CusToM Workshop

Muscle forces tutorial

Charles Pontonnier, Pierre Puchaud

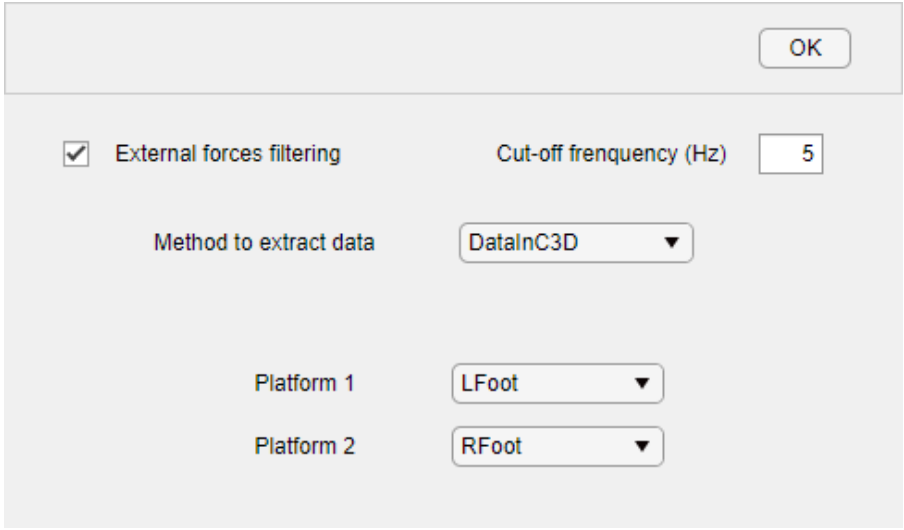
Pre-work

>> Analysis

Generate AnalysisParameters

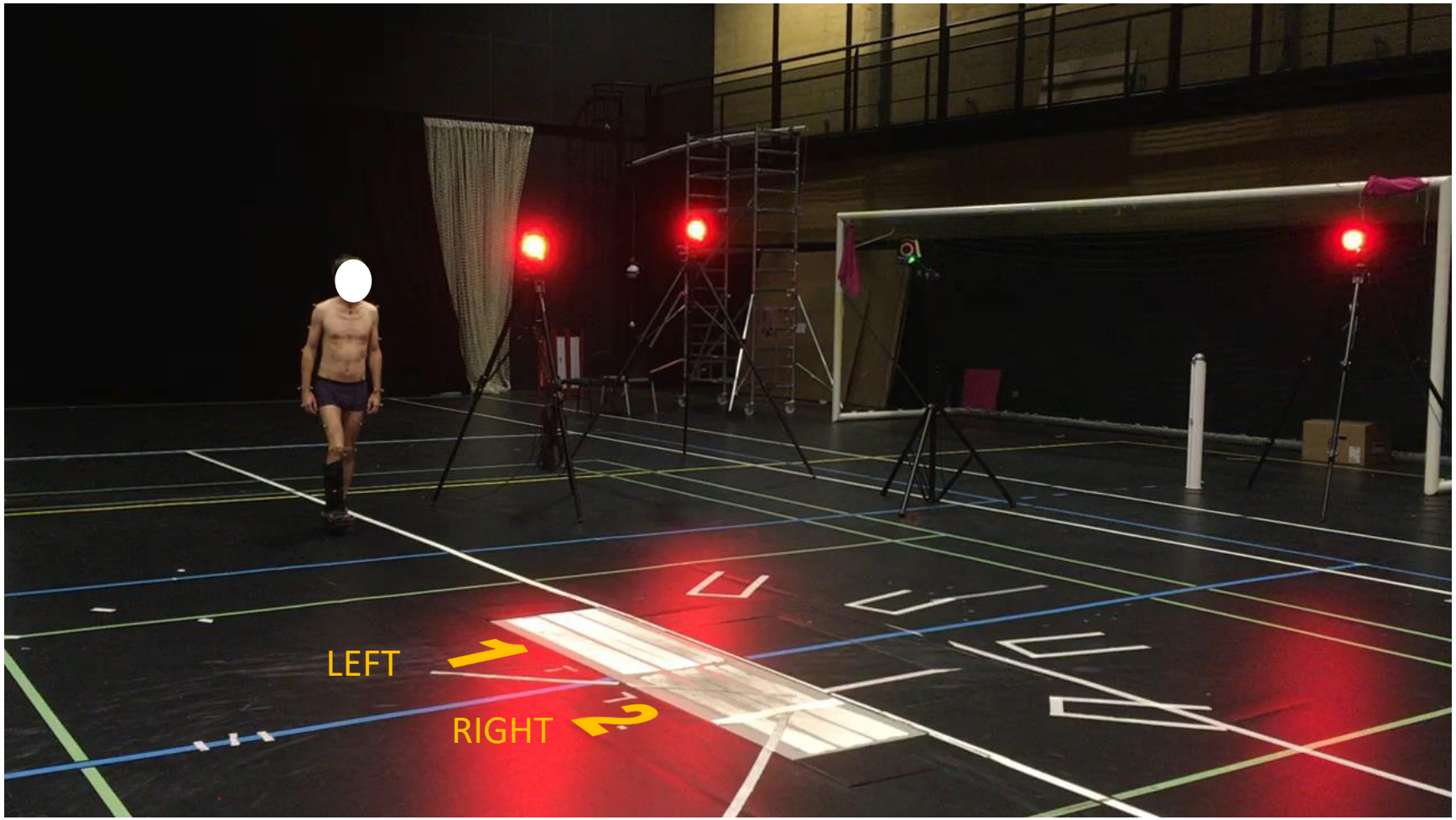
- Open Inverse Dynamics options: enable
- Select « From Experiments » for External forces
- Open Options, select « DataInC3D »
- Select « Lfoot » for Platform 1 and « Rfoot » for Platform 2

This is the source where external forces applied to the model will be read



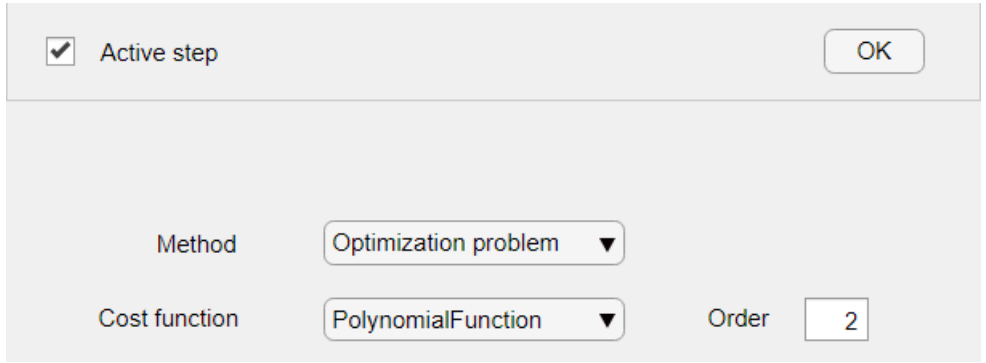
This is a priori knowledge that you should know from your own experiments !!!!!

Here it is



Generate AnalysisParameters

- Open « Muscle forces estimation » Options
- Select **Optimization problem**, and Polynomial function (order 2)

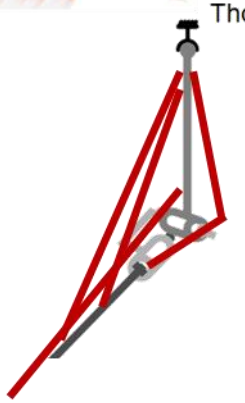


We first go straight

What does this mean ?

