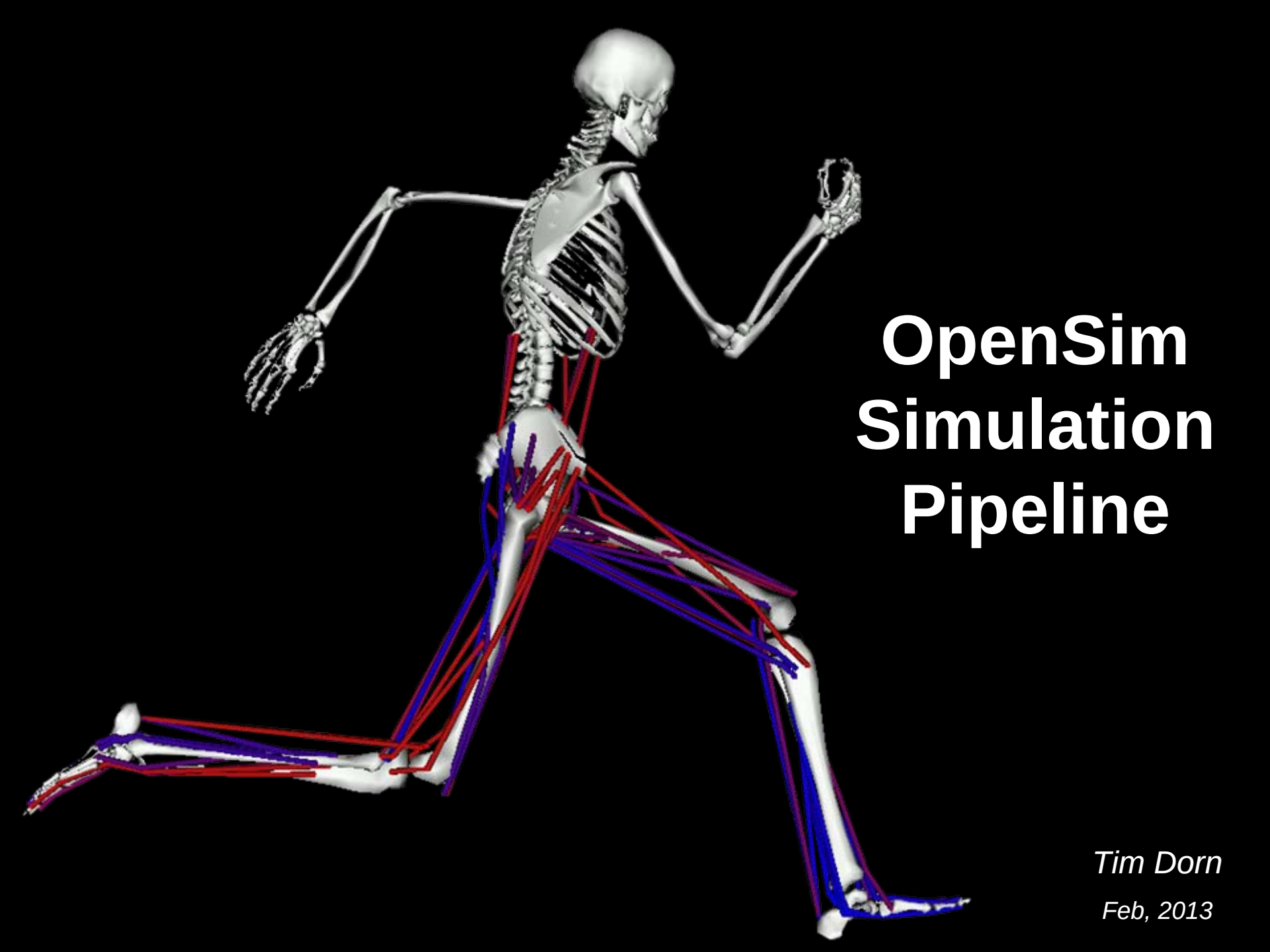
