Understanding Human Motion

Changqing Lu
Gabriela Bravo-Illanes
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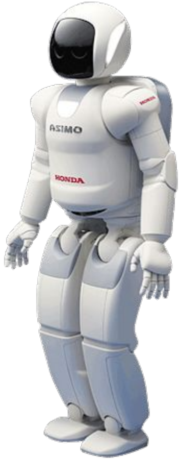

Topics list

1. Overview
2. Human motion strategies
3. Robotics applied in biomechanics

Overview

Gabriela Bravo-Illanes

Modeling Human Motion. Overview.

Sources: Campos, 2009; Gielen,2009; Hiatt, 2017; Simmons, 2005; Millard, 2013

Modeling Human Motion. Overview.

Trajectories

Descriptive models

-Minimum-jerk model (Hand)

---*Quasi-straight smooth trajectories*

---*Bell shaped velocity*

-Fitts Law

-2/3 power law

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Redundancy *(Bernstein's DOF problem)*

--*Minimum work model (Soechting, 1995)'*

--*Donders' law*

--Empirical-statistical modeling using anthropometric data

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--Minimum commanded-torque-change model (Nakano,1999)

--Minimum variance model (Harris, 1998)

Stochastic Optimal Control

---Task Optimization in the Presence of Signal-Dependent Noise (TOPS) (Miyamoto, 2004)

---Minimal intervention principle(Todorov, 2002)

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Human motion databases

--Motion primitives

--Learning by imitation (Schaal, 2003)

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Task Goals

Target location (grasping)
-Visual
-Proprioceptive
-Initial hand location

Predict human actions (Teamwork)
-Probabilistic models
-Machine learning models

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Musculoskeletal models

-Hill-type muscle models
-Cross-type muscle models

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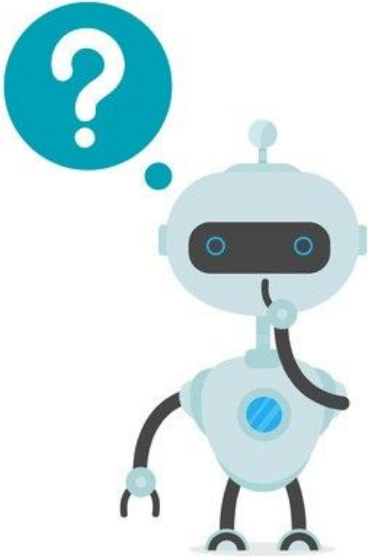
How understand human motion benefits robotics?



How understand human motion benefits robotics?

Sources:Zacharias, 2001; Billard, 2013 ; Siciliano, 2016

How understand human motion benefits robotics?

(Zacharias, 2001)

Human-like motions

- Human robot collaboration
- Safety perception

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SuitX

Human-like motions
- Human robot collaboration
- Safety perception

Better Designs
- Human wearables
  - Exoskeleton
  - Prosthesis
  - Rehabilitation robotics
- Legged robots
- Hands

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Perform complex tasks

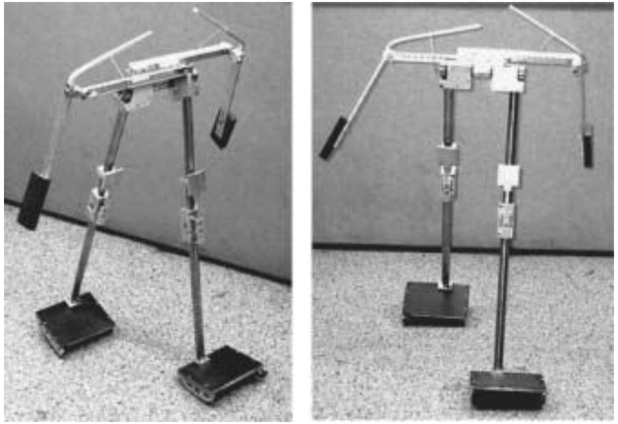
- Controllers inspired in human strategies
- Skills acquisition

Sources:Zacharias, 2001; Billard, 2013 ; Siciliano, 2016

How understand human motion benefits robotics?

Robot Design

Passive dynamic walking



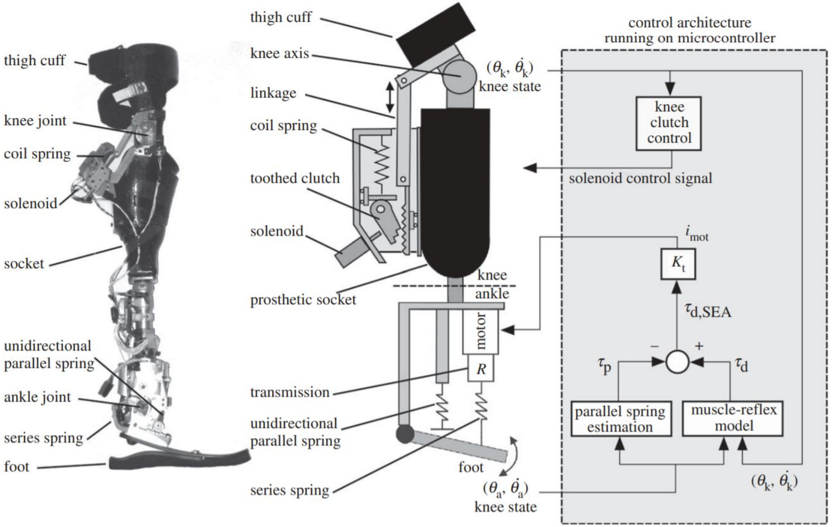
(Collins, 2001)

Imitation of human motion focused on minimizing actuation control

Source: Collins, 2001;McGeer, 1990

Robot Design

Design and control of Lower Limb wearable systems



Control scheme for powered ankle-foot prosthesis (Markowitz, 2011)

"Understanding muscle-tendon behaviour in human locomotion, roboticists can design robots that seamlessly integrate dynamically with the biological leg"

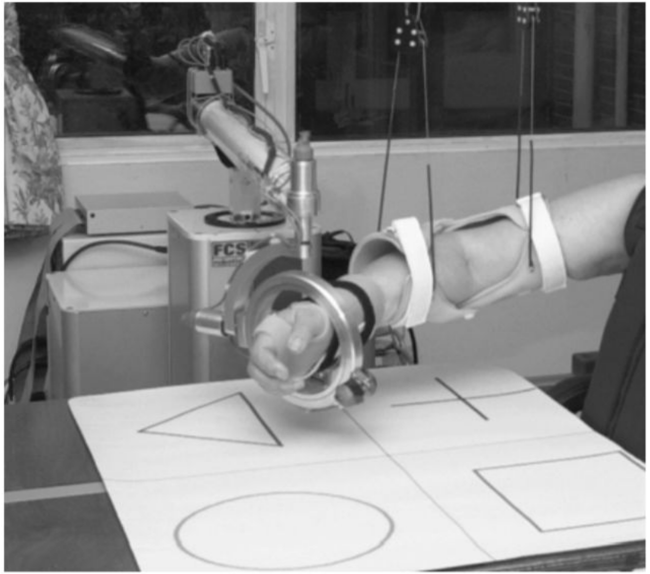
Siciliano, 2016

Source: Markowitz, 2011; Siciliano, 2016

How understand human motion benefits robotics?

Motion Planning

Better rehabilitation robots



Stroke Therapy robot GENTLE system (Loureiro, 2003)

“The creation of human-like trajectories is essential for retraining upper limb movements of people that have lost manipulation functions following stroke”

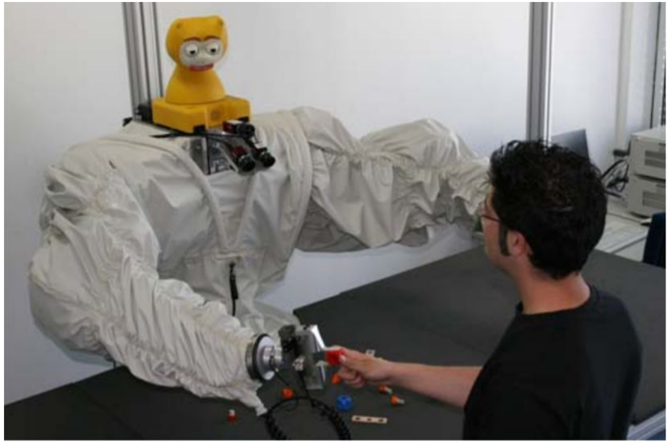
Loureiro, 2003

Source: Loureiro, 2003

How understand human motion benefits robotics?

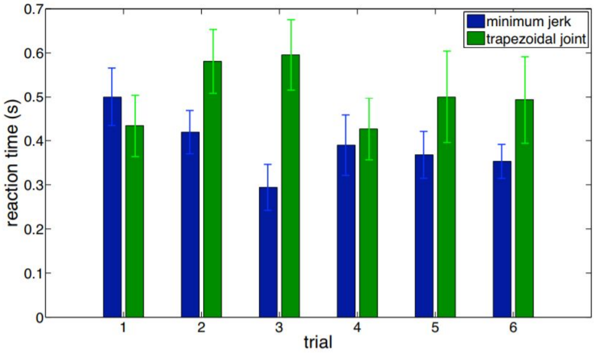
Motion Planning

Human-like movements in Human-robot collaboration

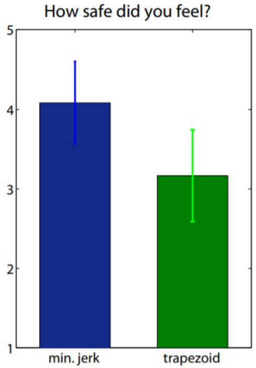


Robots handles human a cube using different speed profiles

"Human Robot interactions should be intuitively simple"



Shorter reaction time for minimum jerk profiles



How safe they felt during the experiment

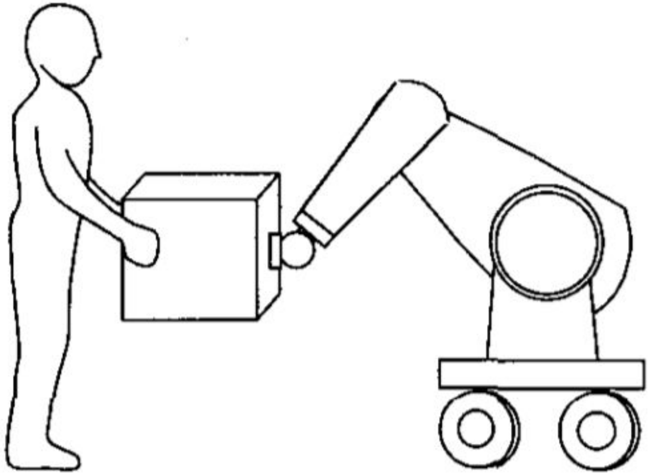
Source: Huber, 2008

How understand human motion benefits robotics?

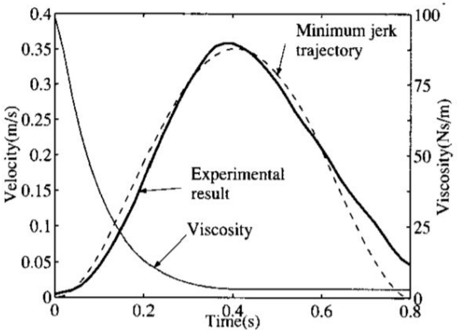
Controllers

Human-robot collaboration

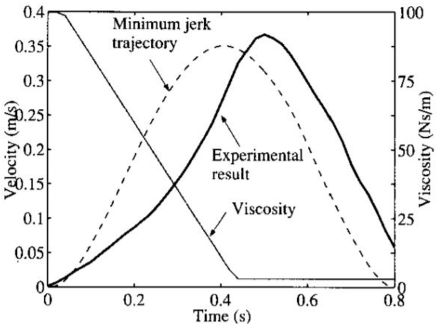
- Human arm is like a damper model whose damping factor changes optimally so that the cost function becomes minimum
- Robot will have an impedance controller where the damping is optimized to mimic human.



Cooperative task by a robot and a human (Ikeura, 2002)



Optimal solution (Ikeura, 2002)

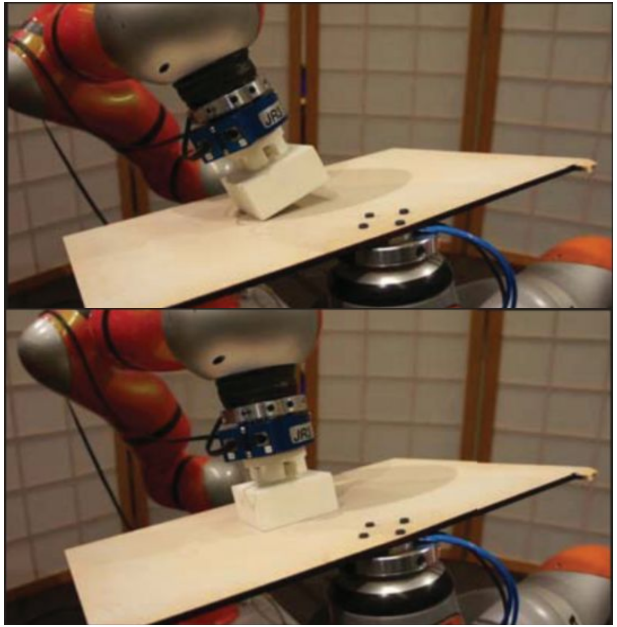


Solution when decreasing damping factor linearly (Ikeura, 2002)

How understand human motion benefits robotics?

Controllers inspired in humans

Surface-surface contact under uncertainty. Compliant contact primitives



Study human strategies to achieve the same task, and replicate them in the proposed control:

- Subjects decrease angular velocity before complete alignment
- They do not control contact force to remain at a fixed value

Source: Khansari, 2016

How understand human motion benefits robotics?

Task Planning

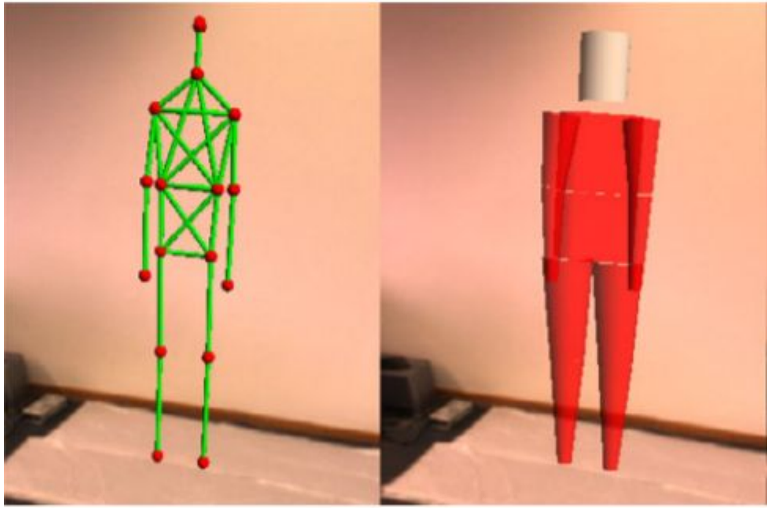
Collaborative tasks with probabilistic Movement primitives

1. Robot learn how to two humans collaborate in assembling a box using motion capture data of theirs wrist.
2. Robot predict human movement based on known motion primitives and probabilistic models
3. Robot predicts and generate appropriate movement primitive

Source: Maeda ,2014

Environment perception

Human motion tracking



Models of human-motion helped to create a simplified algorithm for visual tracking of the human movement.