The resulting problem to solve for MS forces estimation will be:

Thorax

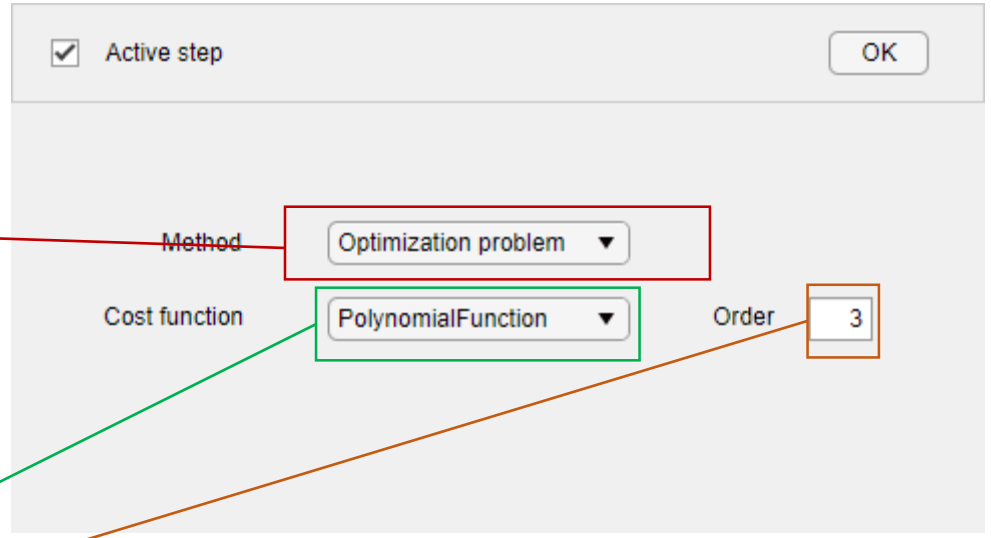


$$\min f(F)$$

$$\text{s.t.} \quad \vec{\tau} = \sum_i \overrightarrow{F_{m_i}} \times \overrightarrow{R_{m_i}}$$

$$F_{min_i} < F_{m_i} < F_{max_i}$$

$$i = 1 \dots n_m$$



$$f(\boldsymbol{F}) = \sum_{i=1}^{n_m} \left(\frac{F_{m_i}}{F_{max,i}} \right)^3$$

Alternatives

Change order to p ⟶ $f(\boldsymbol{F}) = \sum_{i=1}^{n_m} \left(\frac{F_{m_i}}{F_{max,i}} \right)^p$

p ↗ Muscle synergy

Change Polynomial Function to MinMax ⟶ $f(\boldsymbol{F}) = \max_{m \in [\![1:n_m]\!]} \left(\frac{F_m}{F_{max,m}} \right)$ ⟶ $p \to \infty$ Maximal Synergy

See Rasmussen, J., Damsgaard, M., & Voigt, M. (2001). Muscle recruitment by the min/max criterion—a comparative numerical study. *Journal of biomechanics*, *34*(3), 409-415.

RUN

What CusToM is doing ?

... Anthropometric Model Generation done
Geometrical Calibration ...
... Geometrical Calibration done
Preliminary Computations ...
... Preliminary Computations done

→ Not new

Moment Arms Computation ...
Starting parallel pool (parpool) using the 'local' profile ...
connected to 2 workers.
... Moment Arms Computation done

What CusToM is doing ?

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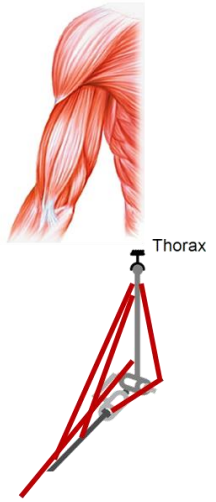
Moment Arms Computation ...
Starting parallel pool (parpool) using the 'local' profile ...
connected to 2 workers.
... Moment Arms Computation done

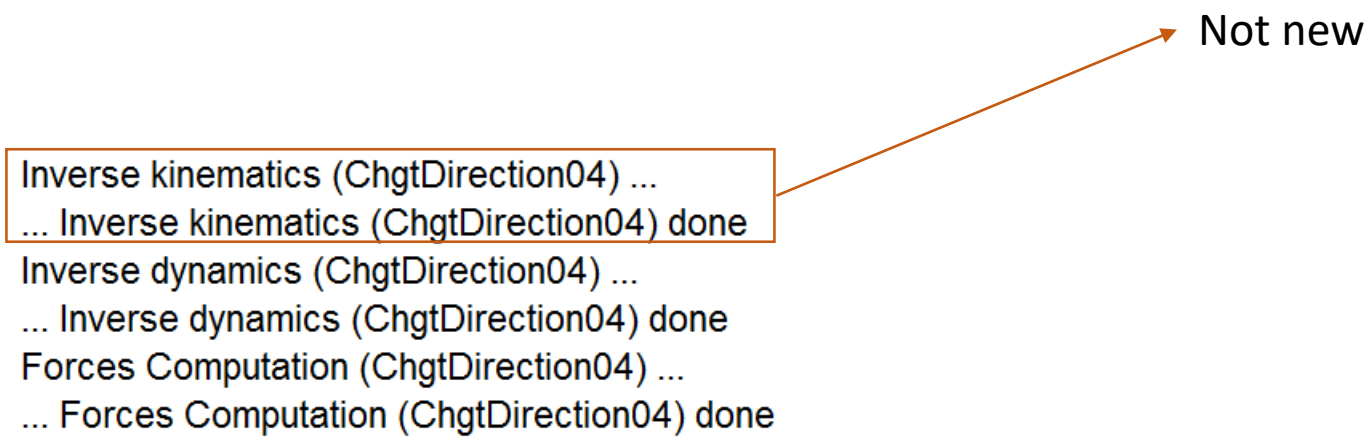
→ New

$$\vec{\tau} = \sum_i \overrightarrow{F_{m_i}} \times \overrightarrow{R_{m_i}}$$

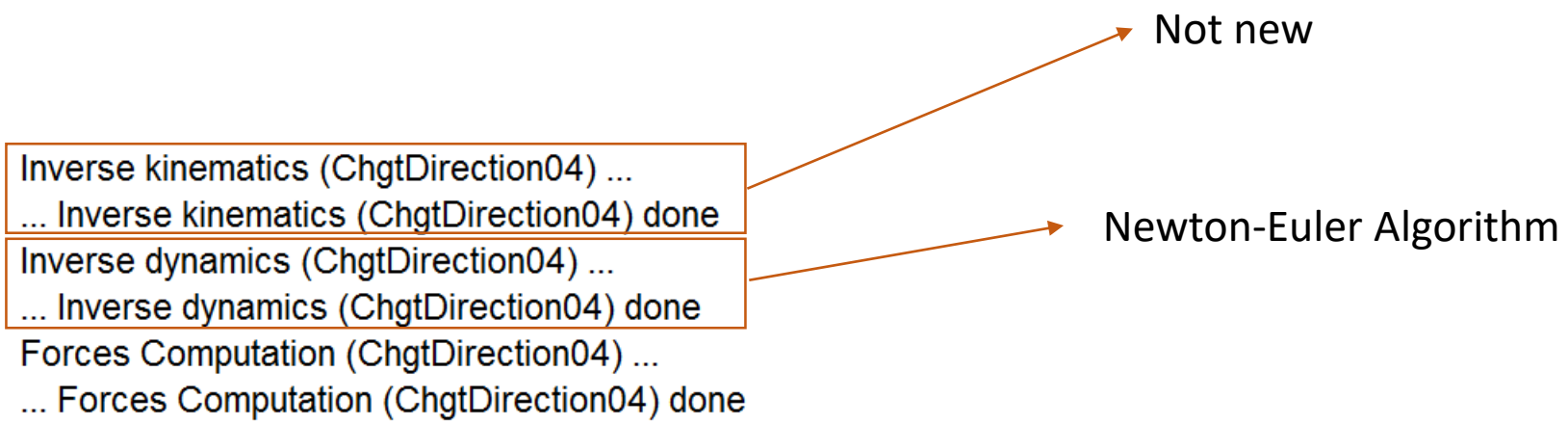
Analytical solution computed and gathered as a matlab function



What CusToM is doing ?



What CusToM is doing ?