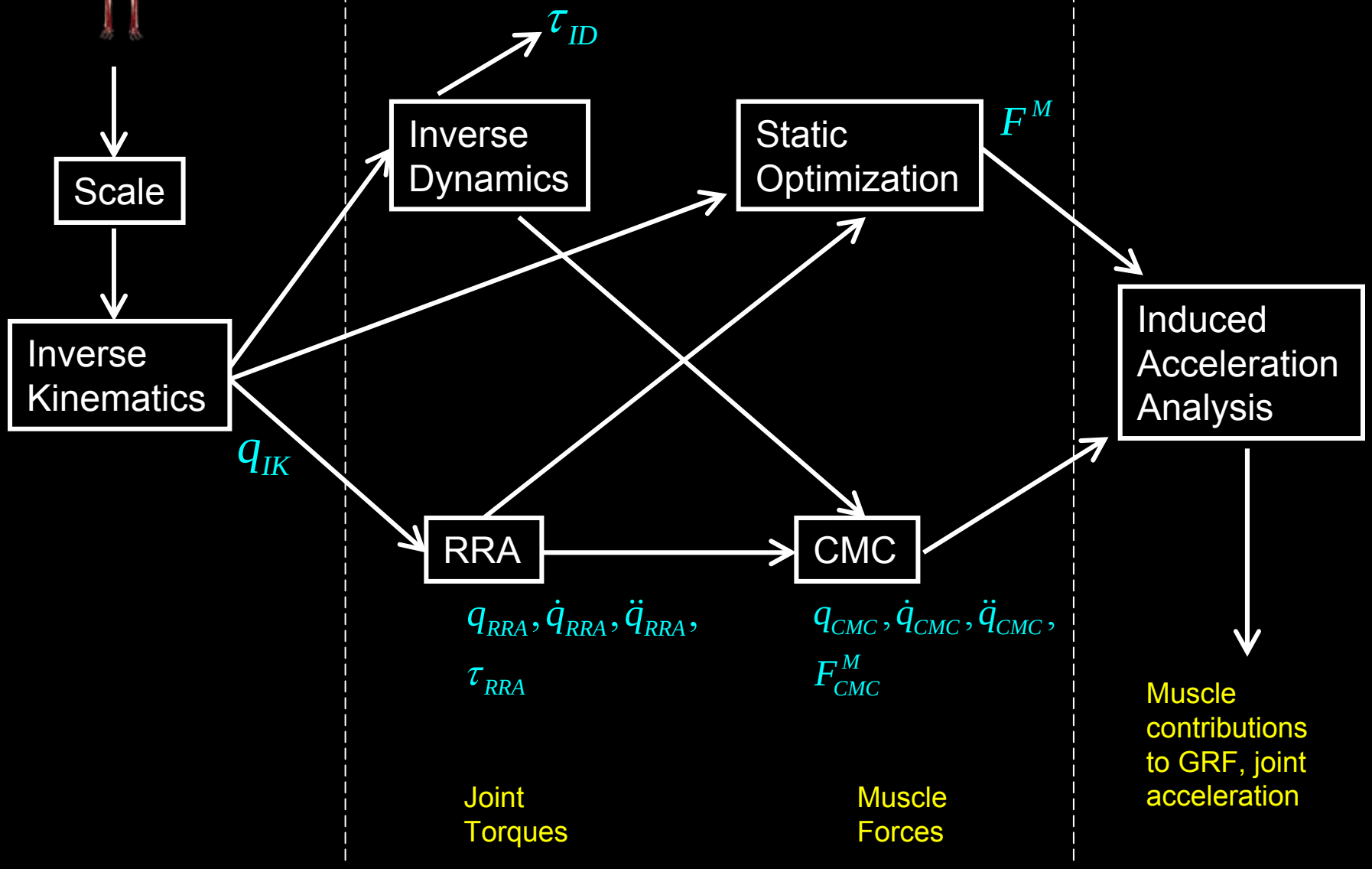