Source: Hecht, 2009

How understand human motion benefits robotics?

Learning human skills

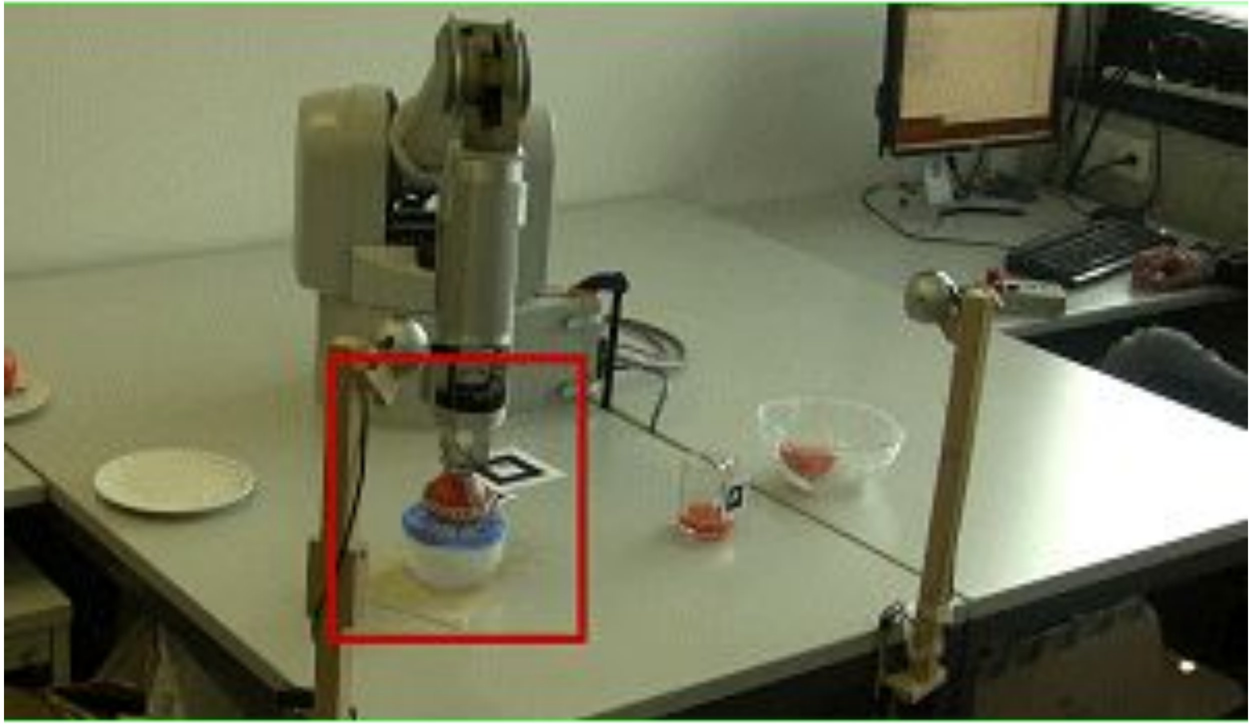
Juicing an orange Task Teaching

Source: Billard, 2013

How understand human motion benefits robotics?

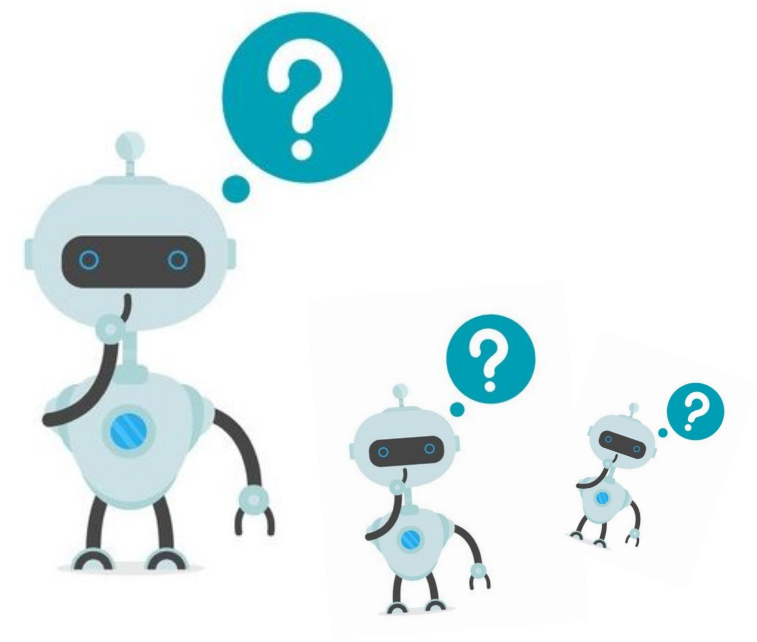
Learning human skills

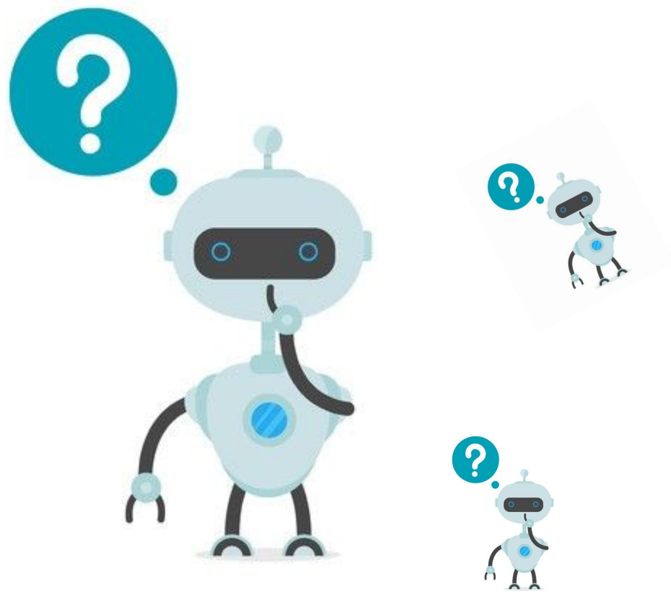
Juicing an orange Task Reproduction



Source: Billard, 2013

Humans can benefits from robotics concepts?





Benefits of applying robotics concepts in human motion modeling

Rehabilitation

-Generation of exercises for physiotherapy (Campos, 2009)
-Assessment of motion disorders (Campos, 2009)
-Rehab. of human digits (Valero-Cuevas, 2000)

Injury/ disorders prevention

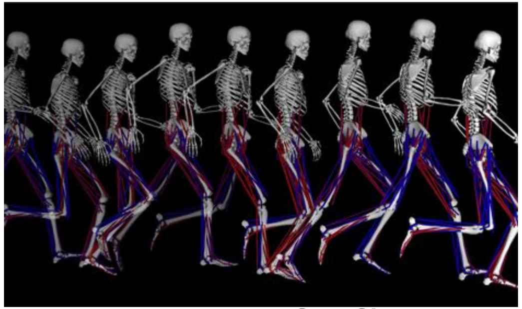
-Work-related musculoskeletal disorders (Wang, 2015)
-Ergonomics analysis (De Magistris, 2015)

Improve performance

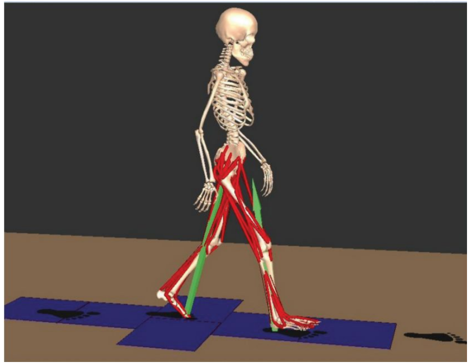
-Piano (Zhang, 2011)
-Athletics/Sports (Demircan, 2009)

Analize biomechanical consequences of surgical reconstructions

-Joint replacements
-Tendon transfers
-Post operative function of shoulder (Holzbaur, 2005)

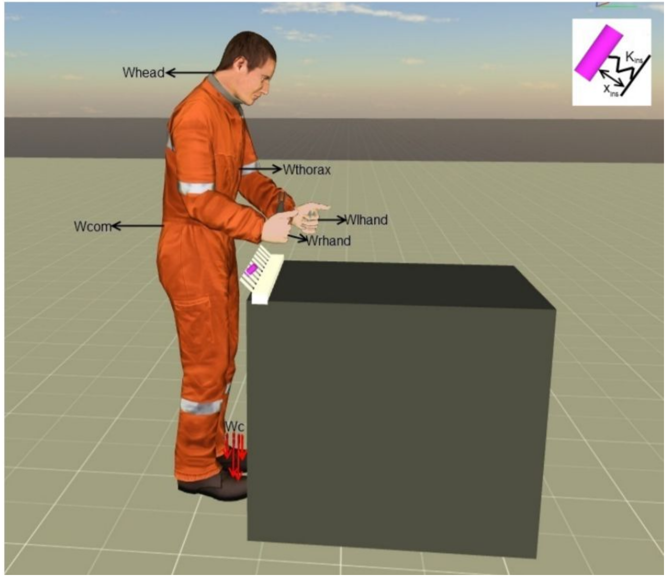


OpenSim (Seth, 2011)



SIMM (Delp, 1995)

Ergonomics analysis

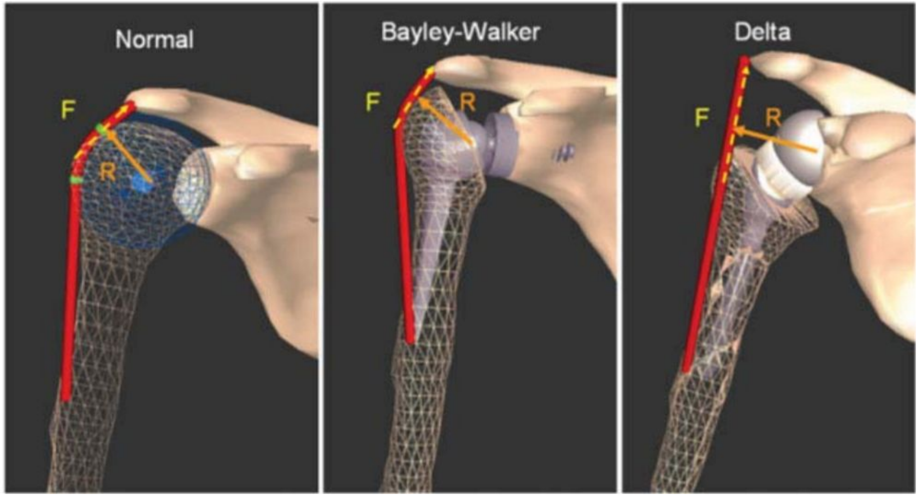


Simulation of insert-fitting task under different conditions (using one hand, using two hands, using a tool). Risk of biomechanical overload measured with OCRA method. (De Magistris, 2015)

Digital human models can be used to help workstation and work activity design to reliably identify and assess workplace induced musculoskeletal disorders and other biomechanical risks factors

Source: De Magistris, 2015

Shoulder replacement



Visual representation of the difference in moment arms of the middle deltoid muscle for natural subjects and those with B–W and Delta prostheses (Masjedi, 2010)

Comparison of two shoulder prosthesis full range of motion and joint stabilization using musculoskeletal models (SIMM)

Source: Masjedi, 2010

Human Motion Strategies

Changqing Lu

Human motion strategies

Interdisciplinary: Neuroscience, biomechanics, physiology, robotics, computer science...

Methods: simulation on proposed hypothesis, building human motion database...

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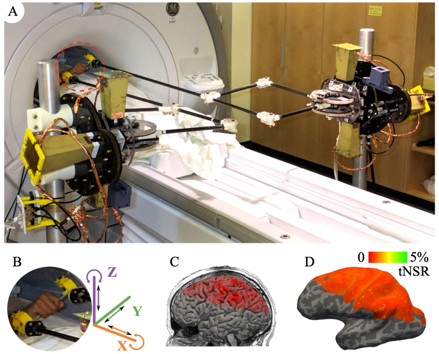

Haptic fMRI Interface (Menon, 2017)


Manual Intelligence Lab (Maycock, 2010)

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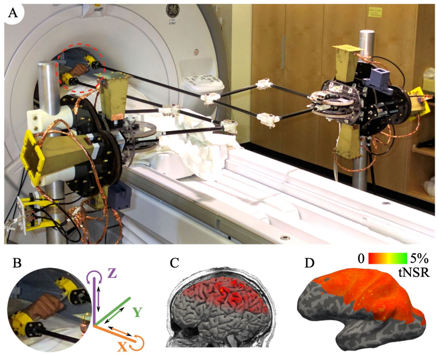


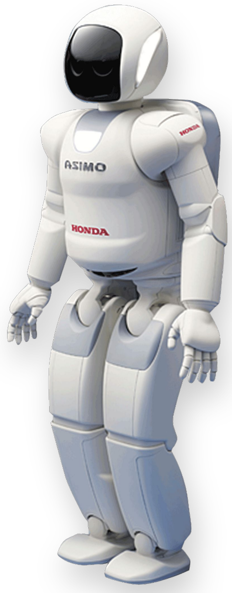
Haptic fMRI Interface (Menon, 2017)


Manual Intelligence Lab (Maycock, 2010)

bio-inspired
human-inspired model

Robotics

- Manual intelligence
- Cognitive intelligent robots
- Humanoids with **general** application



Kinematics – “Body schema” and “Peripersonal space”

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Robot
- Jacobian
- Operational Space

Human
- Body schema
- Peripersonal Space

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Robot

Jacobian

Operational Space

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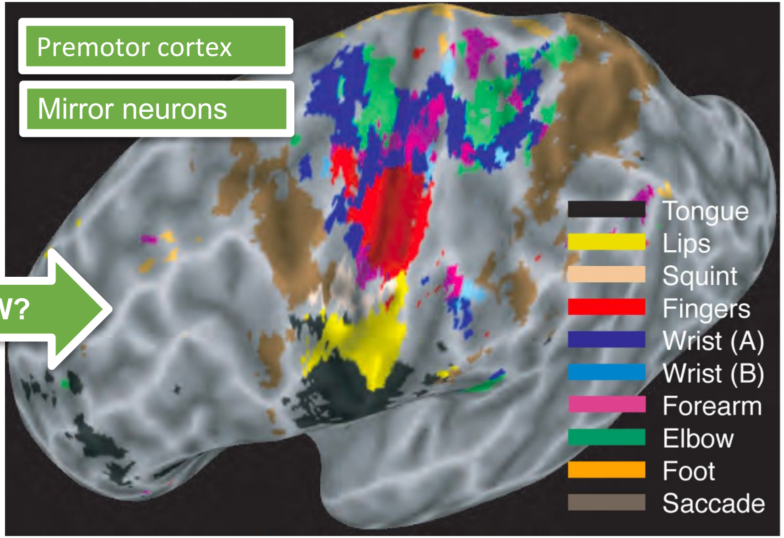
Body schema

Peripersonal Space

HOW?