Newton Euler-Algorithm

For more details, see 5_INVERSE-DYNAMICS.pdf

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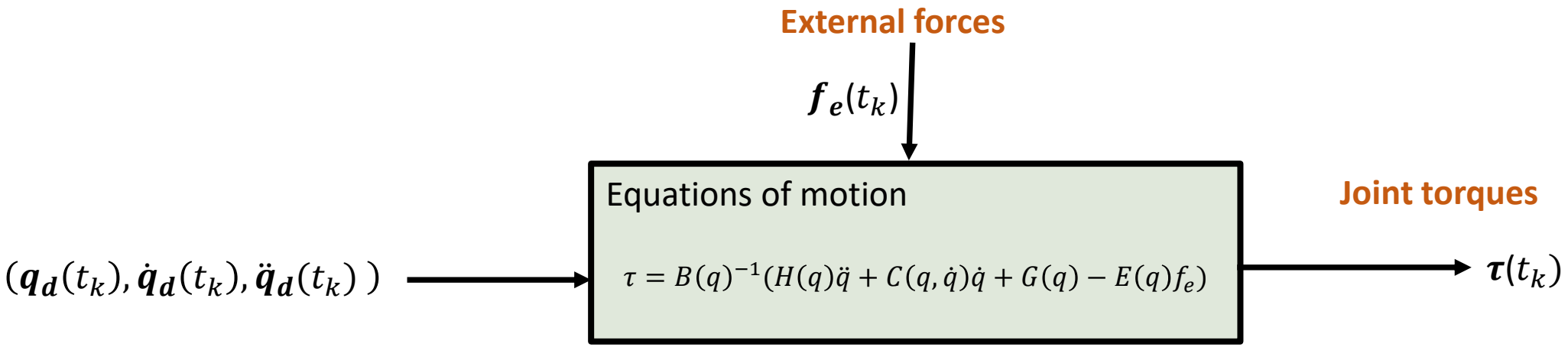
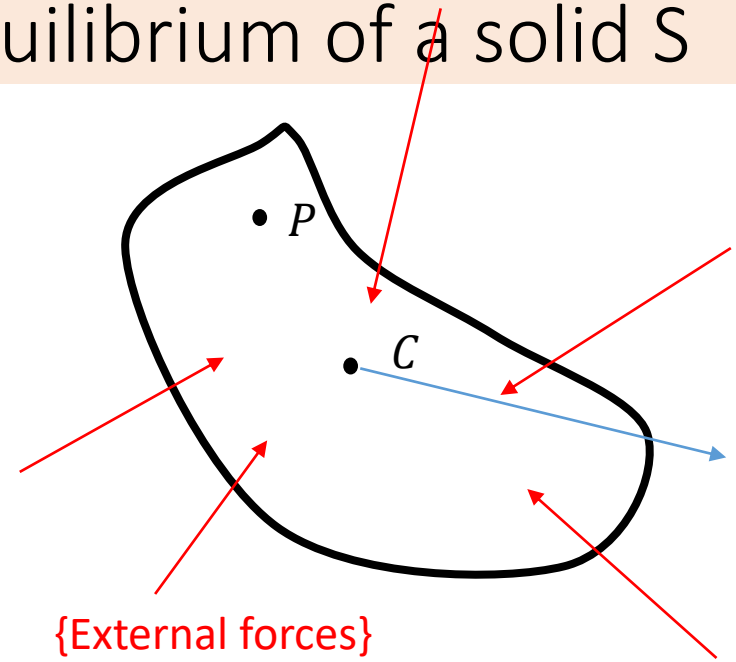
Main issue

At time t_k



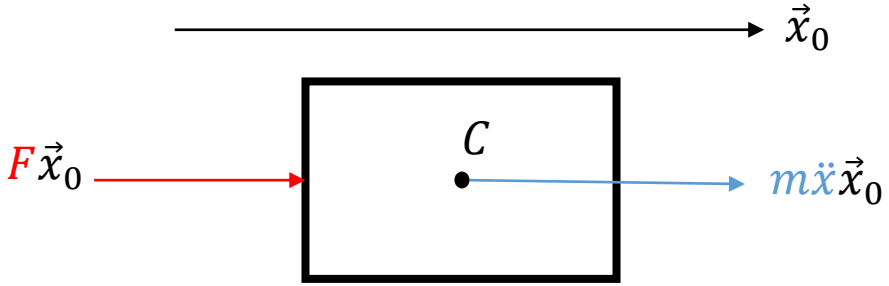
Angles, angular velocities and accelerations

Equilibrium of a solid S



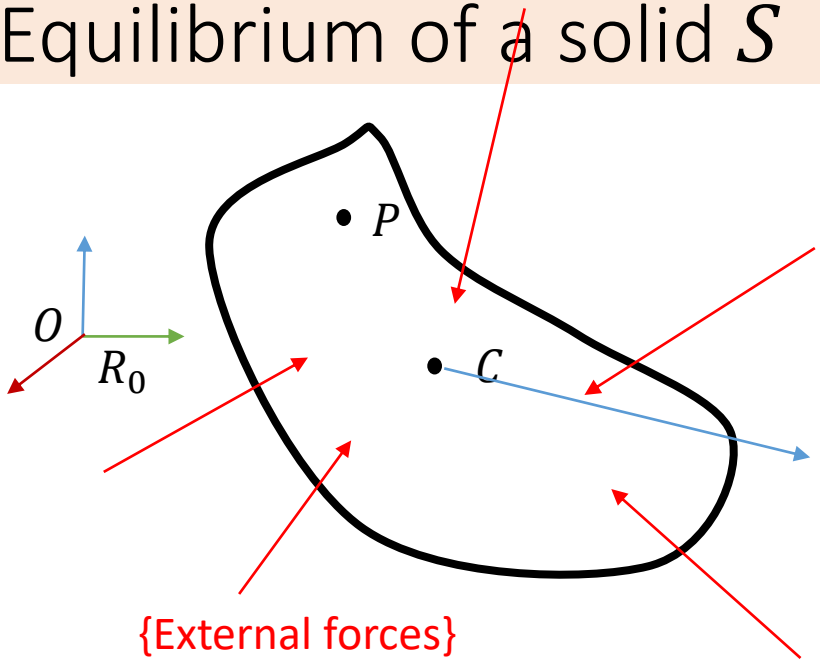
{Acceleration quantities}={External forces}

"For a single solid in translation…"



$m\ddot{x} = F$

Equilibrium of a solid S



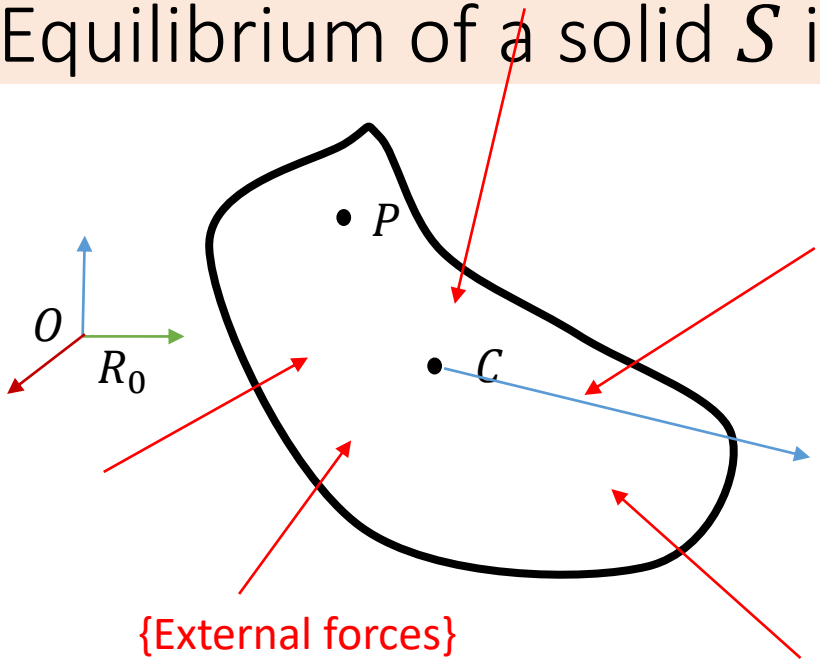
{Acceleration quantities}

At the center of mass

$$\begin{cases} \boldsymbol{f} = m\ddot{\boldsymbol{c}} & (1) \\ \boldsymbol{\tau}^{(c)} = \boldsymbol{I}\dot{\boldsymbol{\omega}} + \boldsymbol{\omega} \times \boldsymbol{I}\boldsymbol{\omega} & (2) \end{cases}$$

$\boldsymbol{f}$	external forces
m	solid mass
$\boldsymbol{c}$	center of mass of the solid in R_0 (world) frame
$\boldsymbol{\omega}$	angular velocity of the solid in R_0
$\boldsymbol{I}$	inertia matrix of the solid in R_0
$\boldsymbol{\tau}^{(c)}$	torque associated to external forces, expressed in R_0 at the center of mass