# OpenSim Simulation Pipeline

*Tim Dorn*

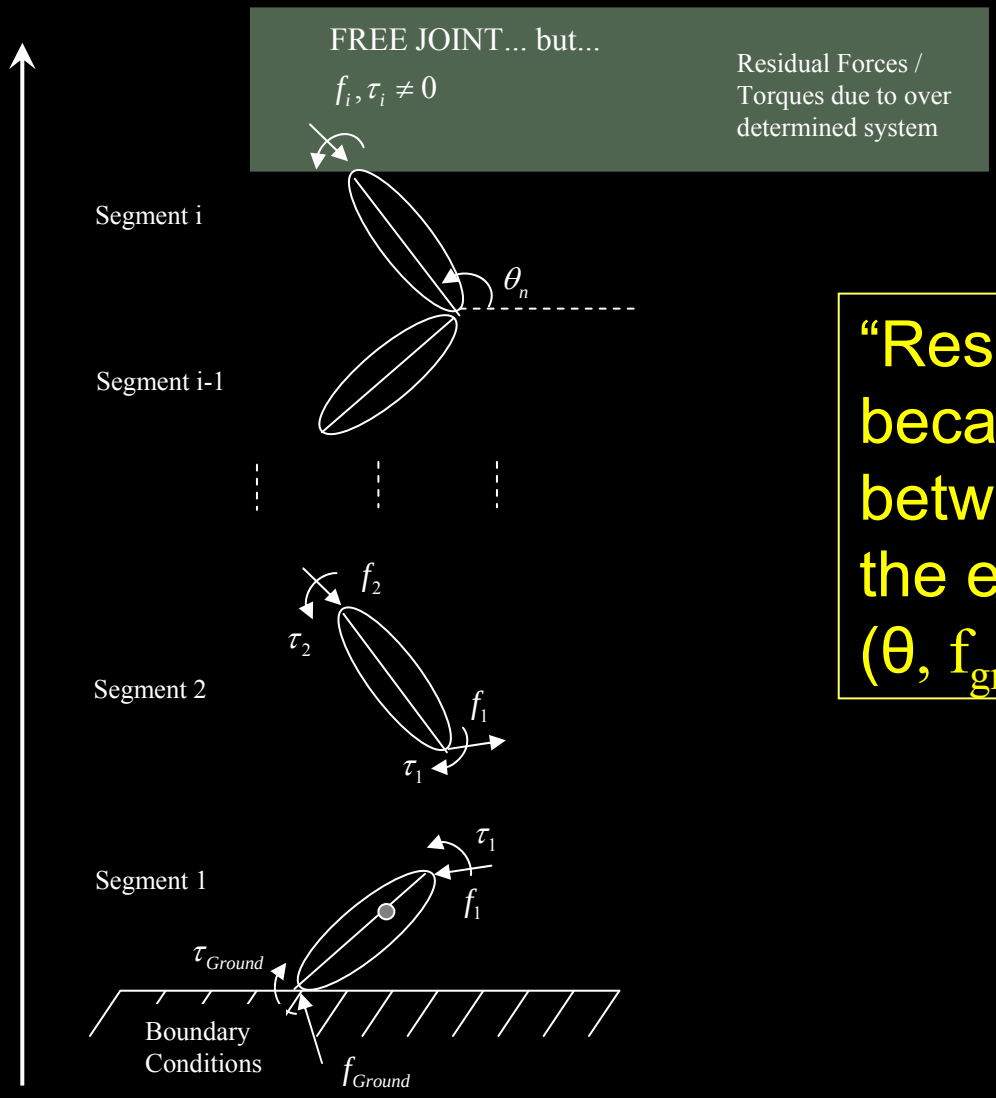
*Feb, 2013*

# Pipeline tools: what's available?



# Inverse Dynamics

Solved algebraically from the ground up:
NO FORWARD INTEGRATION




"Residuals" appear because of a mismatch between the model and the experimental data ($\theta$, $f_{ground}$, $\tau_{ground}$).

Solve for distal reactions:

$$f - m\ddot{x} = 0$$

$$\tau - I\ddot{\theta} = 0$$

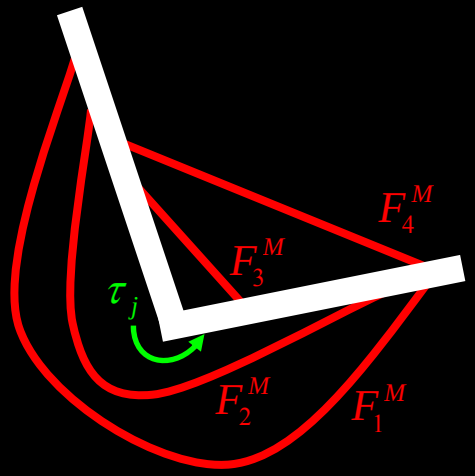
# Are “residuals” bad?