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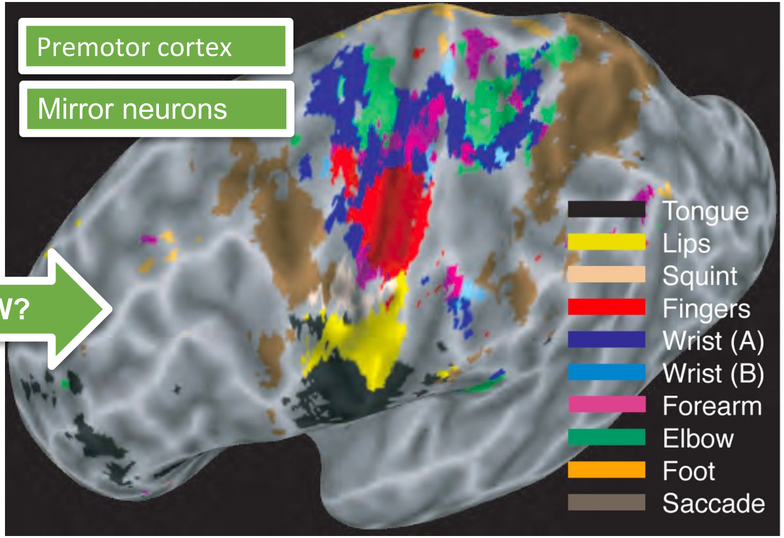

Tool-use: extension of peripersonal space or update of body schema?

Inverse Kinematics: dealing with redundancy

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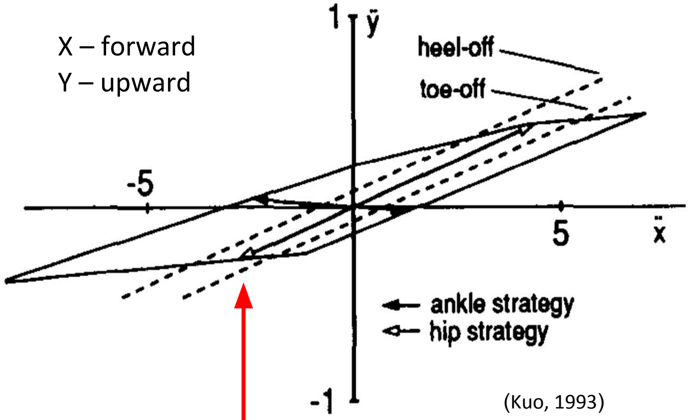
Posture Stability

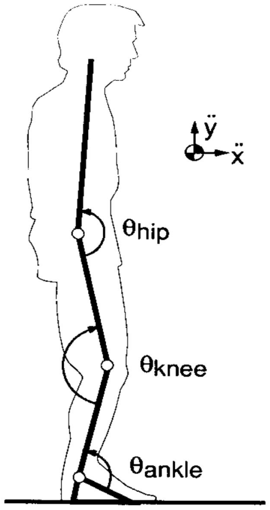
- Feasible acceleration set (FAS)
- Hip strategy vs. ankle strategy

X – forward
Y – upward



(Kuo, 1993)

hip strategy more "parallel" to the constraints



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Inverse Kinematics: dealing with redundancy

Posture Stability

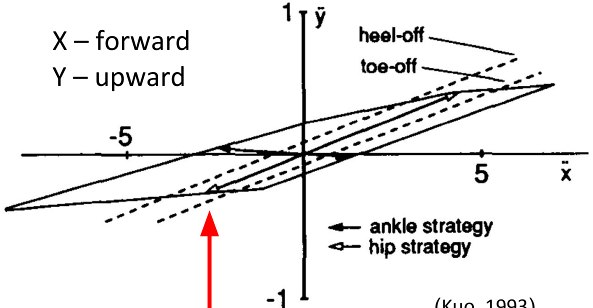
- Feasible acceleration set (FAS)
- Hip strategy vs. ankle strategy

Posture Sway

Exploratory redundant motion

- Responsive forces from the ground

X – forward
Y – upward



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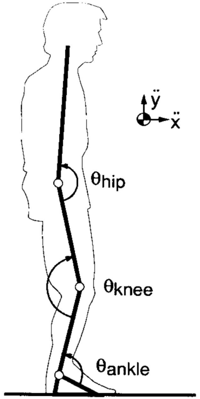

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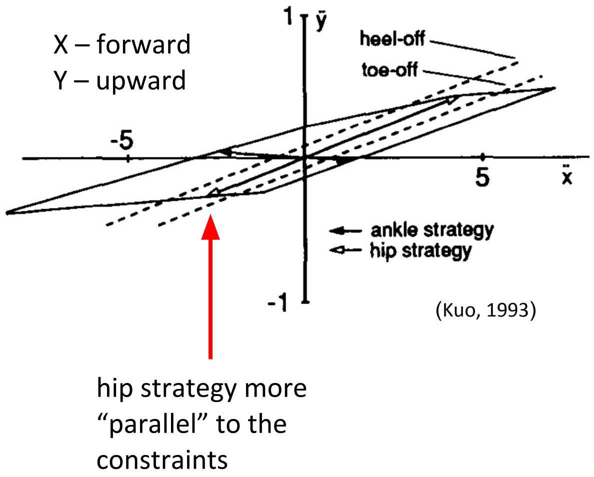
Sit-to-stand Motion

Identifying the control variables to plan trajectories

- Control stability of body center
- Head Position less controlled



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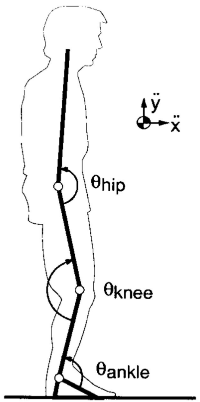

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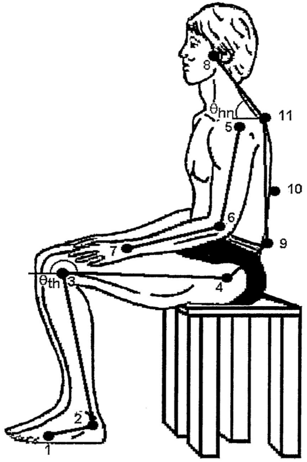

(Scholz, 1998)

Task Space Control - Grasping

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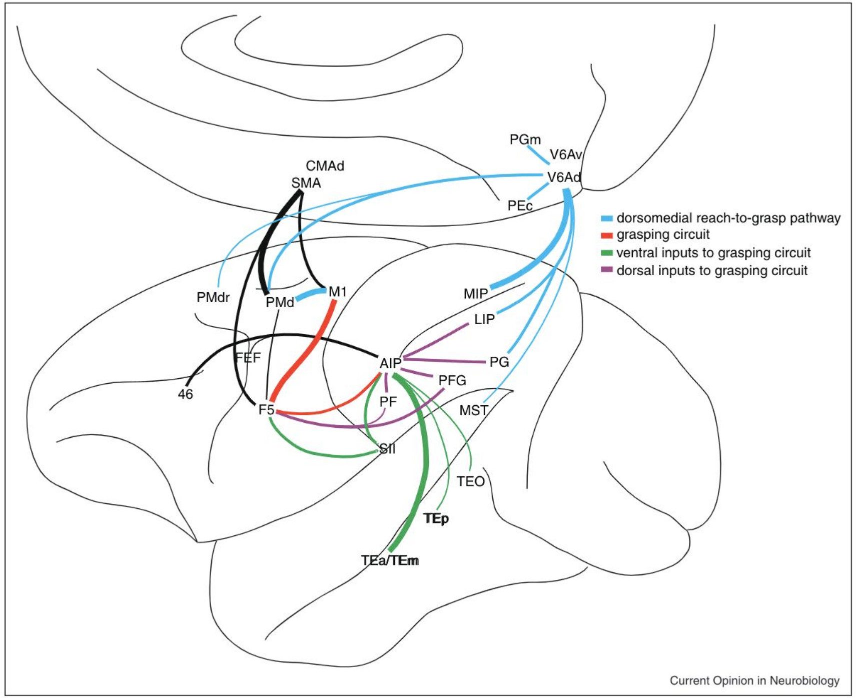
Complex biomechanics

- Transfer visual and spatial information
  - Location/size/shape/orientation…
- Fast process



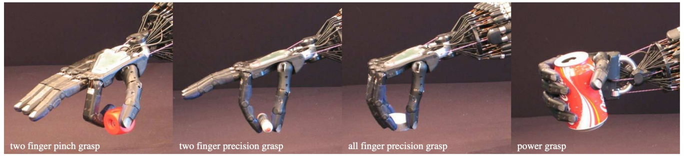
From neuroscience: Cortical grasping network (Davare, 2011)

Task Space Control - Grasping

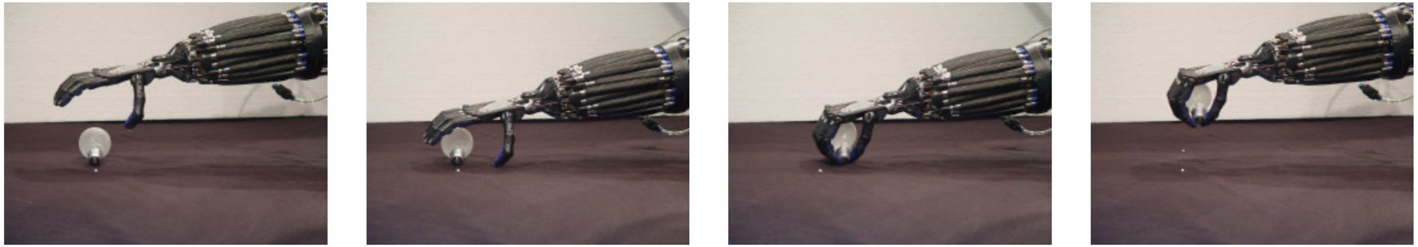
Parameters input:
- a relative position
- a relative orientation
- an approach distance

“Pre-grasp” phase

Position and joints angles



4 predetermined grasp strategies

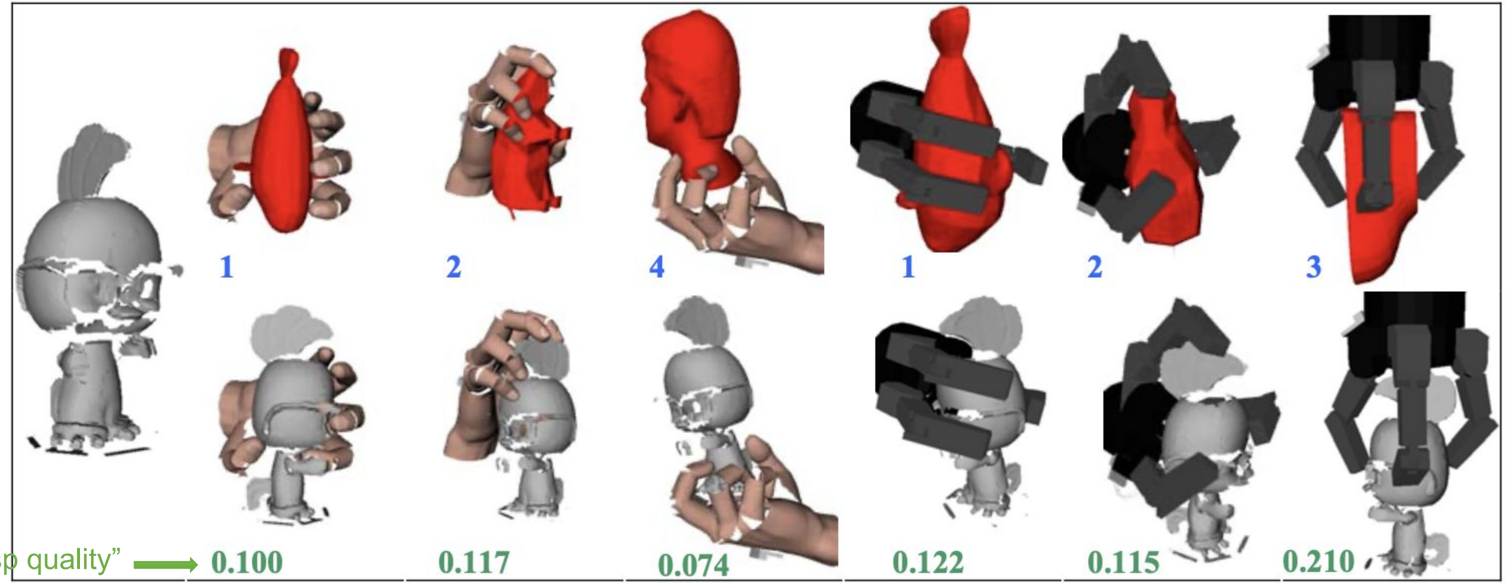


(a) Pre-grasp pos. (b) Grasp position. (c) Object grasped. (d) Object lifted.