Equilibrium of a solid S in human motion analysis



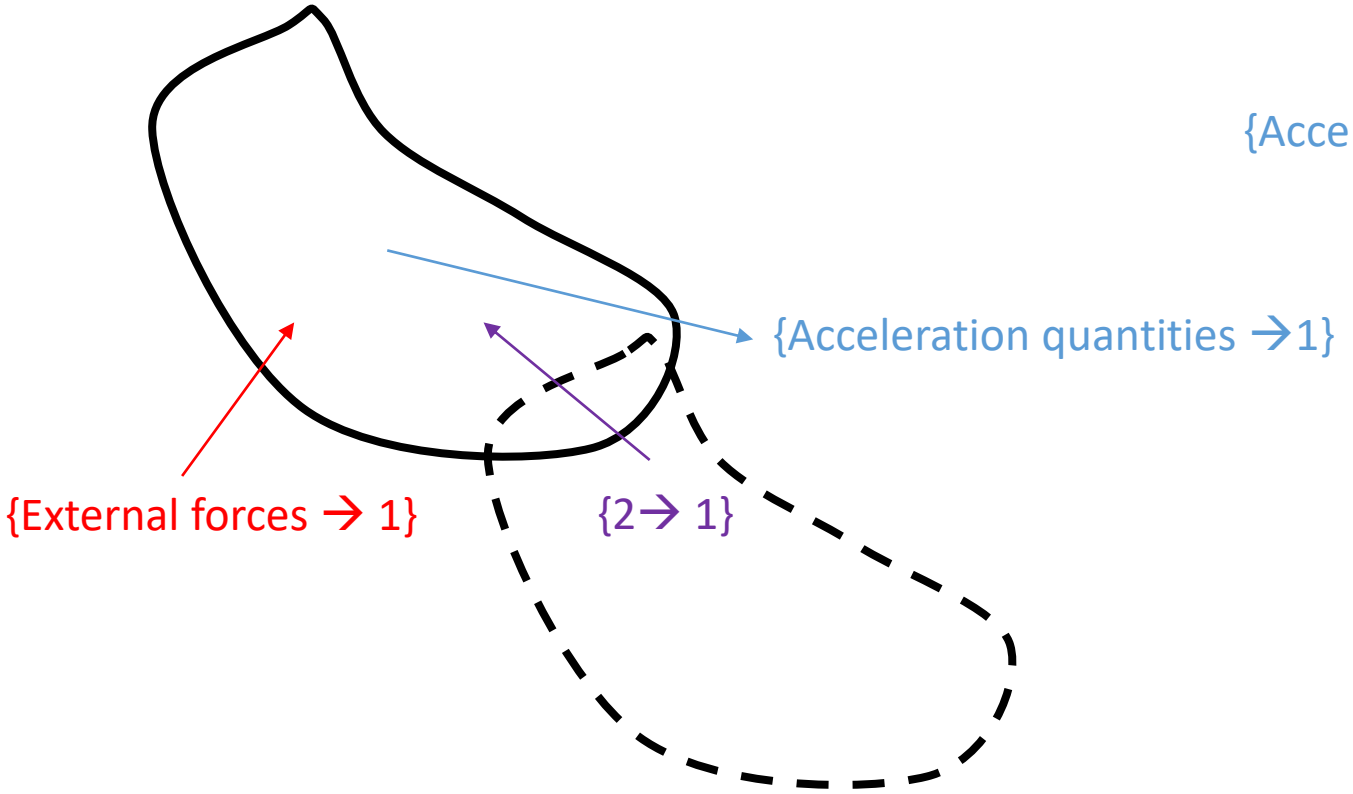
{Acceleration quantities}

At the center of mass

$$\begin{cases} \boldsymbol{f} = m\ddot{\boldsymbol{c}} & (1) \\ \boldsymbol{\tau}^{(c)} = \boldsymbol{I}\dot{\boldsymbol{\omega}} + \boldsymbol{\omega} \times \boldsymbol{I}\boldsymbol{\omega} & (2) \end{cases}$$

$\boldsymbol{f}$	external forces → known (measured)
m	solid mass → known (measured/estimated)
$\boldsymbol{c}$	center of mass of the solid in R_0 (world) frame → known (computed from $\boldsymbol{q}$)
$\boldsymbol{\omega}$	angular velocity of the solid in R_0 → known (computed from $\boldsymbol{q}$)
$\boldsymbol{I}$	inertia matrix of the solid in R_0 → known (measured/estimated)
$\boldsymbol{\tau}^{(c)}$	torque associated to external forces, expressed in R_0 at the center of mass → known (measured)

