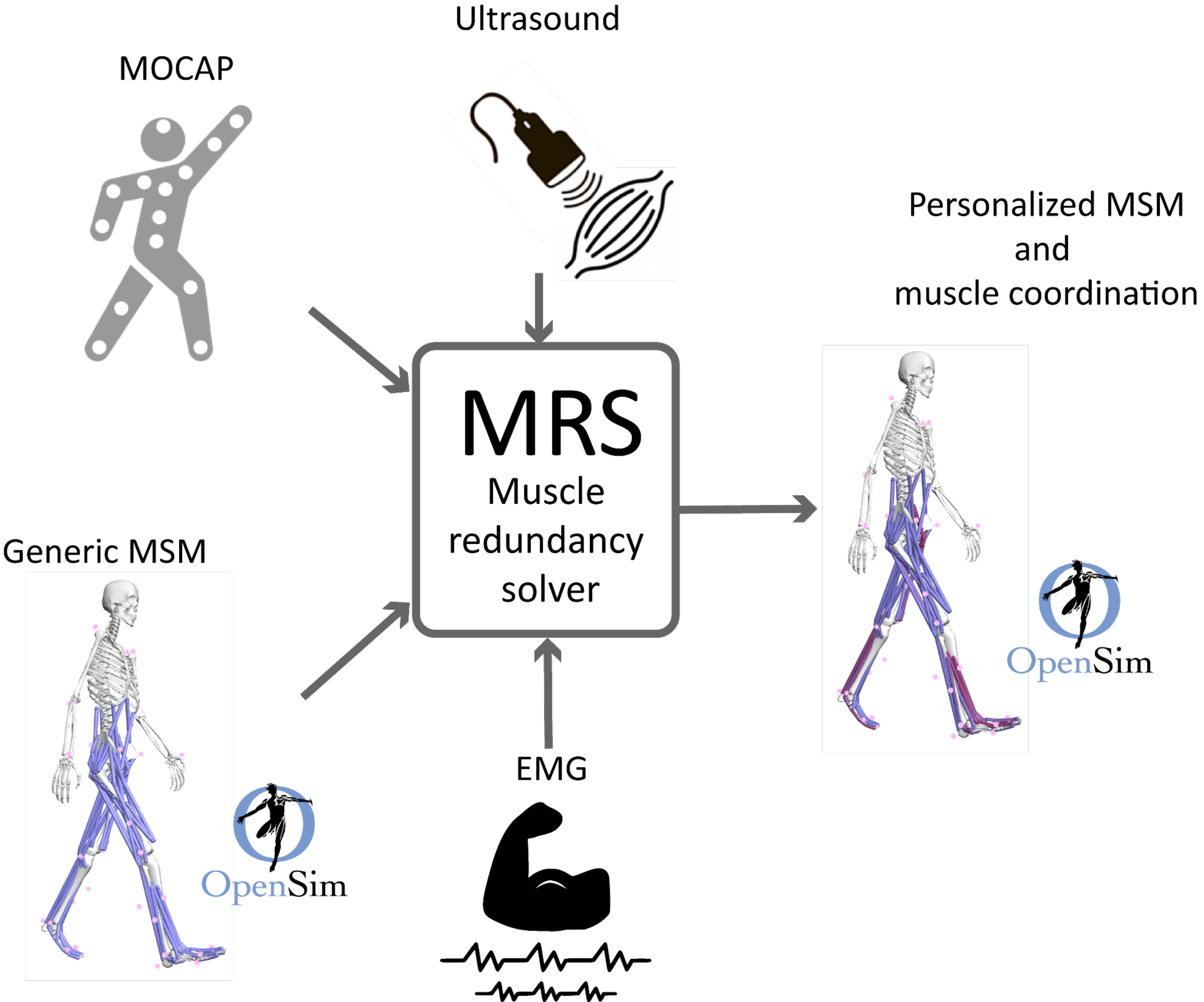

Ultrasound
MOCAP
Personalized MSM
and
muscle coordination
MRS
Muscle
redundancy
solver
Generic MSM
OpenSim
OpenSim
EMG

Functionalities

- Input:
  - Processed motion capture data
  - Musculoskeletal model
  - Muscle activity pattern (EMG)
  - Fiber lengths (ultra-sound)