(Rothling, 2007)

Task Space Control - Grasping

Data-driven grasp: constructing a grasp database; low-dimension "eigengrasp"



(Godfeder, 2011)

Task Space Control – Object manipulation

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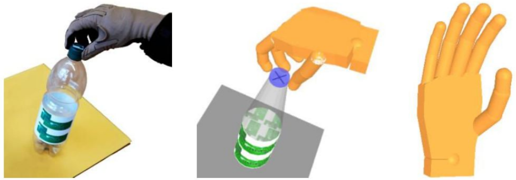
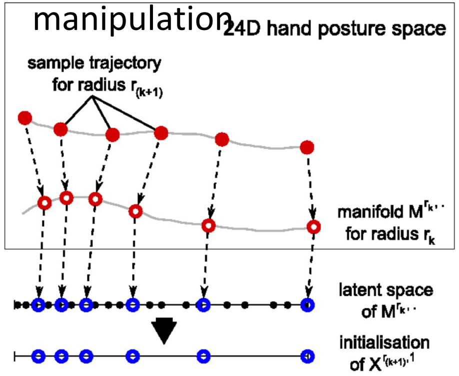
Manipulation manifolds: incorporating time as a manipulation parameter



Cap-turning manipulation



Training with small amount of data

(Steffen,2008)

Task Space Control – Object manipulation

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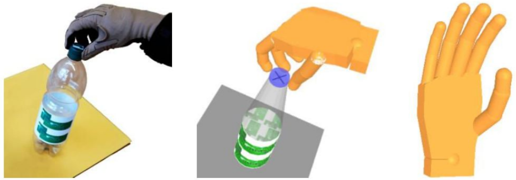

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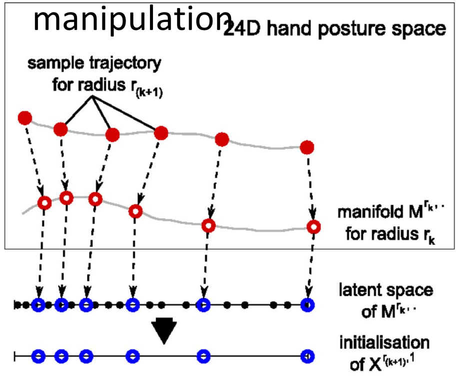

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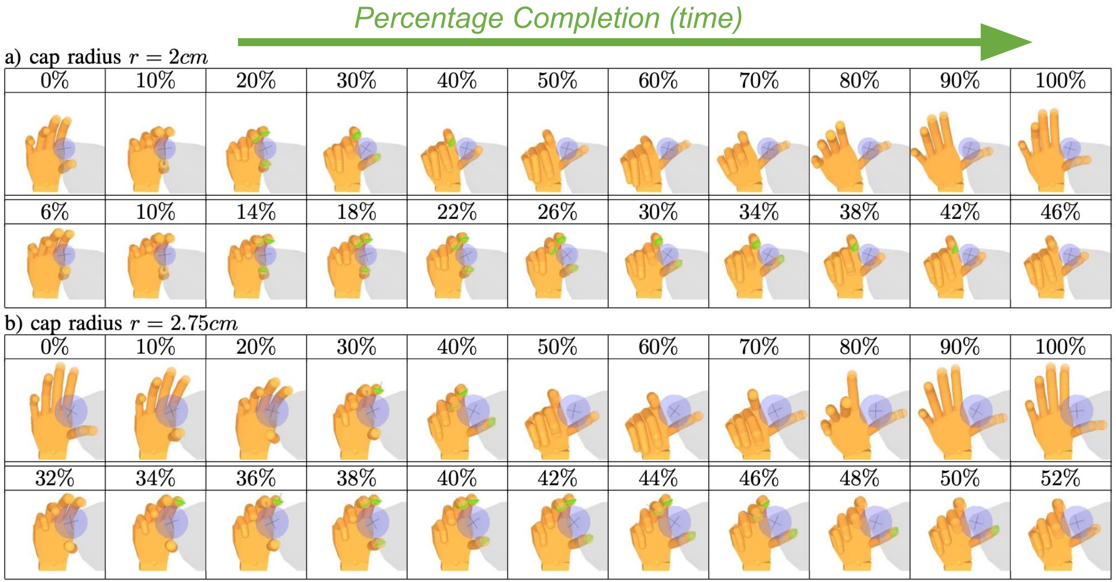


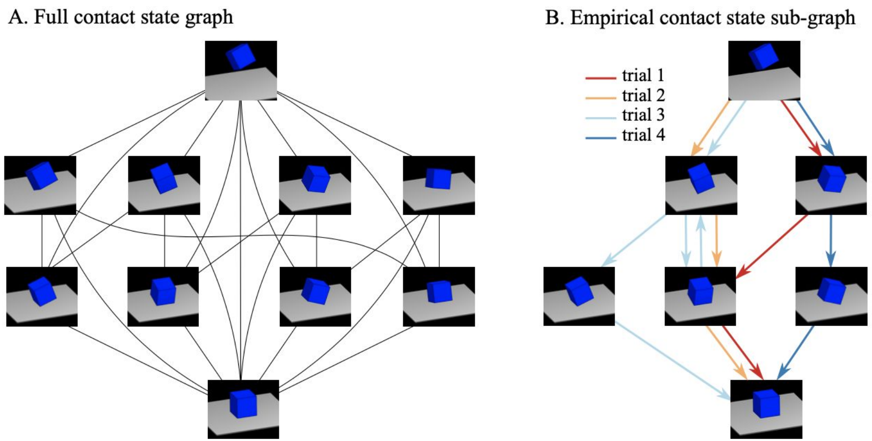
Result: turning caps with different radius with one manipulation manifold

(Steffen,2008)

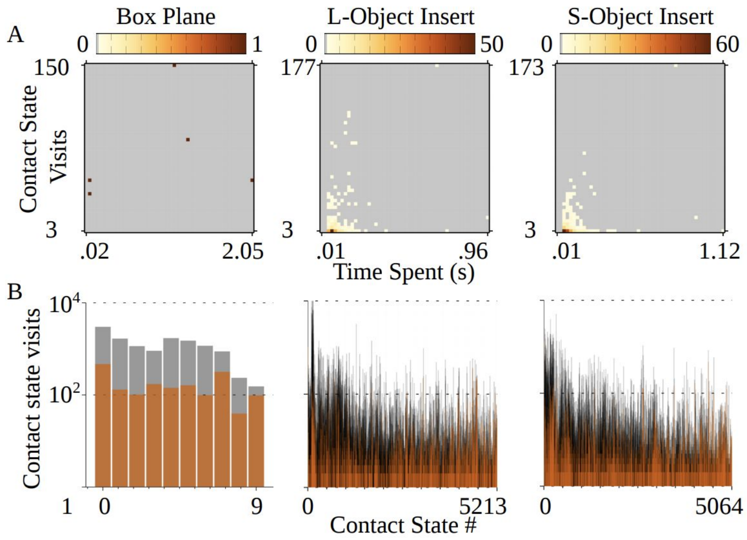
Task Space Control – Object manipulation

Contact manipulation tasks: traversing the contact-state graphs

(Klingbeil, 2014)



Subset of contact states

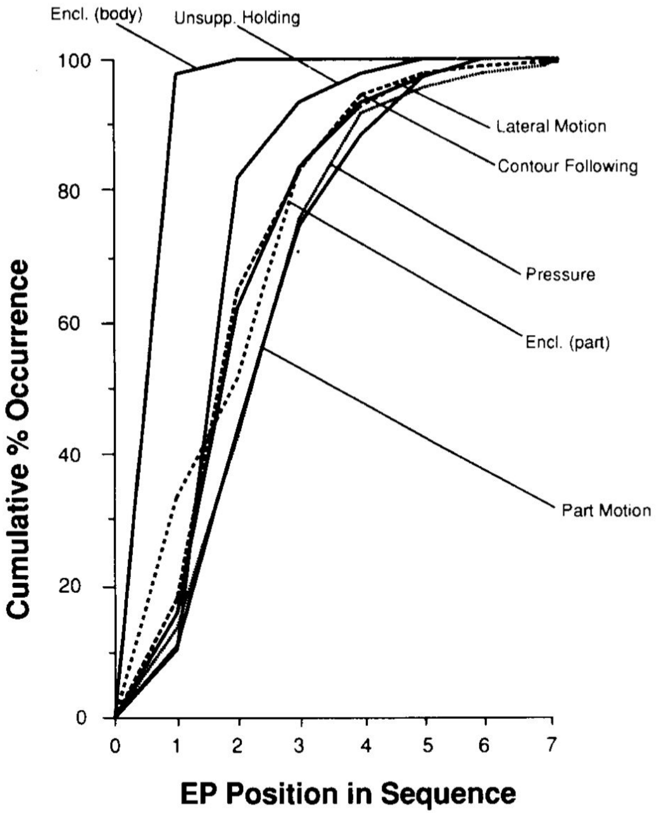


Contact states visited for different tasks

Task Space Control – Hands as perceptual tools

Two-stage haptic exploration for object identification (1992)

- Stage 1: Grasp and lift
- Stage 2:
    - contour following
    - lateral motion
    - Enclosure
    - unsupported holding
    - …



(Klatzky, 1992)

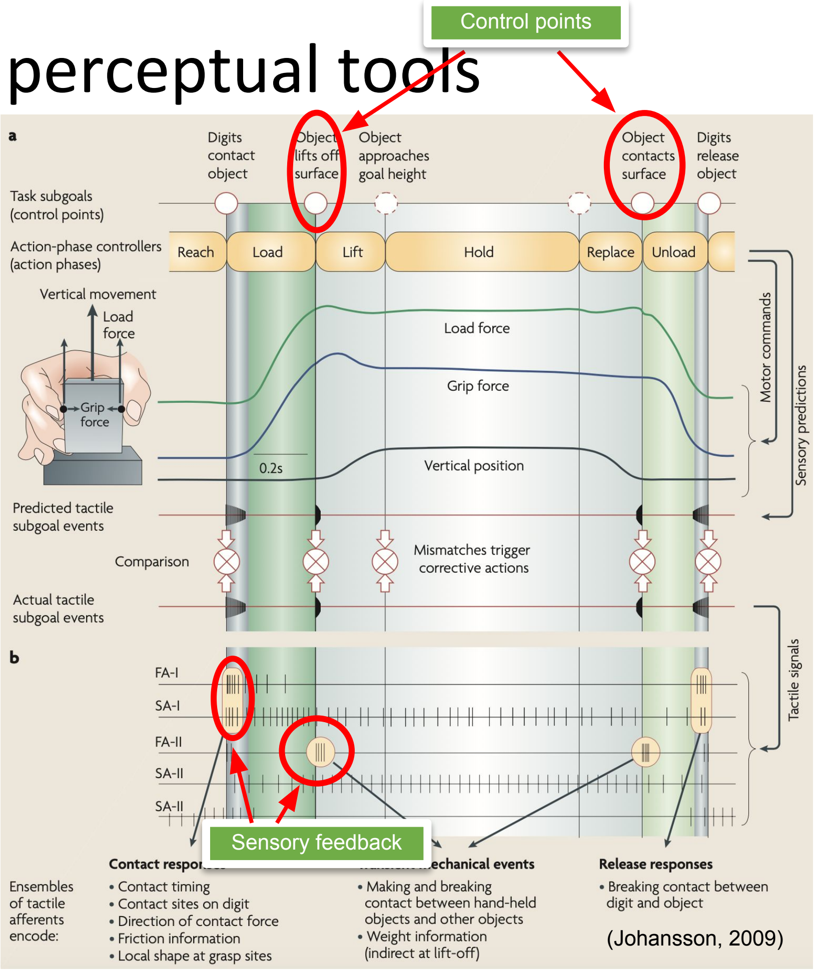
Task Space Control – Hands as perceptual tools

Difficult to understand in a higher neuroscience level…

Task Space Control – Hands as perceptual tools

Observed:

- Sensory feedback defining “control points”
- Corrective actions (predicted/actual)



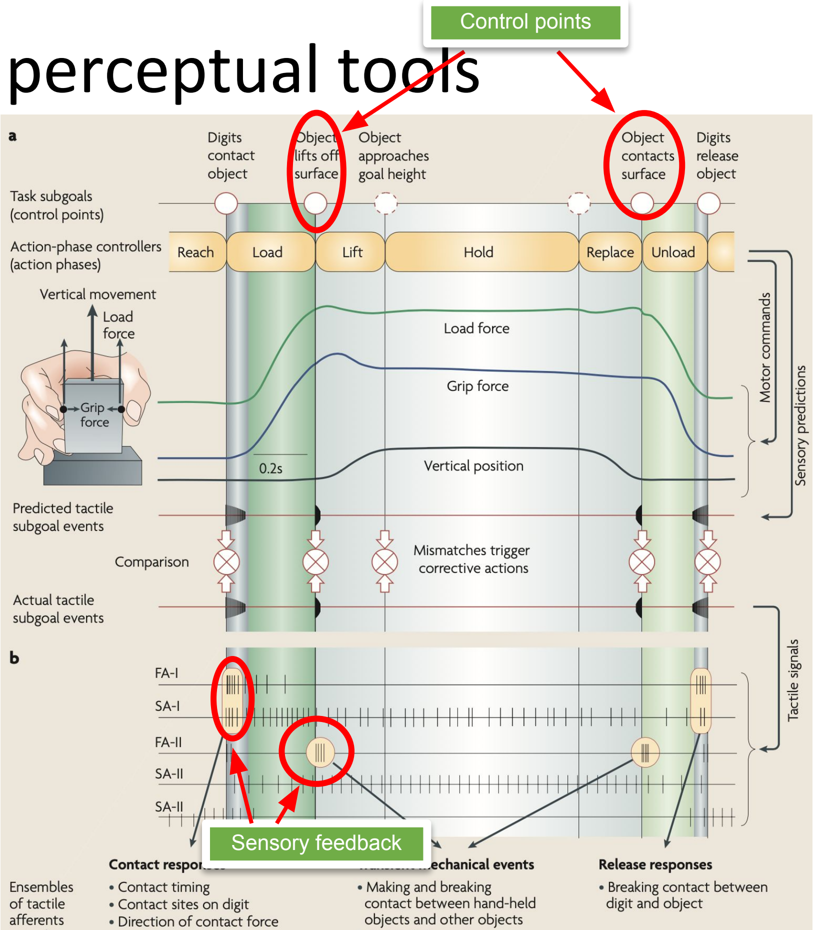
Task Space Control – Hands as perceptual tools

Observed:

- Sensory feedback defining “control points”
- Corrective actions (predicted/actual)

Unanswered:

- Which brain regions control manipulation?
- What is the CNS embodiment for a given manipulation task?
- What mechanisms coordinating sensory interactions and predictions?