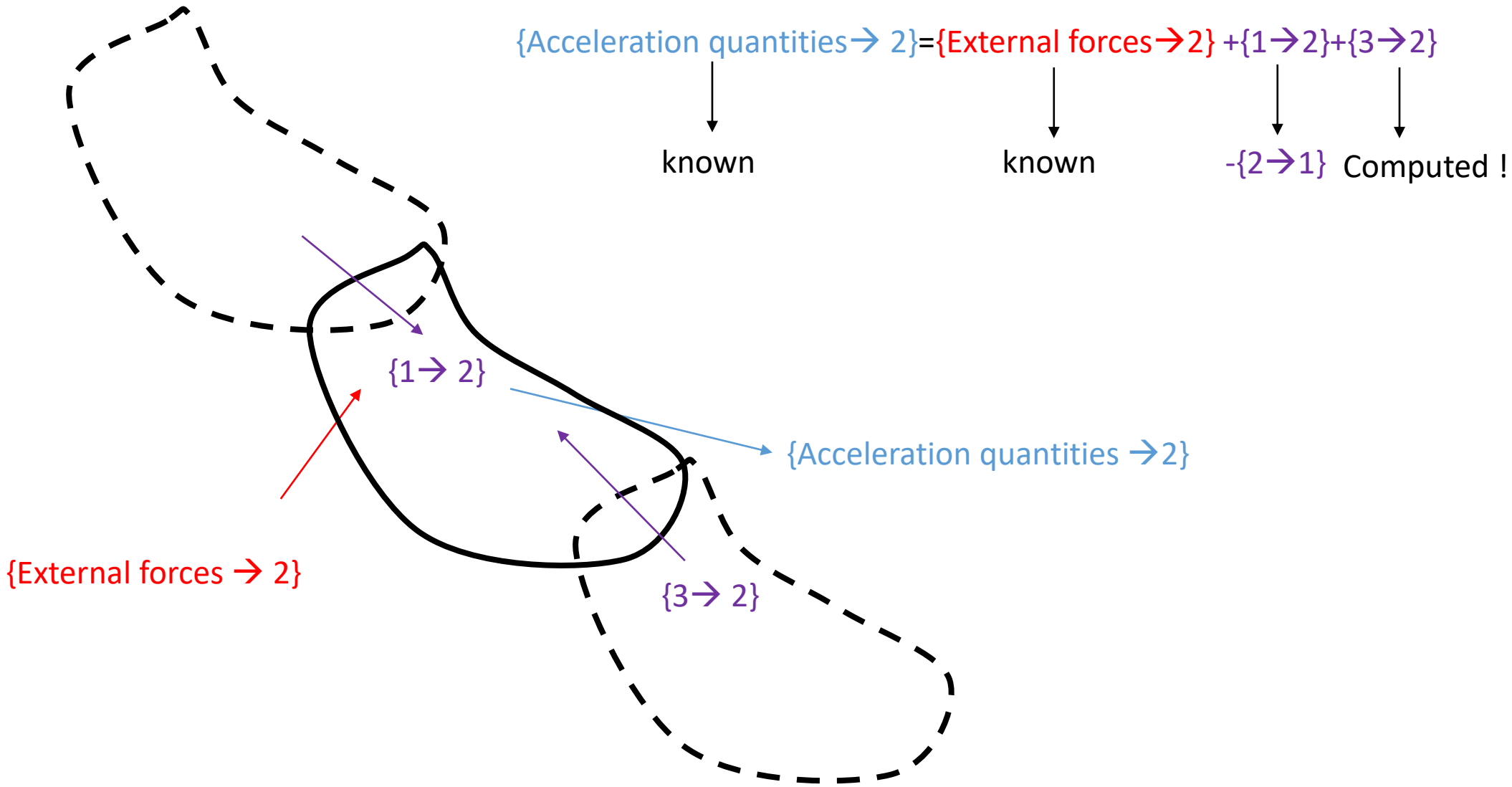
Equilibrium of a chain of solids S



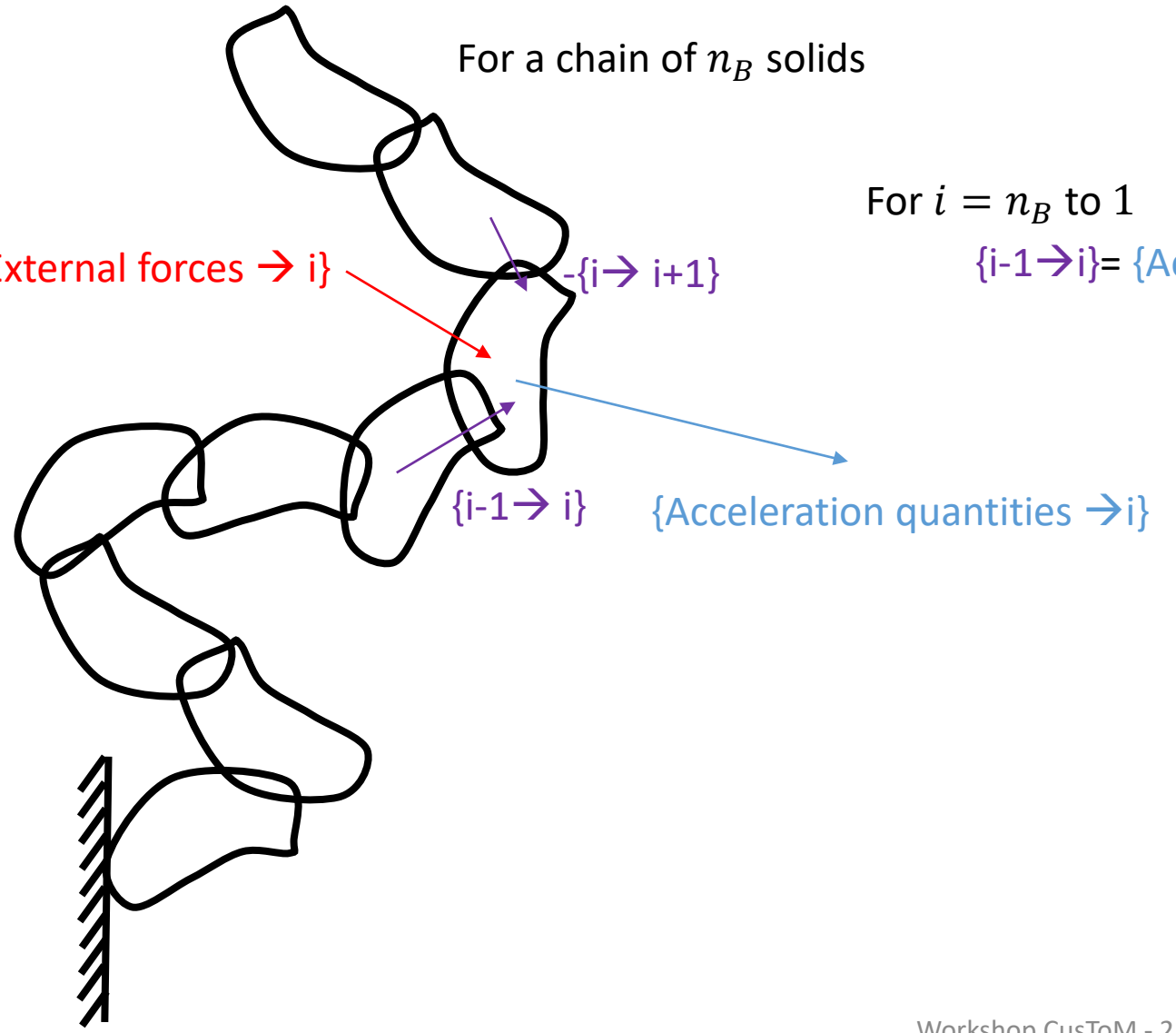
{Acceleration quantities→ 1}={External forces→1}+{2→1}

known known Computed !

Equilibrium of a chain of solids S



Newton Euler algorithm

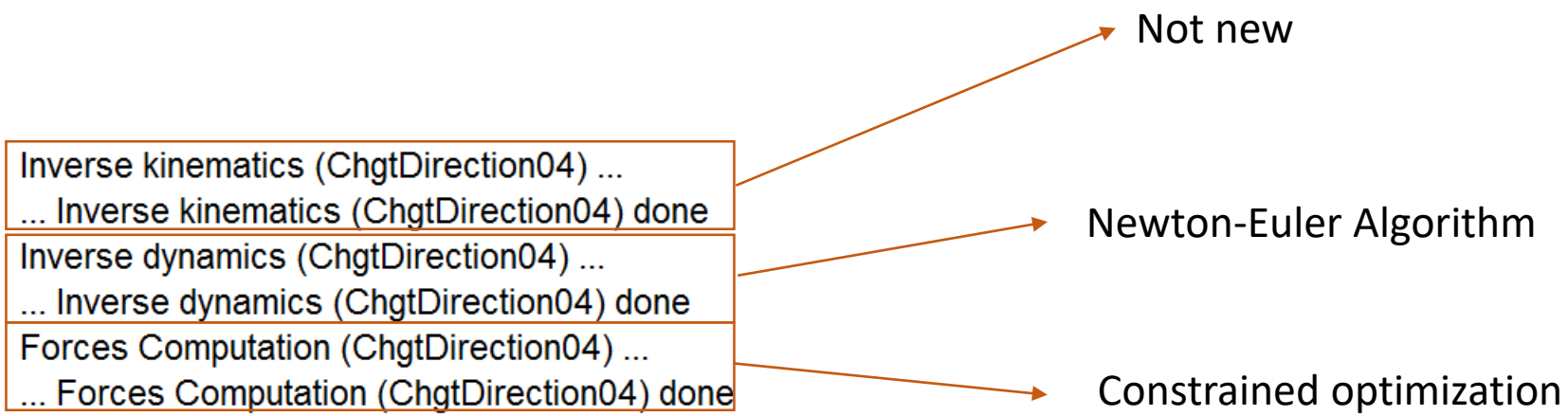


For $i = n_B$ to 1

{i-1→i}= {Acceleration quantities→ i}-{External forces→i}+{i→ i+1}

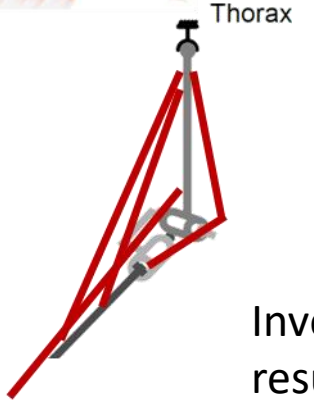
Easy ! But with a bit more of details…

What CusToM is doing ?



Constrained optimization

At each frame, solve



$$\min f(F)$$

$$\text{s.t. } \vec{\tau} = \sum_i \overrightarrow{F_{m_i}} \times \overrightarrow{R_{m_i}}$$

$$F_{min_i} < F_{m_i} < F_{max_i}$$

$$i = 1 \dots n_m$$

Inverse dynamics results !

Sequential Quadratic Programming Method

Replaces the cost function by a quadratic approximation and the constraints by linear approximations (and then active-set successive solutions until next step)

Now with the altered gait

First, we need to modify the model

What about the boot ?