**YES:** “Residuals” do not occur in reality: our motion is fully actuated by torques (via muscles) at the joint and NOT by the “hand of god”.

**NO:** We acknowledge that our experimental data contains errors (e.g. noise, skin artifact). We also acknowledge that our models are not perfect. “Residuals”, therefore represent these lumped un-modeled phenomenon / errors. Having zero “residuals” would mean that we are modeling our subject perfectly and with perfect experimental data, which is highly unlikely.

# Static Optimization

Solved independently at each time step:
NO FORWARD INTEGRATION




More muscles than joints:
over-determined problem

solve for: $\mathbf{a} = \mathbf{a}^{\mathbf{M}}$

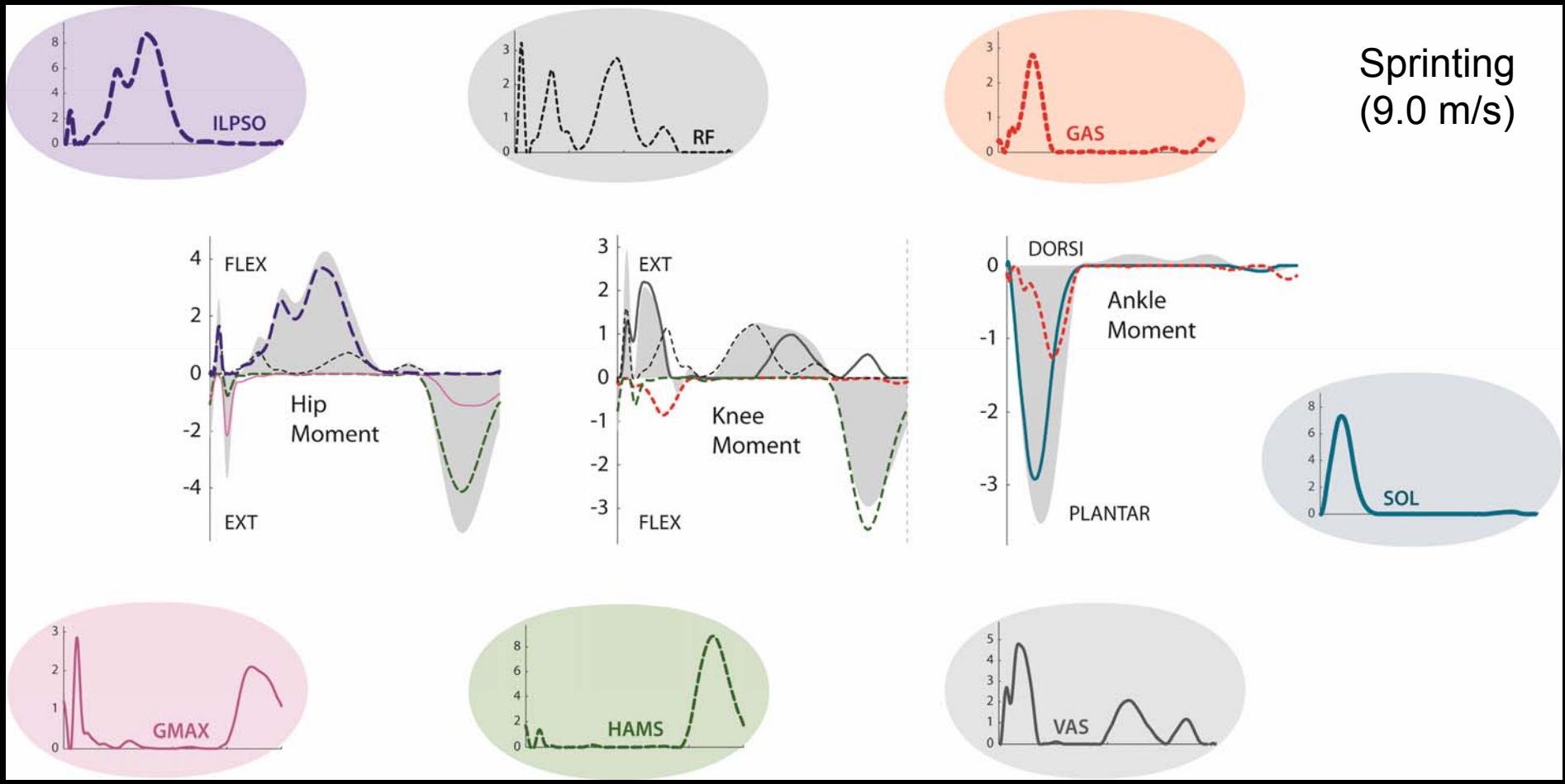
by minimizing: $J(\mathbf{a}) = \sum_{i=1}^{nm} \left(a_i^M\right)^2$