(Johansson, 2009)

Robotics and Neuroscience - Cognitive nature of action

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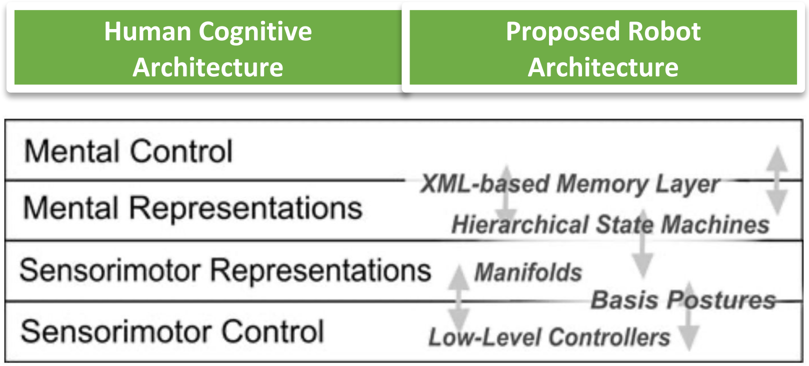
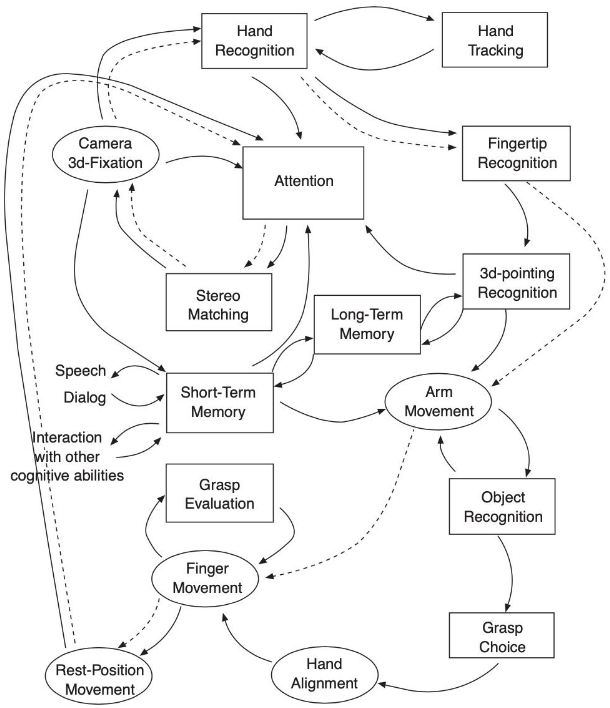


(Maycock et al., 2010)



Functional modules of the **GRAVIS** architecture (Schack, 2009)

Robotics Applied in Biomechanics

Shivani Guptasarma

Some questions about human movement

What are the principles governing it?
What are the mechanisms causing it?

How can we “improve” it?
How can we imitate it?

Some questions about human movement

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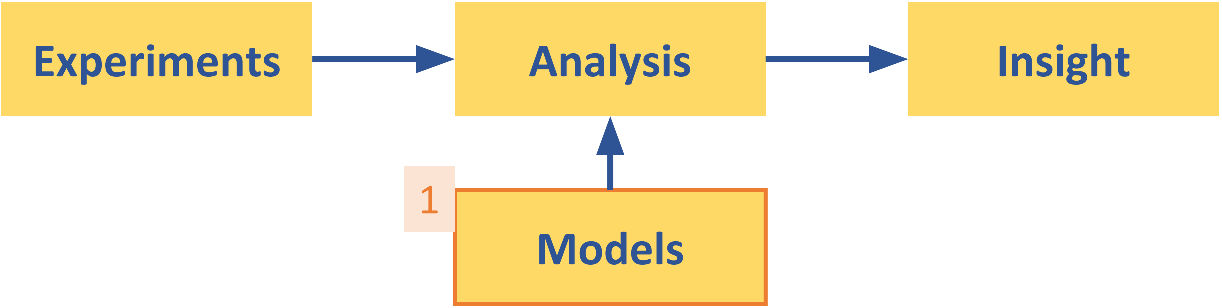

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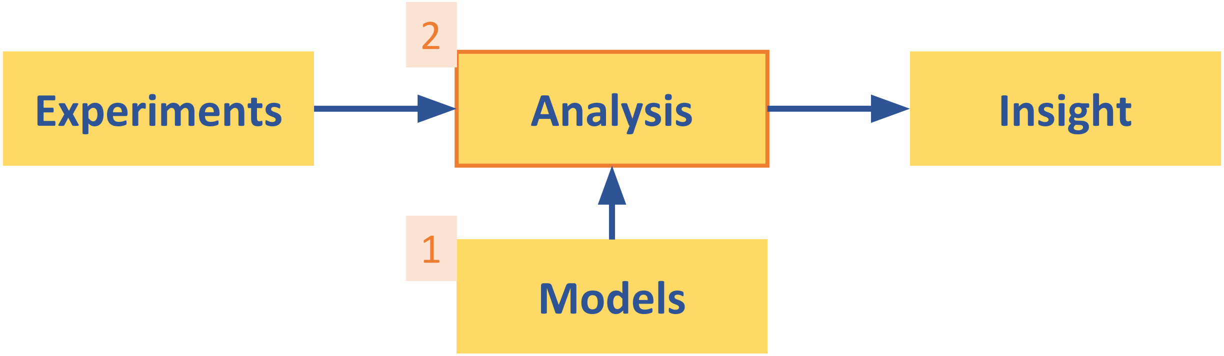

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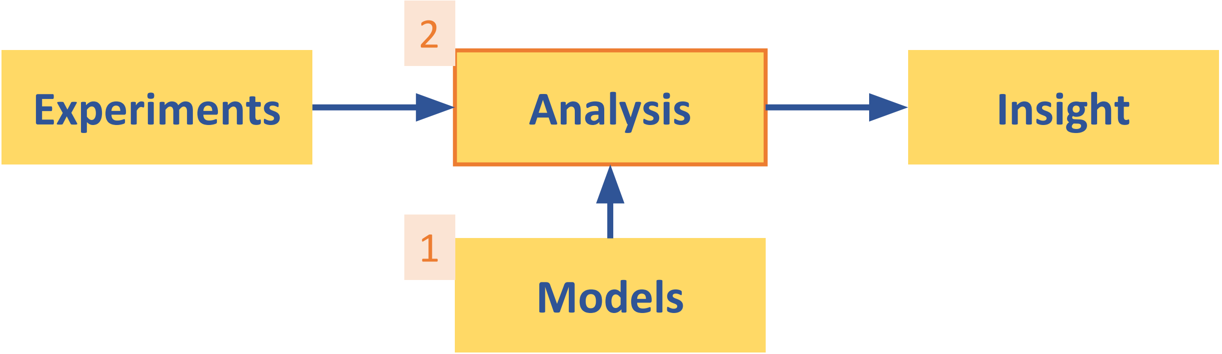

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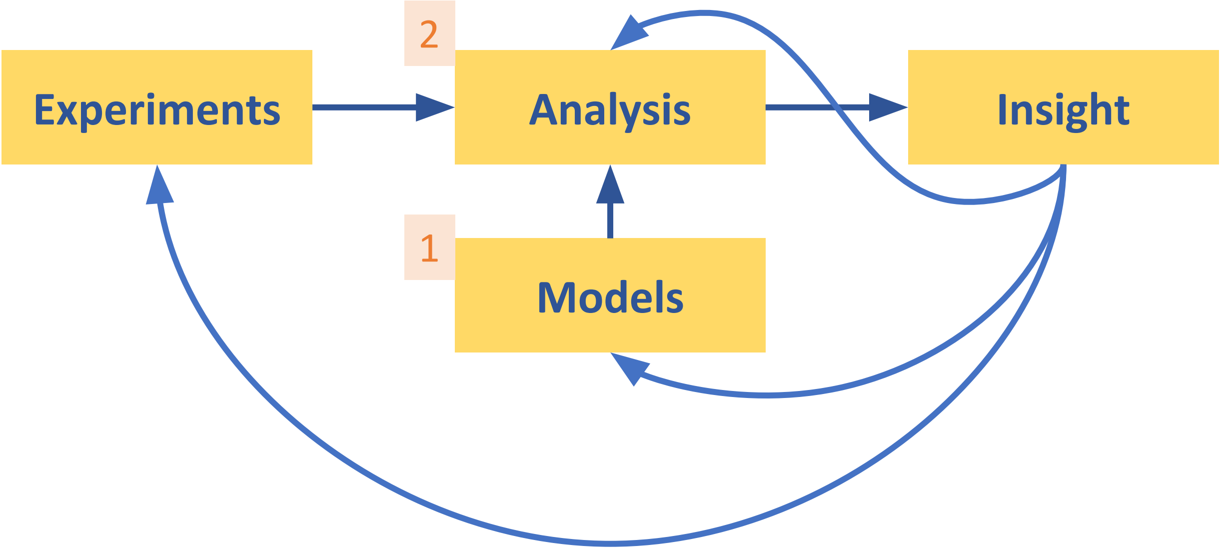

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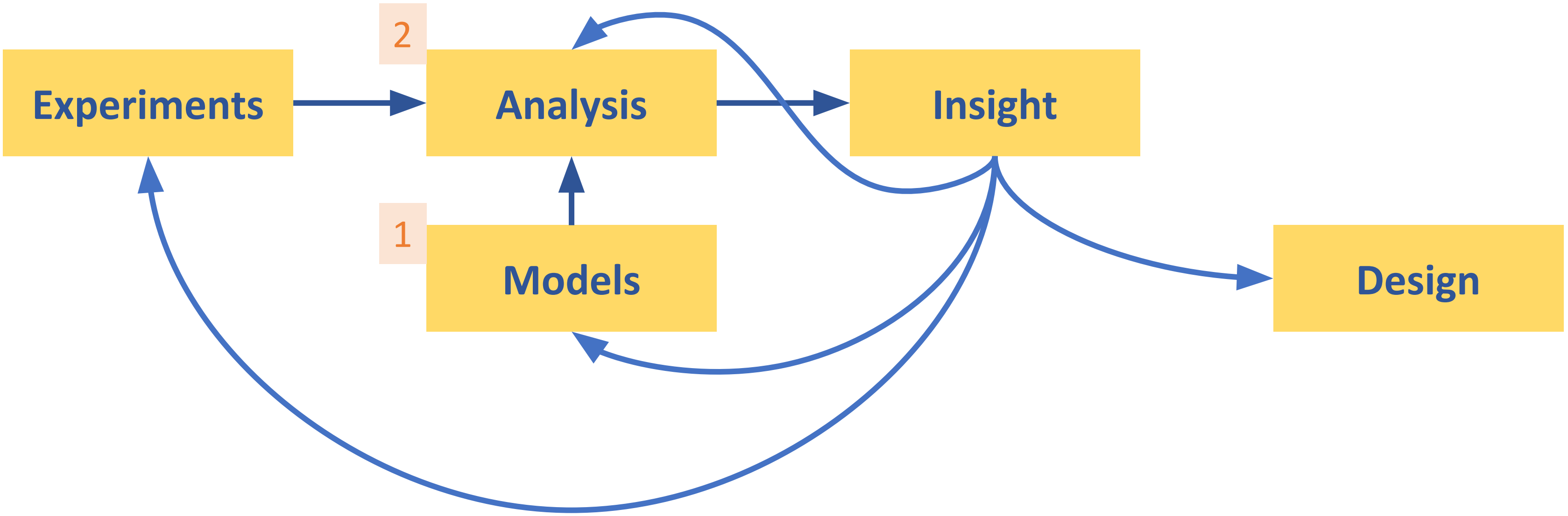

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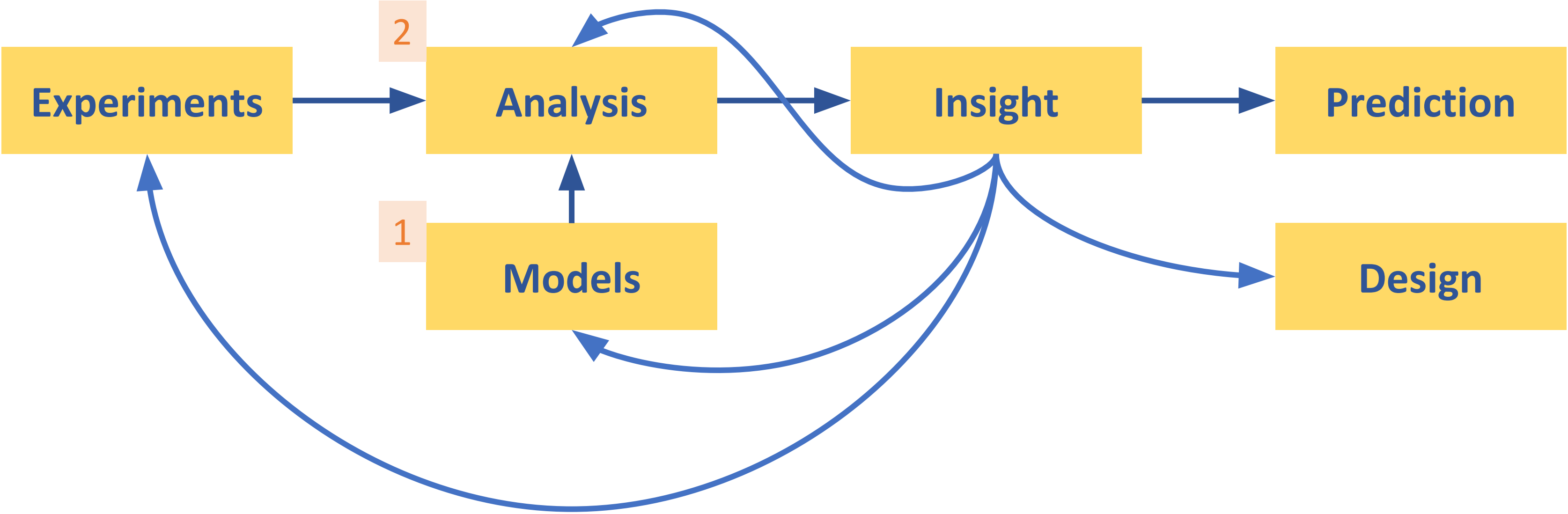

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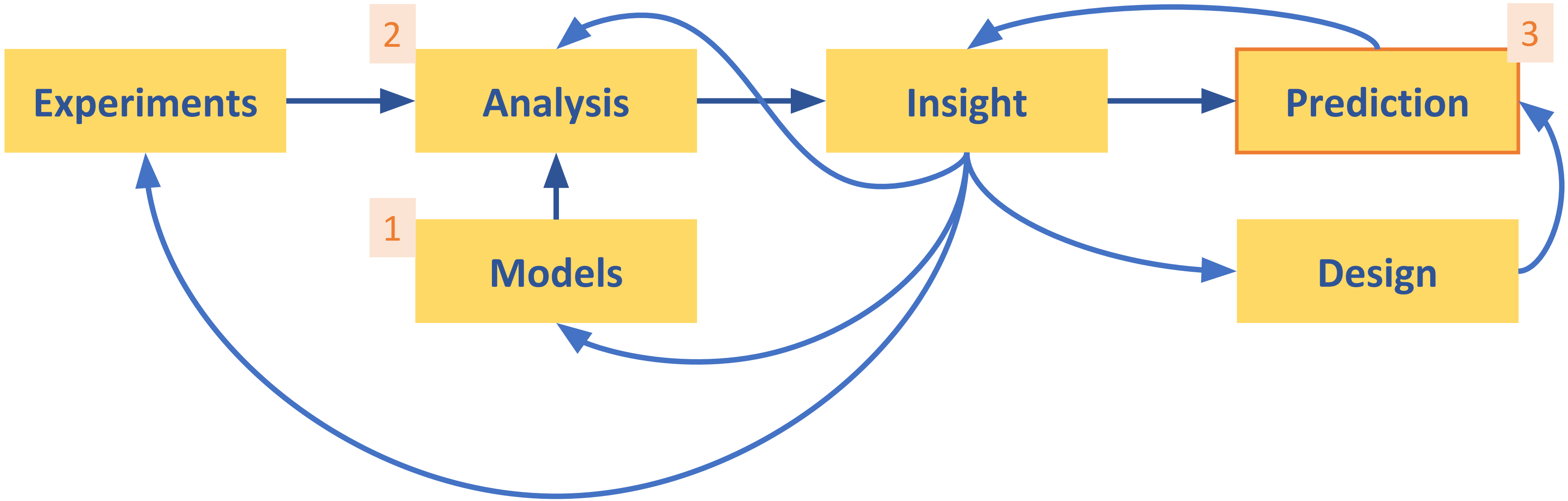