1kg cylinder (R,L) centered on the {shank+foot} segment of the subject

$$R = 0.06\text{m}$$
$$L = 0.44\text{m}$$

$$\bar{\bar{I}}(G_{shankfoot}, \{\text{shank+foot+boot}\}) = \bar{\bar{I}}(G_{shankfoot}, \{\text{shank+foot}\}) + \begin{bmatrix} m(\frac{R^2}{4} + \frac{L^2}{12}) & & \\ & m\frac{R^2}{2} & \\ & & m(\frac{R^2}{4} + \frac{L^2}{12}) \end{bmatrix}$$

$$m_{shankfoot+boot} = m_{shankfoot} + 1$$

Model modification

$$\bar{\bar{I}}(G_{shankfoot}, \{\text{shank+foot+boot}\}) = \bar{\bar{I}}(G_{shankfoot}, \{\text{shank+foot}\}) + \begin{bmatrix} m(\frac{R^2}{4} + \frac{L^2}{12}) & & \\ & m\frac{R^2}{2} & \\ & & m(\frac{R^2}{4} + \frac{L^2}{12}) \end{bmatrix}$$

$$m_{shankfoot+boot} = m_{shankfoot} + 1$$

Open the biomechanical model

BiomechanicalModel.OsteoArticula

Fields	name
7	'Thorax'
8	'RClavicle_J1'
9	'RClavicle_J2'
10	'RClavicle'
11	'LClavicle_J1'
12	'LClavicle_J2'
13	'LClavicle'
14	'ThoraxSkull_J1'
15	'ThoraxSkull_J2'
16	'Skull'
17	'RHip_J1'
18	'RHip_J2'
19	'RThigh'
20	'RShankFoot'

Fields to modidy

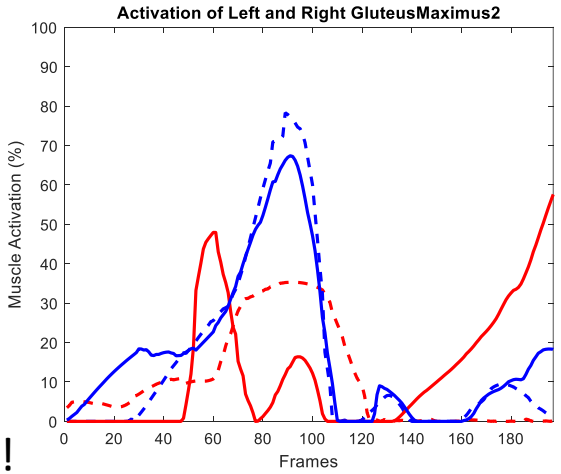
```
BiomechanicalModel.OsteoArticularModel(20).I
BiomechanicalModel.OsteoArticularModel(20).m
```

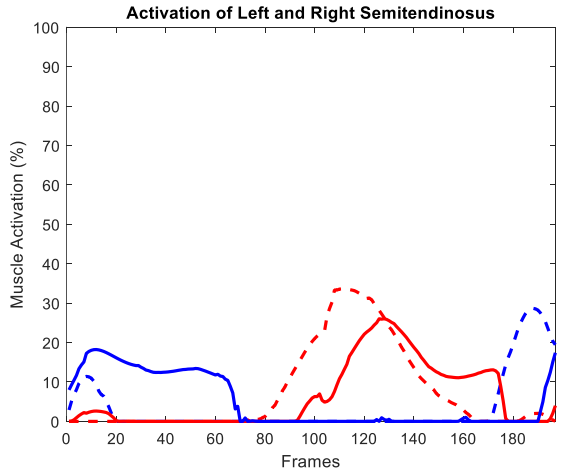
SAVE !

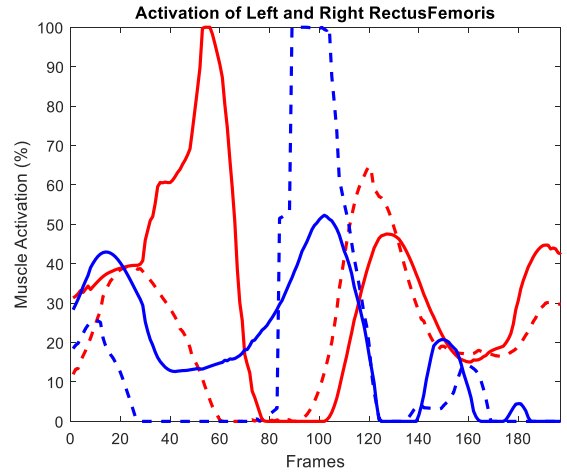
RUN

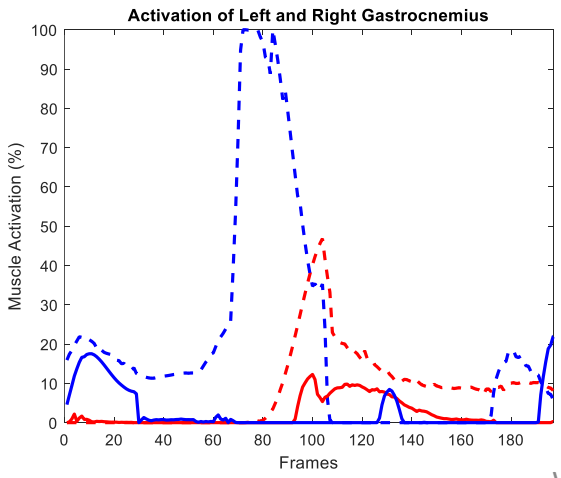
Results

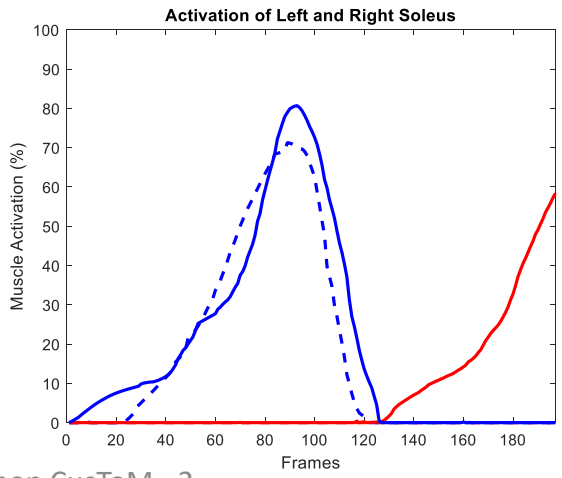
Pierre will soon provide you EMG measures to compare !
#SupervisionBullyJoke