subject to: $\sum_{j=1}^{nj} \sum_{i=1}^{nm} \left[ \underbrace{a_i^M \cdot F_{o,i}^M \cdot f\left(l_i^M, v_i^M\right)}_{active} + \underbrace{F_{p,i}^M}_{passive} \right] \cdot MomArm_{i,j} = \tau_j$

$\mathbf{0} < \mathbf{a}^{\mathbf{M}} < \mathbf{1}$

# Static Optimization

Joint moments are resolved into individual muscular torques



# What pipeline is best for me?

Scale

Inverse Kinematics

$q_{IK}$

Inverse Dynamics

$\tau_{ID}$

Static Optimization

$F^M$

RRA

$q_{RRA}, \dot{q}_{RRA}, \ddot{q}_{RRA},$

$\tau_{RRA}$

CMC

$q_{CMC}, \dot{q}_{CMC}, \ddot{q}_{CMC},$

$F^M_{CMC}$

Induced Acceleration Analysis

Muscle contributions to GRF, joint acceleration

Joint Torques

Muscle Forces

| | Inverse Dynamics | RRA |
|---|---|---|
| Forward integration | NO | YES |
| Tracks experimental kinematics | NO | YES |
| Activation & contraction dynamics | NO | YES |
| Time to execute | ~10 sec | ~5 mins |
| Experimental ground force applied to foot | YES | YES |
| Control over “residuals” | NONE | Can reduce residuals at the expense of modifying kinematics |

| | Static Optimization | CMC |
|---|---|---|
| Forward integration | NO | YES |
| Tracks experimental kinematics | NO | YES |
| Activation & contraction dynamics | NO | YES |
| Time to execute | ~2 mins | ~30 mins |
| Experimental ground force applied to foot | YES | YES |
| Time dependant objective function | NO | NO |
| Objective function used distribute muscle force | $\min(a^2)$ across all muscles at each time step | $\min(a^2)$ across all muscles at each time step |

# CMC Versus Static Optimization

ELSEVIER

Journal of Biomechanics 34 (2001) 153–161

JOURNAL OF BIOMECHANICS

www.elsevier.com/locate/jbiomech
www.JBiomech.com

1999 ASB Pre-Doctoral Award

## Static and dynamic optimization solutions for gait are practically equivalent

Frank C. Anderson[a,*], Marcus G. Pandy[a,b]

[a]*Department of Mechanical Engineering, The University of Texas at Austin, Austin, Texas, USA*
[b]*Department of Kinesiology and Health Education, The University of Texas at Austin, Austin, Texas, USA*