  optional

- Solve muscle redundancy problem

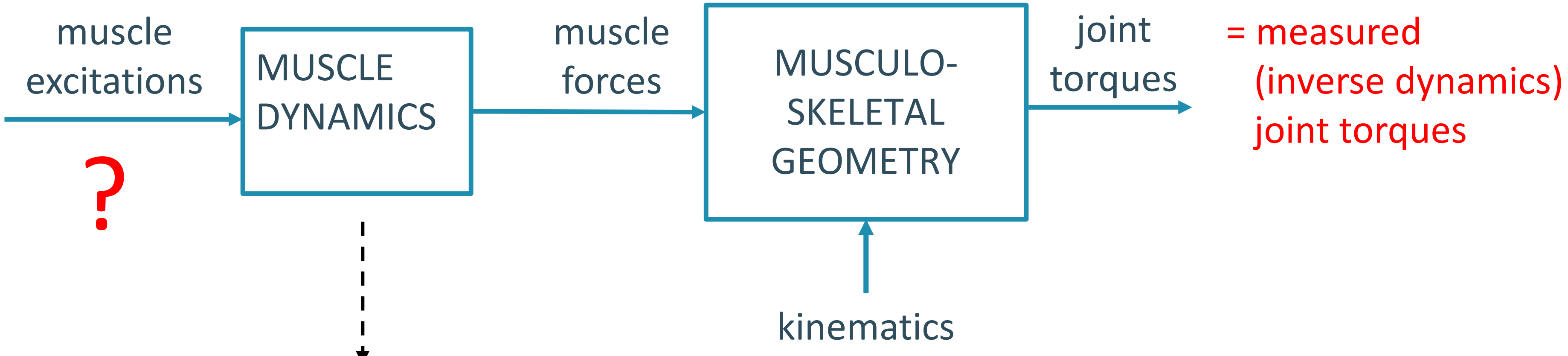
- Estimate muscle-tendon parameters

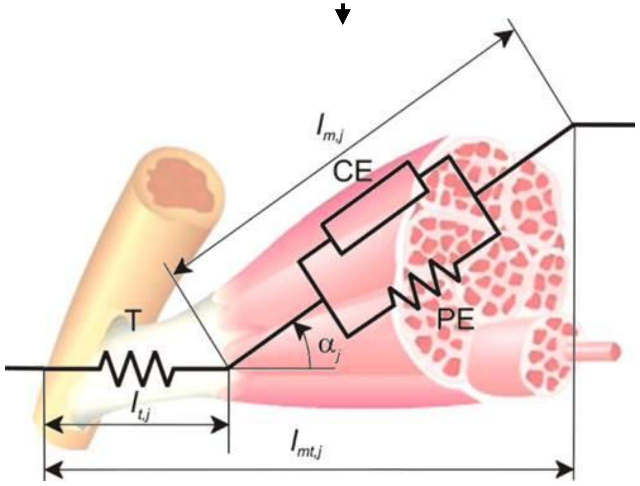
- Perform EMG-driven simulations

Muscle redundancy solver

minimize muscle excitations squared

subject to





Hill-type muscle model

States and controls

STATES

a → muscle activations
$\tilde{l}_m$ → normalized muscle fiber length$s$

CONTROLS (drive the simulation)

e → muscle excitations

HELPER CONTROLS (added for computational efficiency)

a_T → reserve actuator activation

$\tilde{v}_m$ → derivatie of $\tilde{l}_m$

Cost function

$$J = wA \cdot \int \left(e^2(t) + a^2(t)\right) + wT_{res} \cdot \int a_T{}^2(t) + \mathrm{wEMG} \cdot \int \left(e(t) - \hat{e}(t)\right)^2 + wl_M \cdot \int \left(l_M(t) - \hat{l}_M(t)\right)^2 + wv_M \cdot \int v_M^2(t)$$

(1) (2) (3) (4) (5)

(1)Effort

(2)Reserve actuators

(3)Tracking measured EMG (optional)

(4)Tracking measured fiber lenghts (optional)

(5)Fiber velocities (regularization of NLP)

Constraints

- Activation dynamics: $\dot{a} = f(e, a)$
- Contraction dynamics: $\tilde{v}_m = g(\tilde{l}_m, \mathrm{a}, MT_{params})$ with MT_{params} muscle-tendon parameters
- Muscle forces ($F_m = h(\tilde{l}_m, \mathrm{a})$) generate experimental torques (T_{ID}):

  $\rightarrow F_m * \mathrm{R} = T_{ID}$ (with R muscle moment-arm matrix)

Muscle-tendon parameter estimation

- Some of the MT parameters can be estimated

$$l_{Mo} \rightarrow \text{optimal fiber length}$$
$$k_T \rightarrow \text{tendon stiffness}$$
$$l_{Ts} \rightarrow \text{tendon slack length}$$

- Other static MT parameters can be adapted in the OpenSim model

$$F_{Mo} \rightarrow \text{maximal isometric force}$$
$$alpha_o \rightarrow \text{pennation angle @ } l_{Mo}$$
$$v_{Mmax} \rightarrow \text{maximal contraction velocity}$$

Note on overfitting

- Musculoskeletal models typically have many parameters and it might therefore be possible to fit experimental data (EMG and ultrasound-based fiber length) without accurately estimating the underlying MT-parameters.
- Validation of the personalized model is important.
    - Verify that you obtain physiologically plausible muscle activations with the MRS based on the personalized model.
      If not, decrease the number of parameters you are estimating and/or the weight on the data tracking terms in the cost function.
    - Verify (1) that you obtain physiologically plausible muscle activations or (2) that you can reconstruct inverse dynamic joint moments in EMG driven simulation for other movements.

References

Muscle redudancy solver:

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EMG-driven parameter estimation:

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Ultrasound-based parameter estimation:

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