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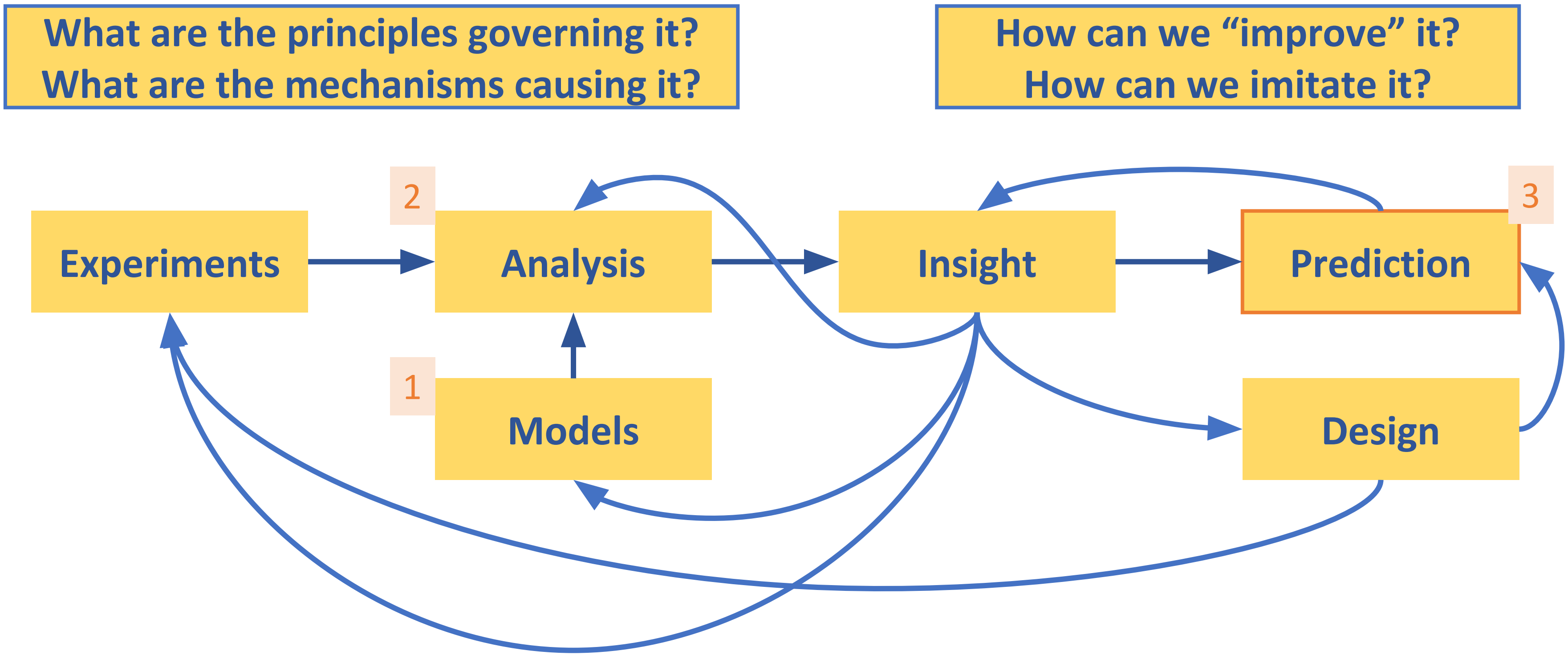

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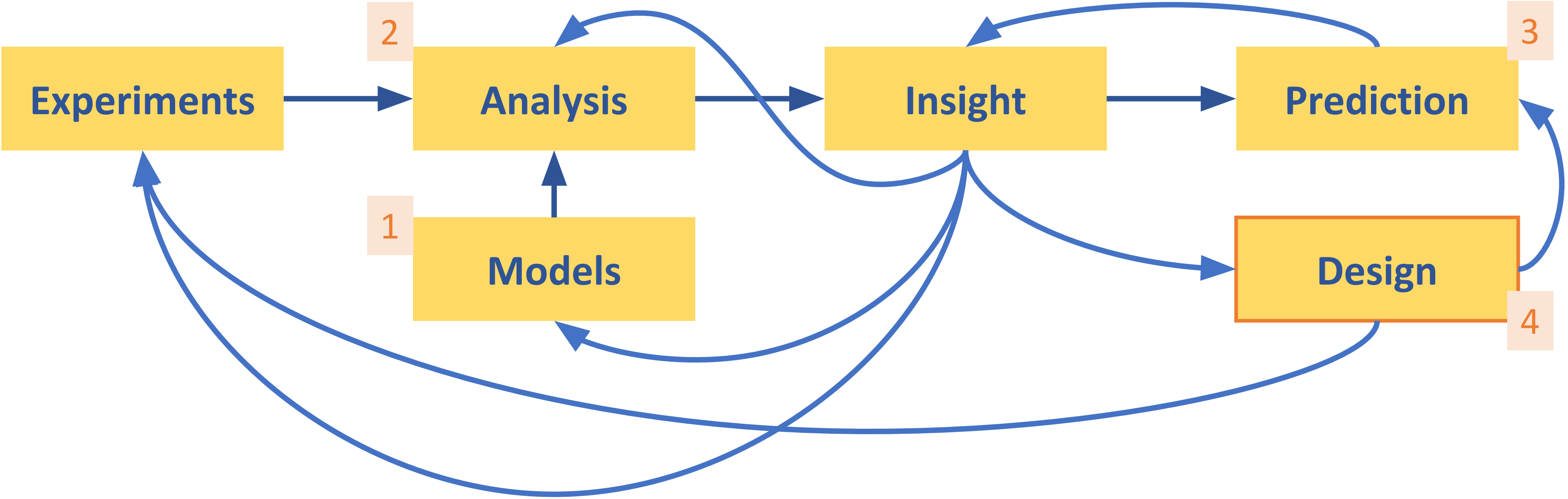


1

Models

The body is a robot!

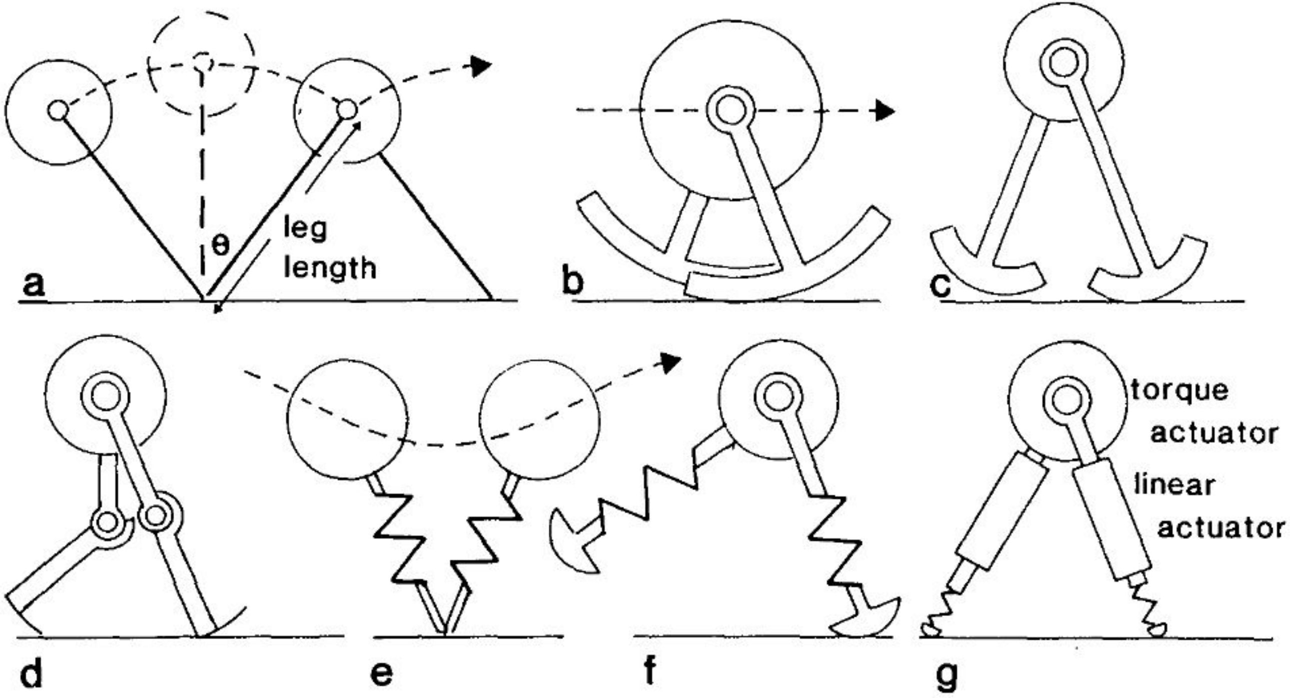
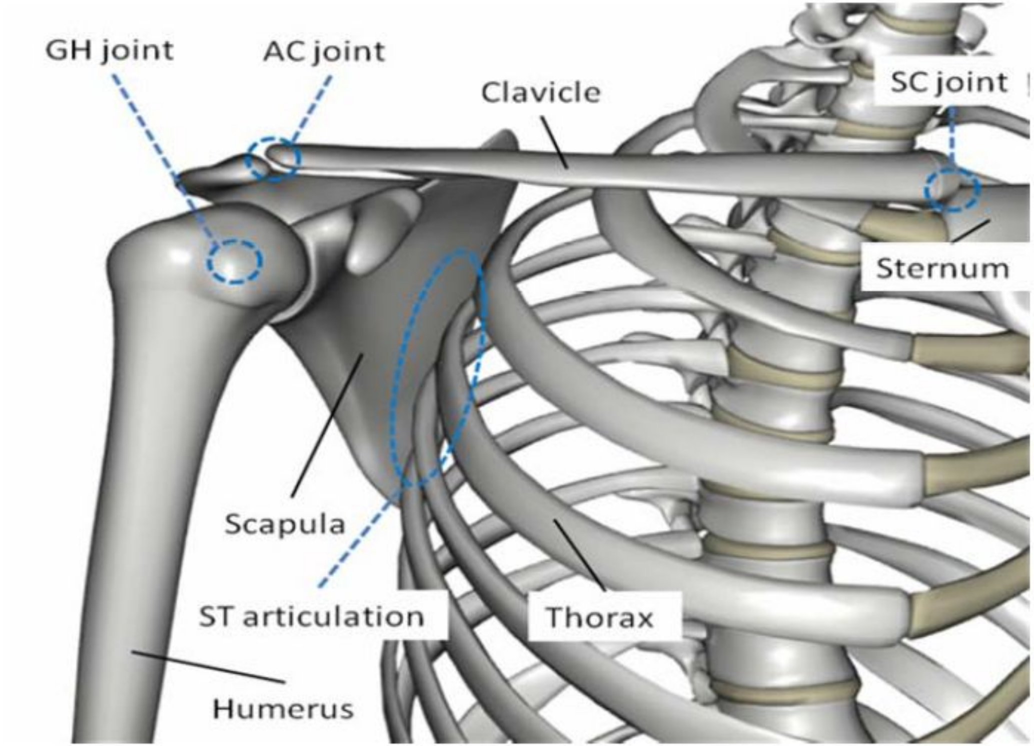


Fig 1. Models of walking and running: a) is the minimal biped; b) the synthetic wheel; c) McGeer's general two-dimensional biped; d) his knee-jointed biped; e) the mass-spring model; f) McGeer's passive running biped; and g) Alexander's force-controlled biped.

Image source: Alexander, 1995

Example: modeling the shoulder (Yang *et al.*, 2010)



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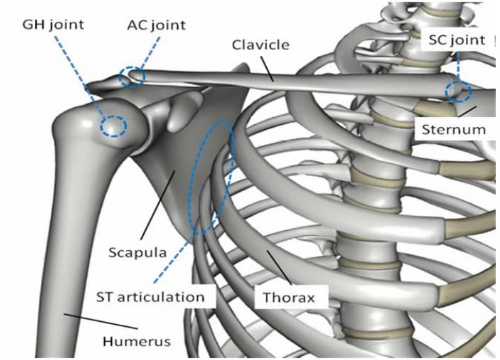
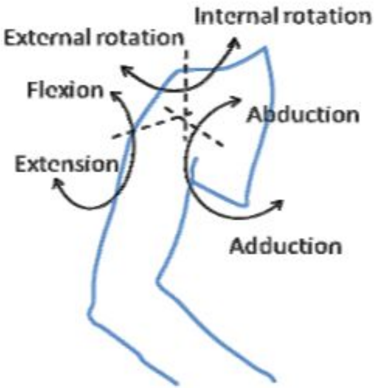
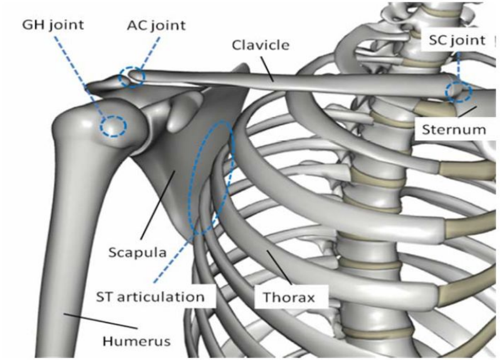
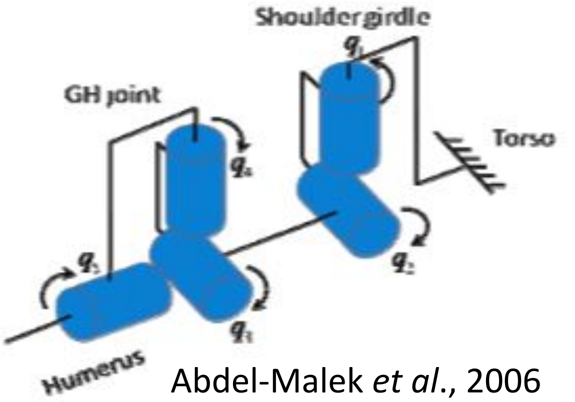