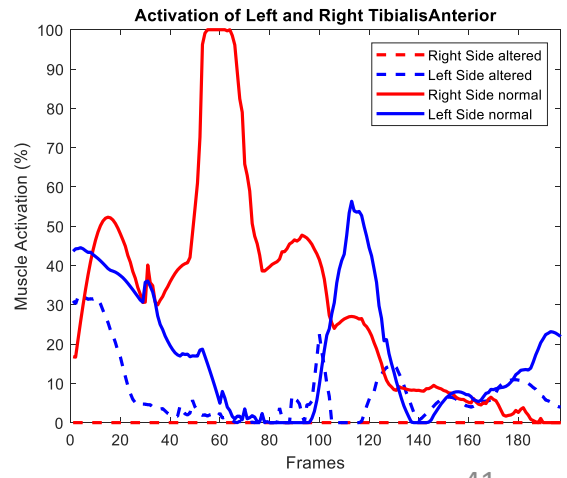






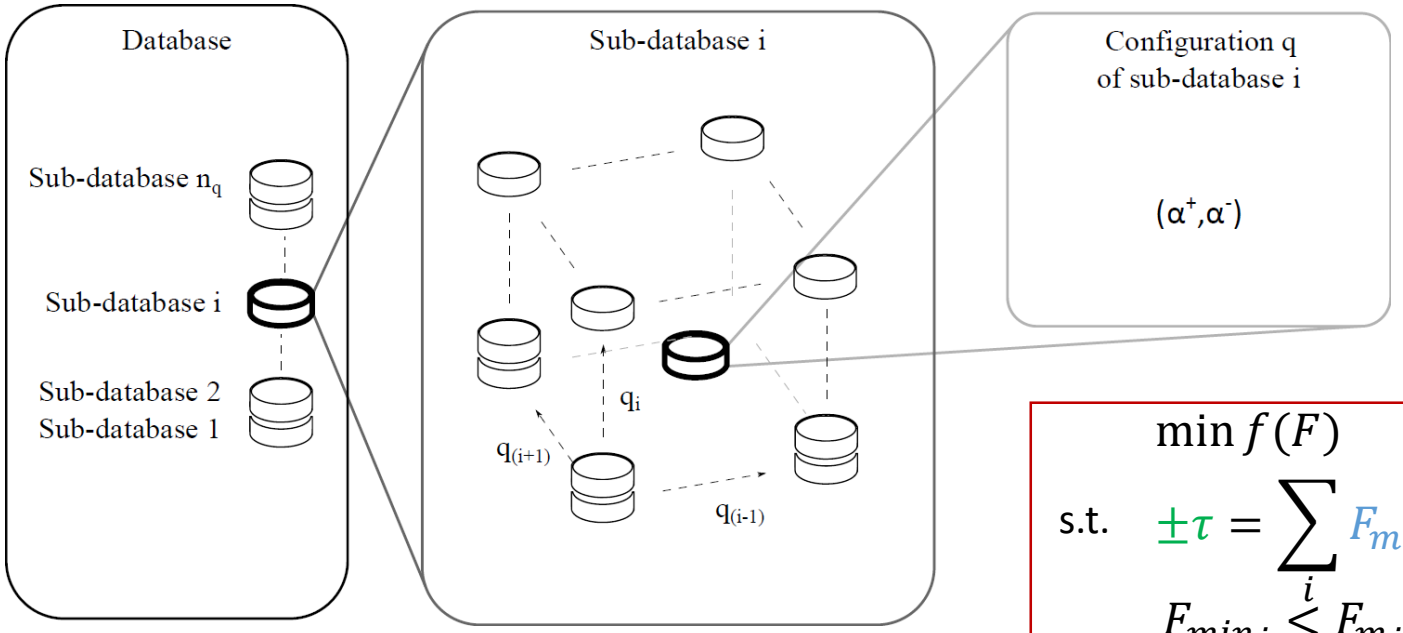


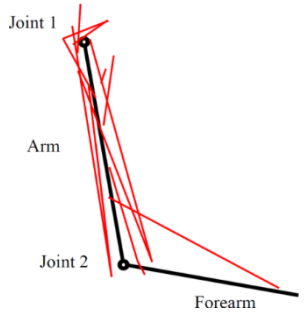




An alternative method: the MusIC method

Database generation





subdatabase

$$\min f(F)$$

$$\text{s.t.} \quad \pm\tau = \sum_i F_{m_i} R_{m_i}$$

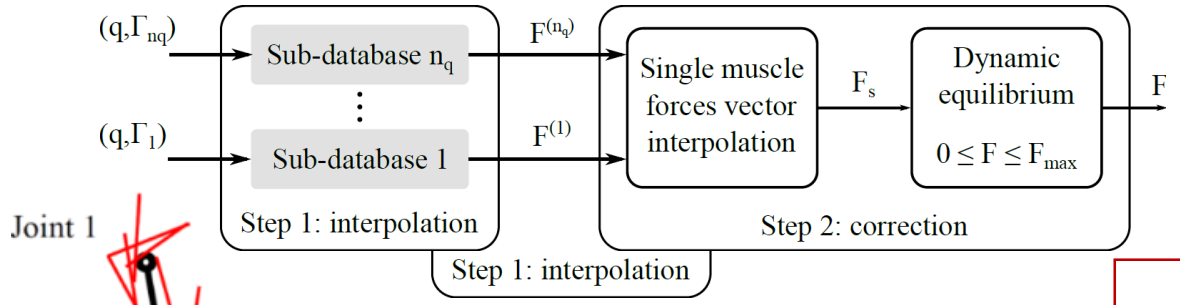
$$F_{min_i} < F_{m_i} < F_{max_i}$$

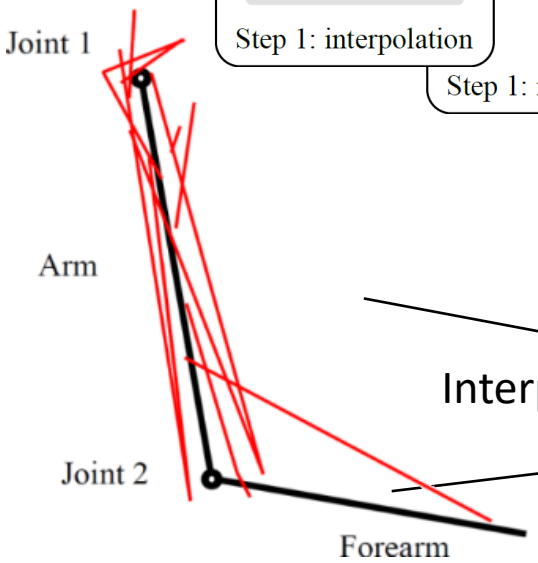
$$i = 1 \dots n_m$$

$$f(\boldsymbol{F}) = \sum_{i=1}^{n_m} \left(\frac{F_{m_i}}{F_{max,i}} \right)^2$$

