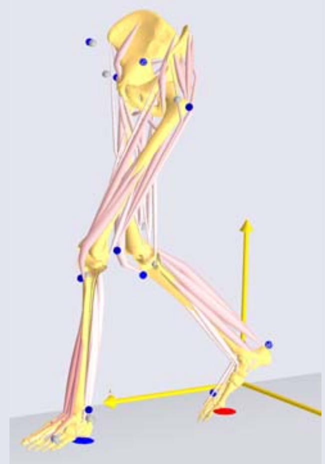
Kinematic measures

- A kinematic measure is anything you can conceivably measure on a mechanical system:
  - Joint angles
  - Positions in space
  - A vector from one moving point to another
  - The distance to a surface
  - Sums of distances
  - Linear combinations of other measures
  - Position of Center of Mass
  - Minimum over a number of other measures



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The point of kinematic measures is:

When you can measure them you can also use them as constraints.

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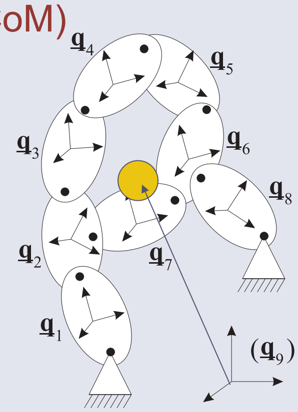
AnyKinCoM
(Center of Mass, CoM)

$$\mathbf{Pos} = \frac{\sum_{i=1}^{n_{segments}} m_i \mathbf{r}_i^{CoM}}{M} \quad \text{where} \quad M = \sum_{i=1}^{n_{segments}} m_i$$



Comments:

- Typical use: Balancing a body

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Demo:

The spine rhythm

The CoM measure for balance

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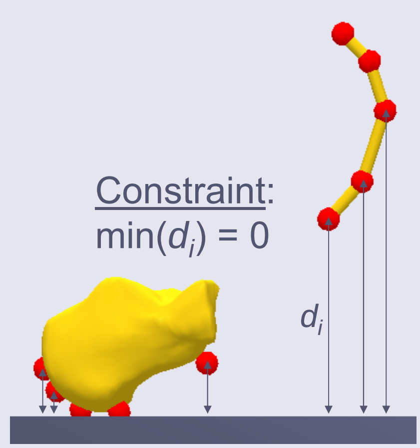
Demo: The min distance measure

- Under development!
- Drive the minimum distance between a set of points and something else.
- Typical use: Contact conditions like a foot on the floor.



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Conclusions

- Kinematics is tricky because it is (very) nonlinear.
- Easy solutions will often limit generality.
- It is possible to capture much of the complexity of human movement by thoughtful implementation.
- Future developments:
  - Over- and under-determinate kinematics
  - Methods less sensitive to starting positions
  - Joint angle constraints
  - Higher pair joints (non-holonomic constraints)
  - Recorded position noise reduction

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Online resources

- AnyBody Technology
  www.anybodytech.com
  - Free demo licenses
  - Tutorials and documentation
  - Replay of webcasts
  - Further info: Email: anybody@anybodytech.com
- The AnyBody Research Project
  www.anybody.aau.dk
  - Public domain library of body models and applications
  - Publications – many for direct download.

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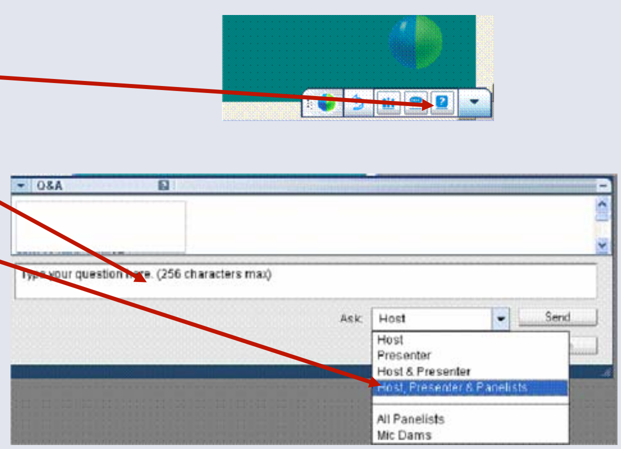

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Thank you! ☺

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31 August: Gait modeling

25 September: Posture and movement synthesis

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