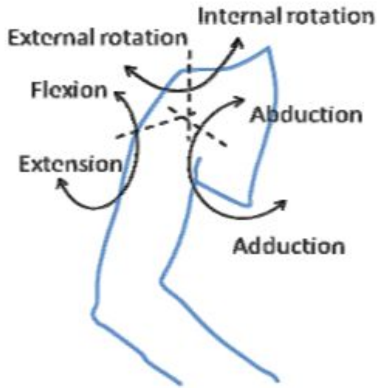
Images: Yang *et al.*, 2010

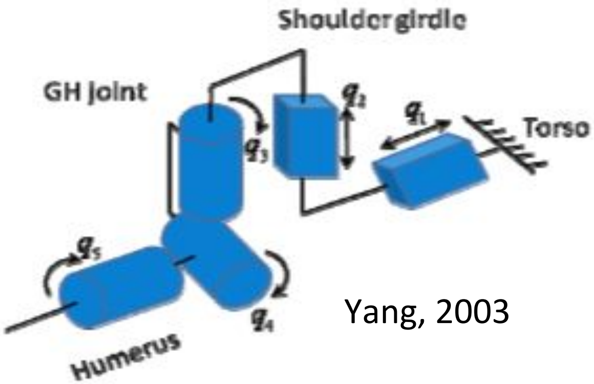
Example: modeling the shoulder (Yang *et al.*, 2010)





Abdel-Malek *et al.*, 2006





Yang, 2003

Images: Yang *et al.*, 2010

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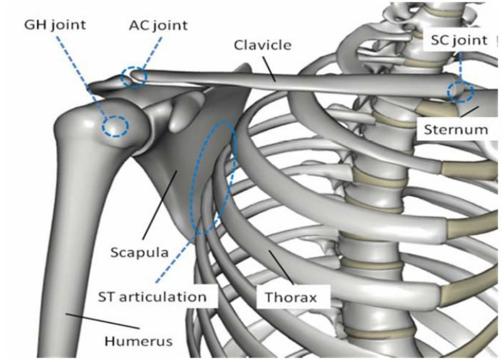

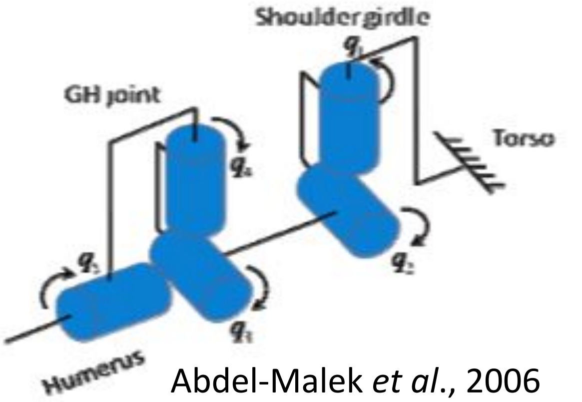

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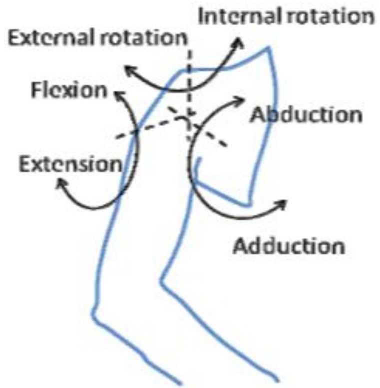
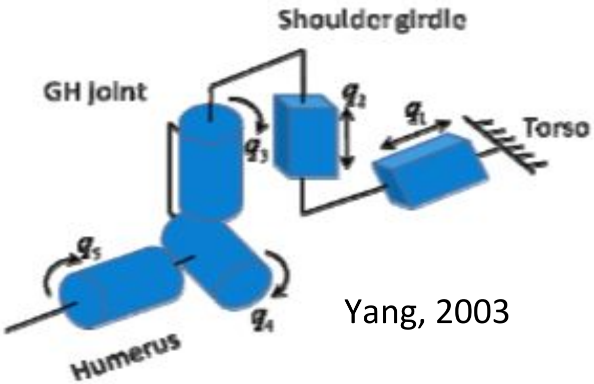
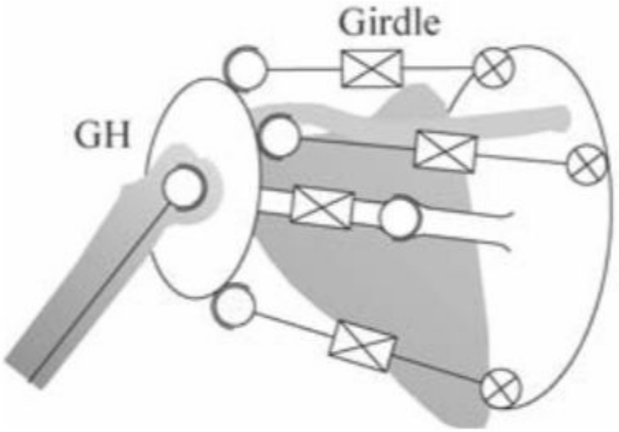




Yang, 2003

Lenarcic and Stanisik, 2003



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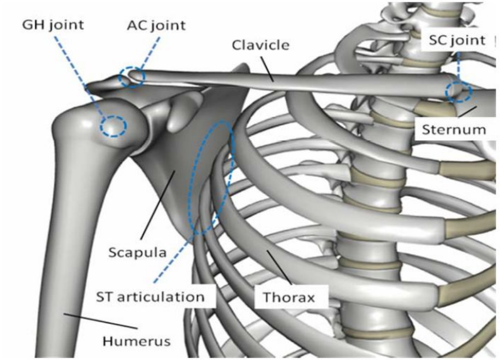

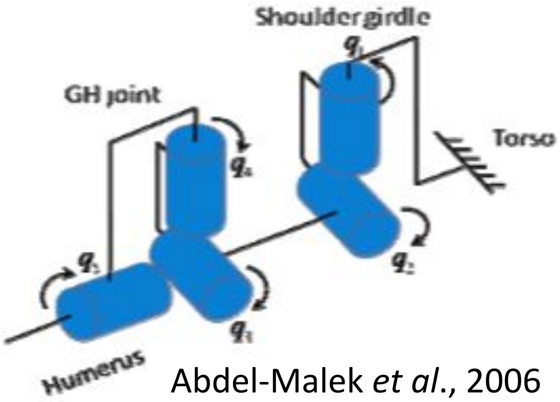

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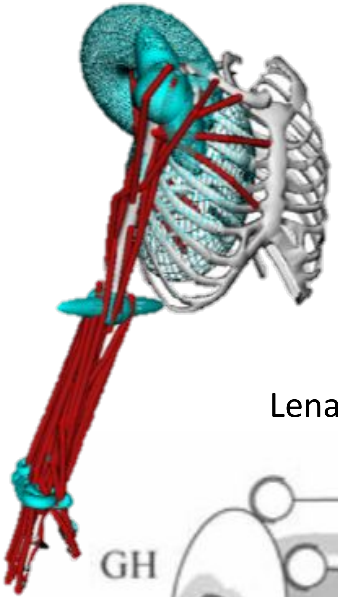
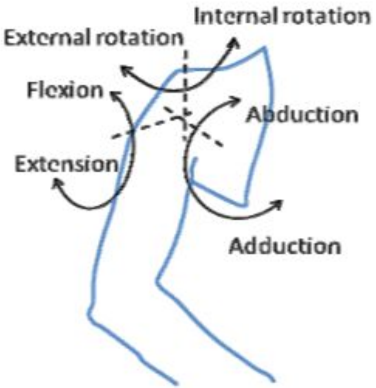
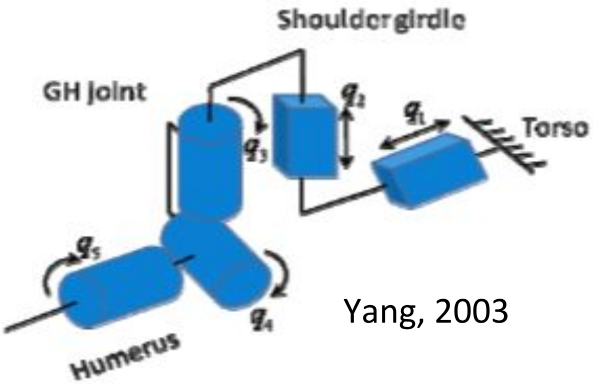


Holzbaur *et al.*, 2005





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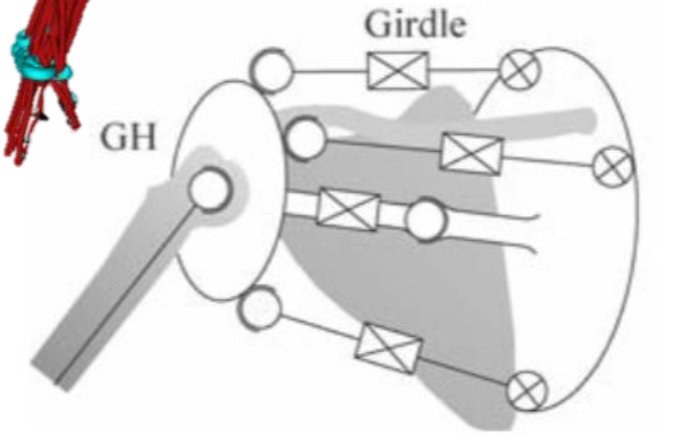


Images: Yang *et al.*, 2010

Analysis

How do we generate motion?