MusIC method

Compute forces from torques and joint configuration





Barycentric interpolation

Interpolation $F^{(1)}$ $F^{(2)}$ → F_s

$$\min f(F) = \|F - F_S\|$$

s.t. $\pm\tau = \sum_i F_{m_i} R_{m_i}$

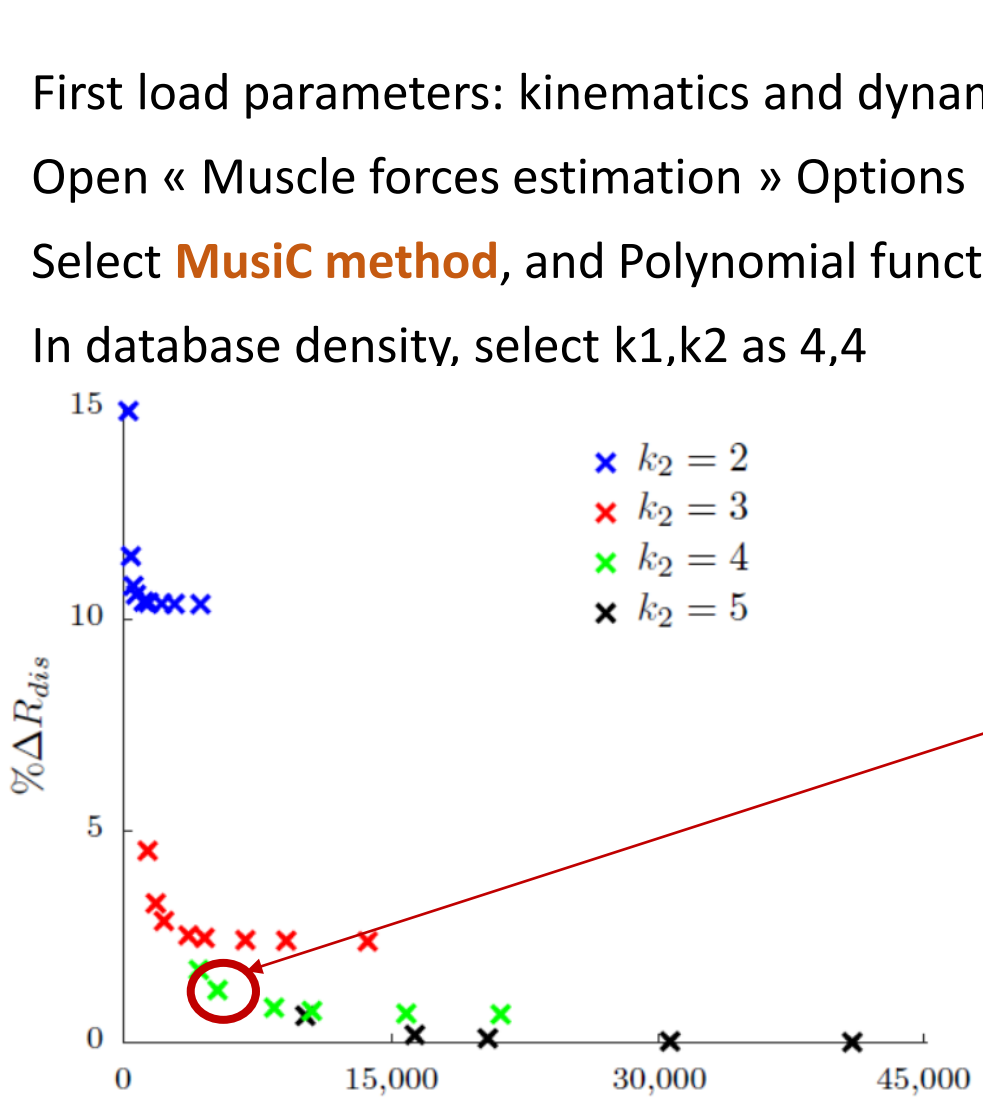
$$F_{min_i} < F_{m_i} < F_{max_i}$$

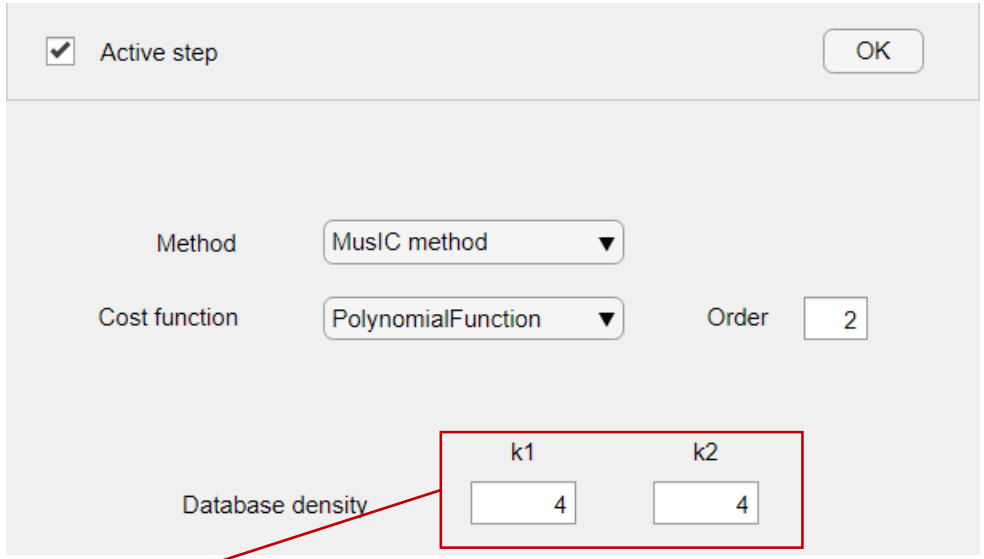
$$i = 1 \dots n_m$$

F_s → Active-set algorithm → F

Generate AnalysisParameters

- First load parameters: kinematics and dynamics are ok!
- Open « Muscle forces estimation » Options
- Select **MusiC method**, and Polynomial function (order 2)
- In database density, select k1,k2 as 4,4





Guaranteeing small error, small computation time

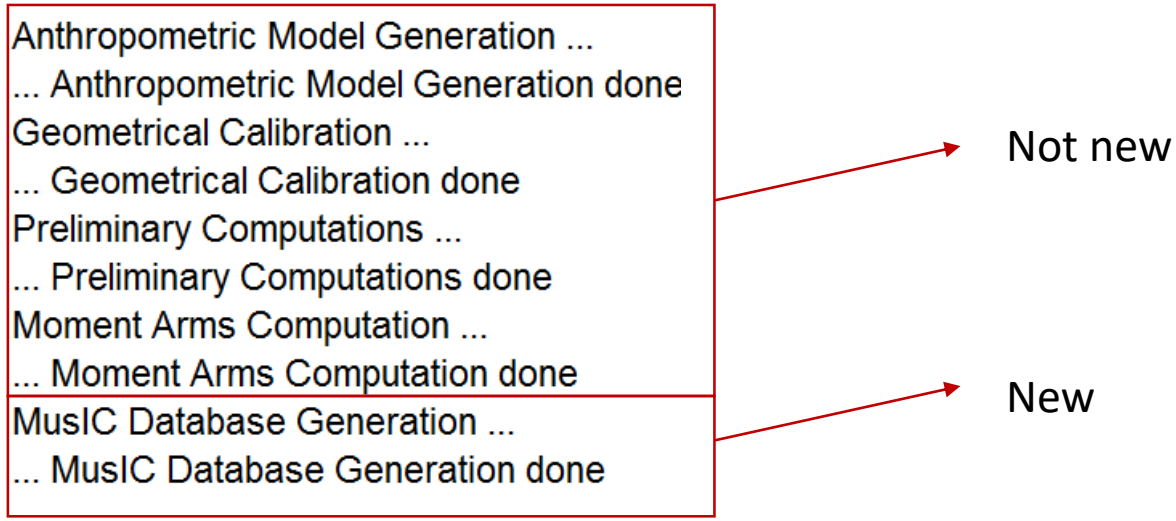
Muller, A., Pontonnier, C., & Dumont, G. (2018). MusIC method enhancement by a sensitivity study of its performance: application to a lower limbs musculoskeletal model. *Computer Methods in Biomechanics and Biomedical Engineering*.

What CusToM is doing ?

Anthropometric Model Generation ...
... Anthropometric Model Generation done
Geometrical Calibration ...
... Geometrical Calibration done
Preliminary Computations ...
... Preliminary Computations done
Moment Arms Computation ...
... Moment Arms Computation done
MusIC Database Generation ...
... MusIC Database Generation done

Not new

What CusToM is doing ?

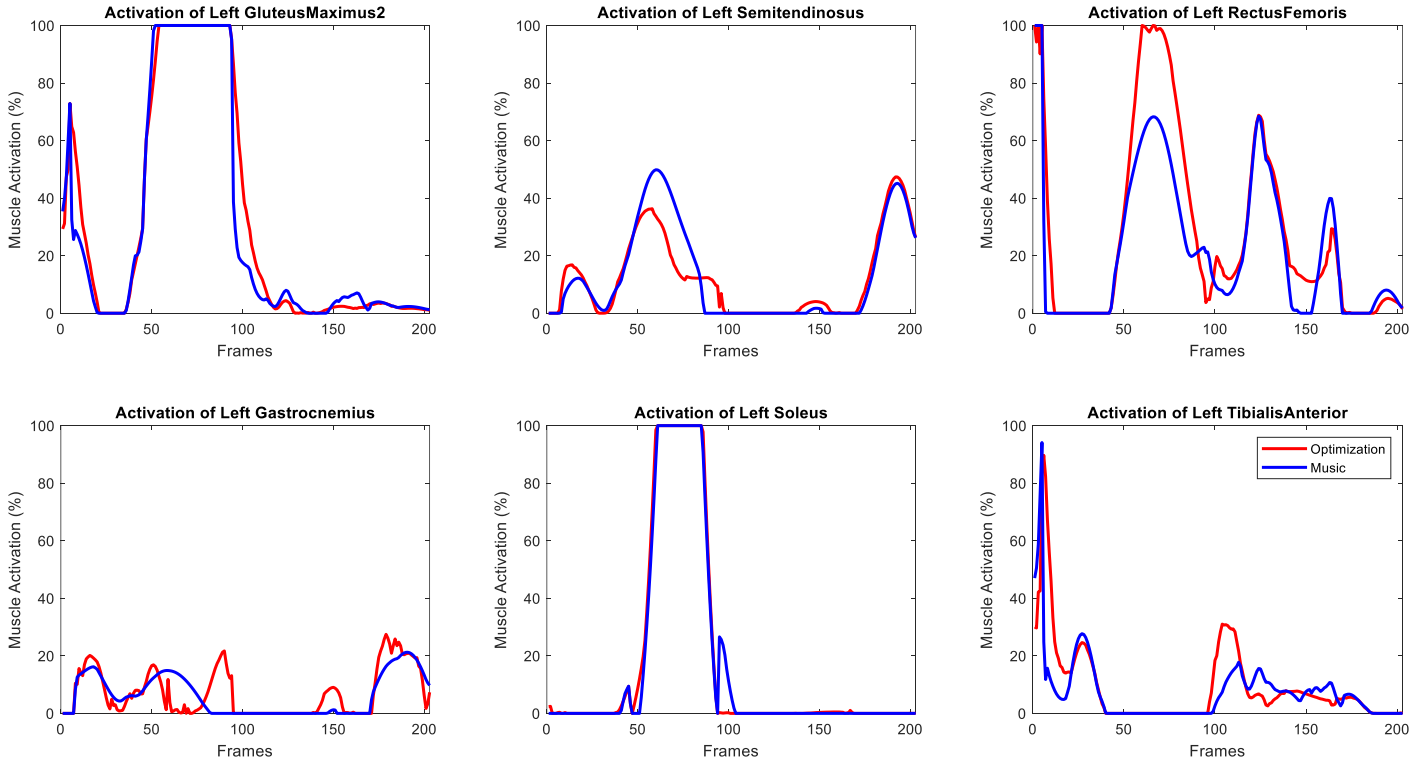


Results

```
>> PostProcessingMuscles2
```

Maybe (4,4) is not that fine…

Pierre will soon provide you EMG measures to compare !
#SupervisionBullyJoke



Conclusion

- Be careful with the choice of the cost function to use in your analysis
- Be careful with the MusIC method
- **A wise choice between offline and online computation (if you have more than 25s of mocap to deal with, it is worth it)**
- **Choose wisely your model, thus you generate it once whatever the processing you want to run**