Accepted 3 July 2000

*Special Issue Article*

Institution of MECHANICAL ENGINEERS

Journal of ENGINEERING IN MEDICINE

## Comparison of different methods for estimating muscle forces in human movement

*Proc IMechE Part H: J Engineering in Medicine*
226(2) 103–112

DOI: 10.1177/0954411911429401
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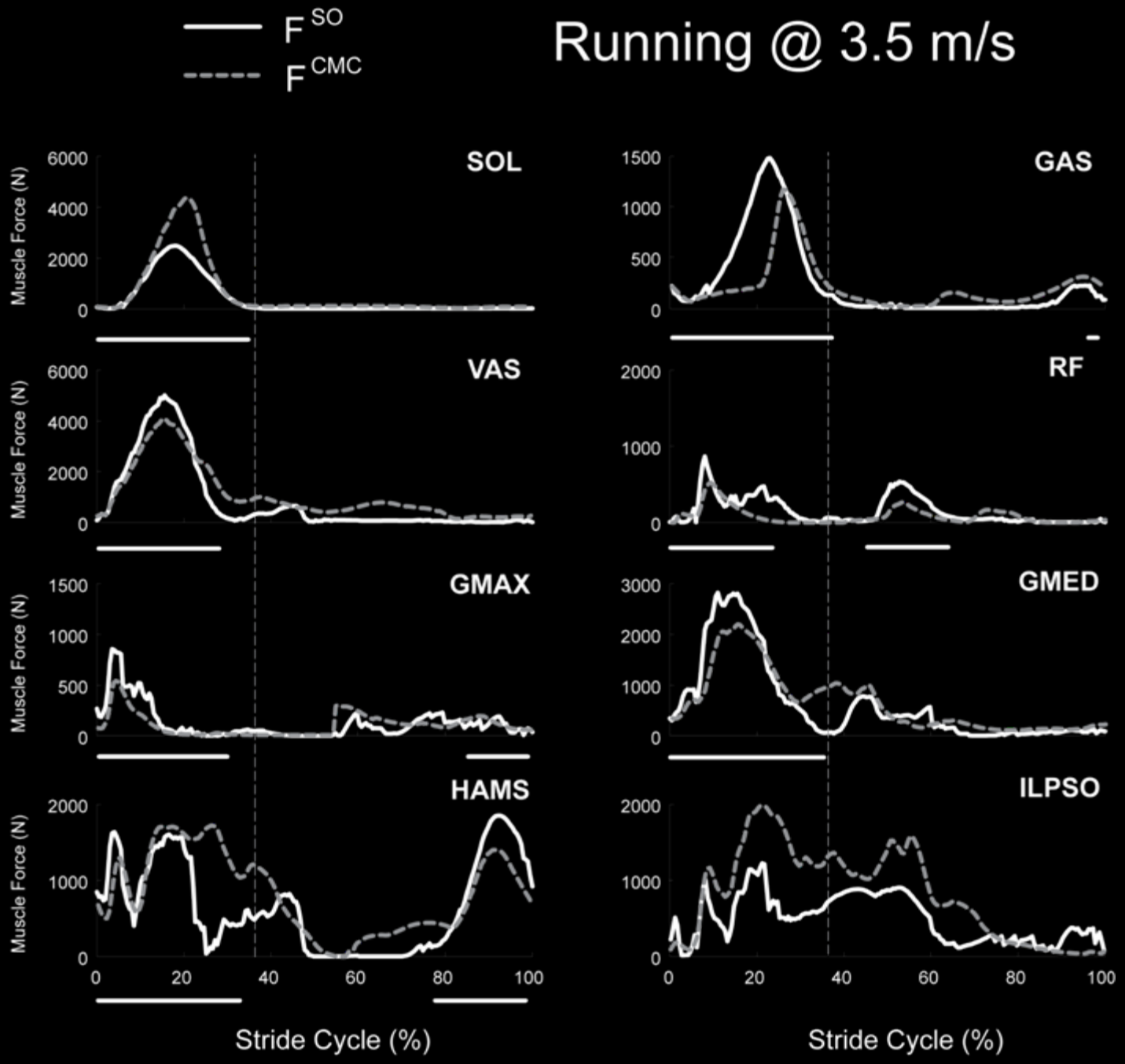
**Yi-Chung Lin, Tim W Dorn, Anthony G Schache and Marcus G Pandy**




**Lin, Y. C., Dorn, T. W., Schache, A. G. and Pandy, M. G.** (2012).
Comparison of different methods for estimating muscle forces in human movement.
*Proceedings of the Institution of Mechanical Engineers Part H-Journal of Engineering in Medicine* **226**, 103-112.