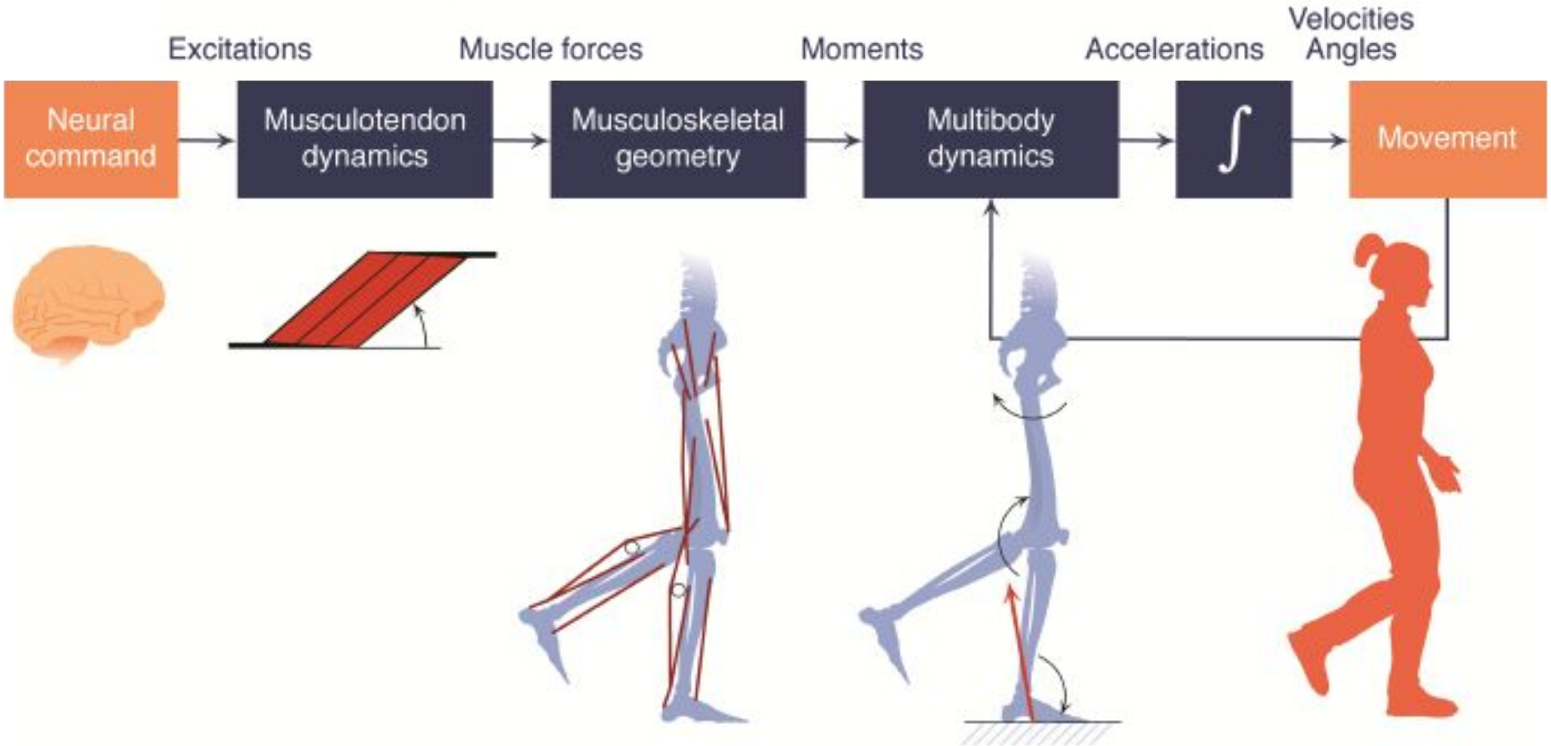
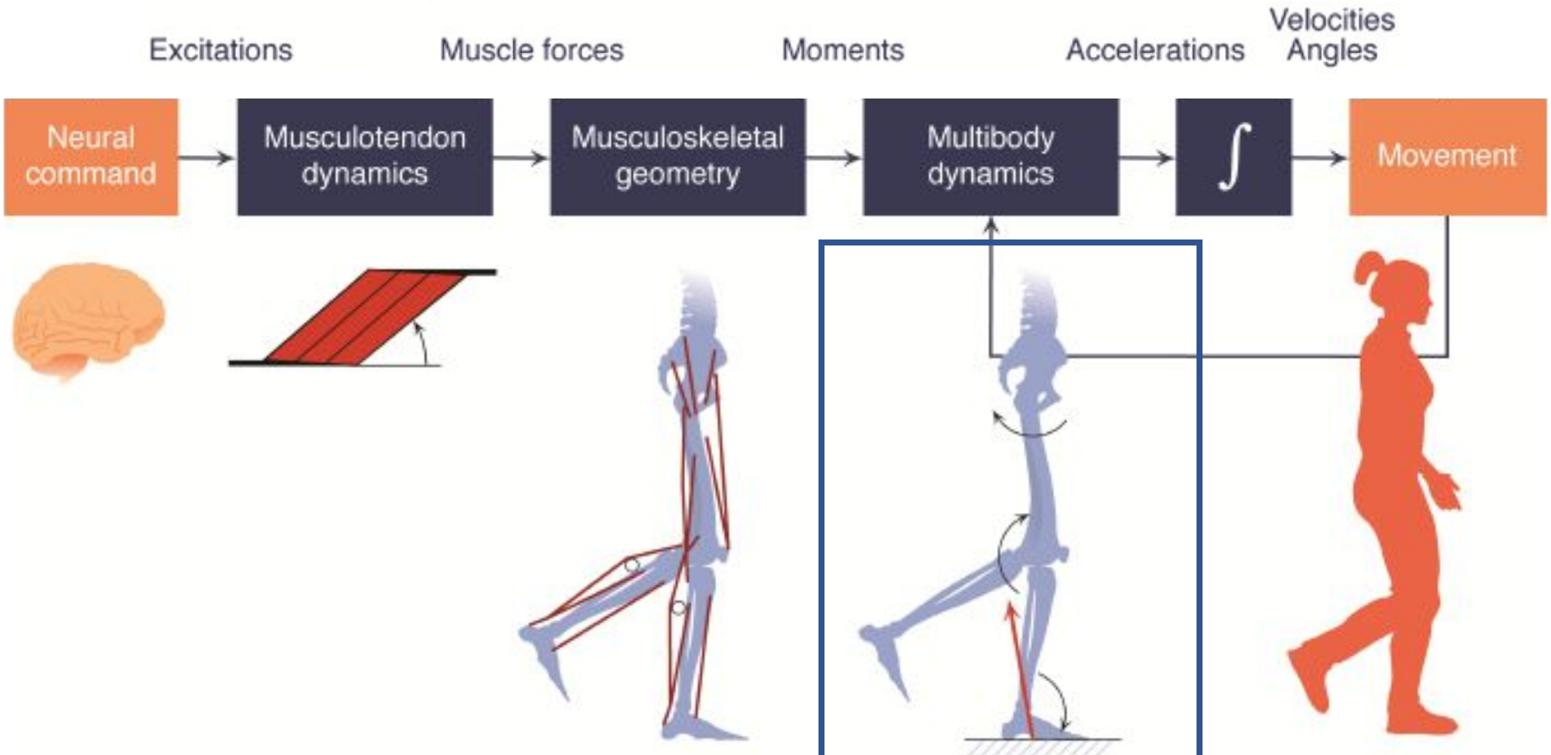
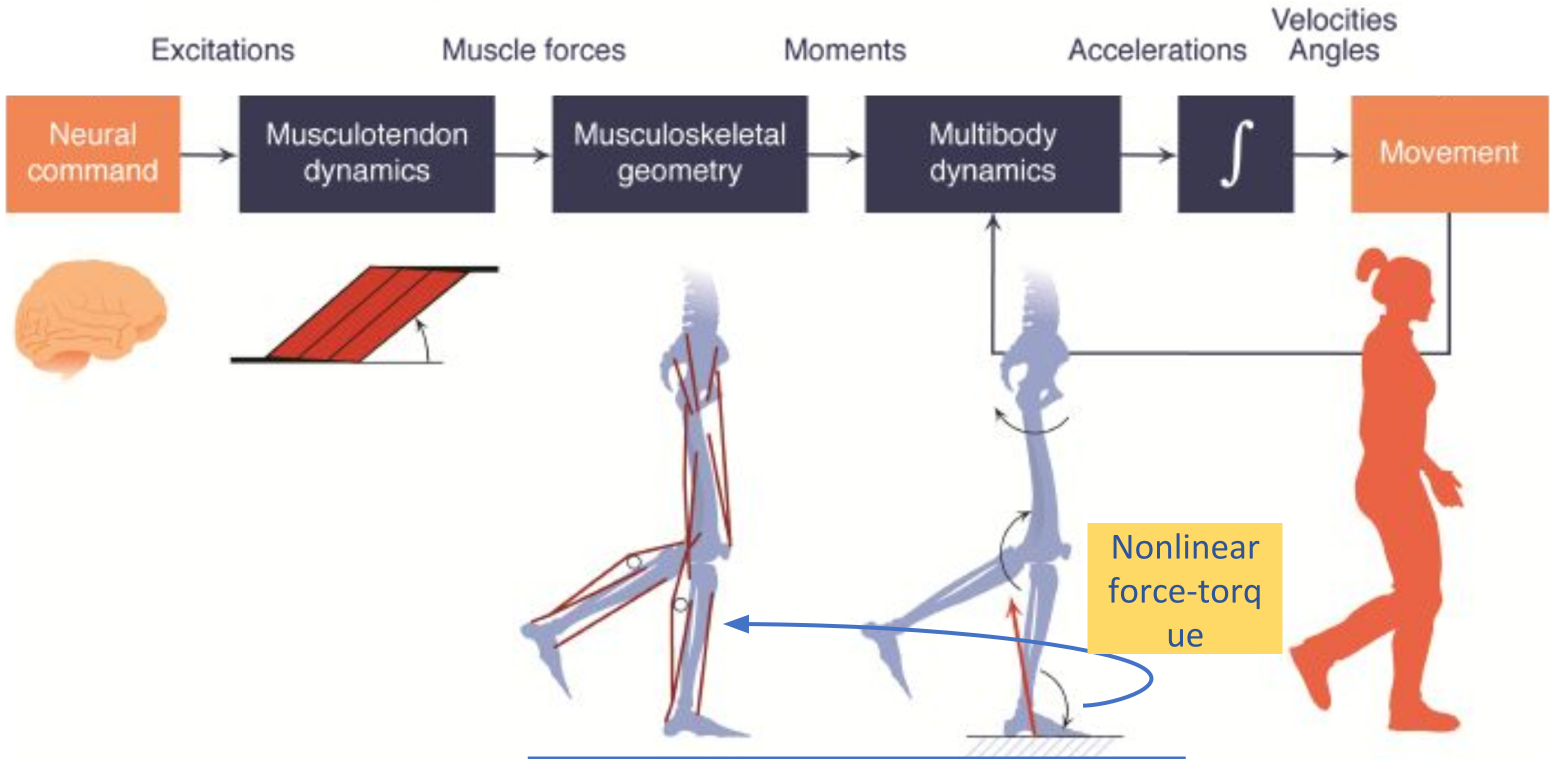


Image adapted from: Seth *et al.*, 2018



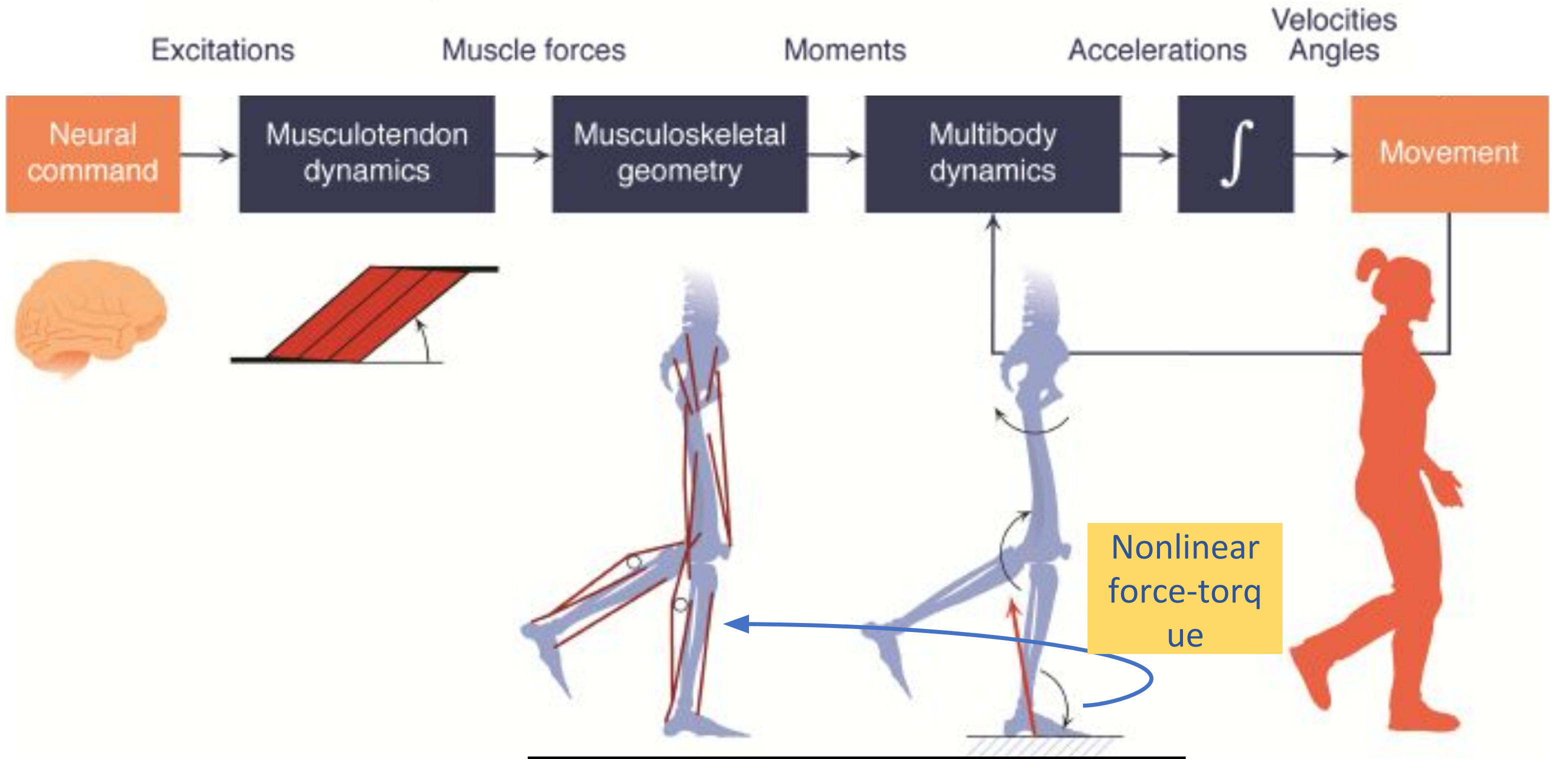
$$A\,(q)\,\ddot{q} + b\,(q, \dot{q}) + g\,(q) = \Gamma = J^T\,F$$

Image adapted from: Seth *et al.*, 2018



$$\mathbf{A}\,(\mathbf{q})\,\ddot{\mathbf{q}} + \mathbf{b}\,(\mathbf{q},\,\dot{\mathbf{q}}) + \mathbf{g}\,(\mathbf{q}) = \boldsymbol{\Gamma}$$

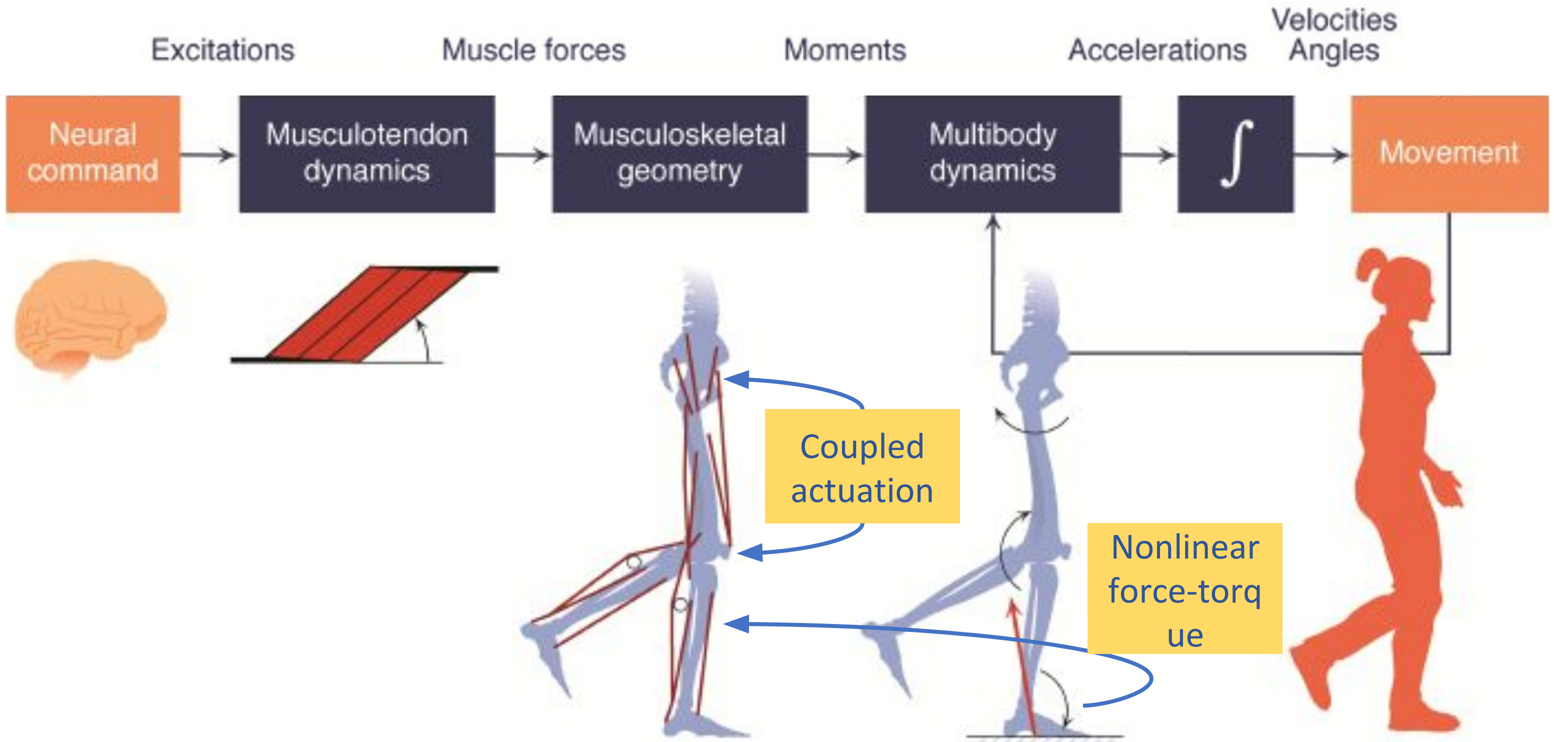
Image adapted from: Seth *et al.*, 2018



$$\mathbf{A}\,(\mathbf{q})\,\ddot{\mathbf{q}} + \mathbf{b}\,(\mathbf{q},\,\dot{\mathbf{q}}) + \mathbf{g}\,(\mathbf{q}) = \boldsymbol{\Gamma} = \mathbf{L}^{\mathbf{T}}\mathbf{m}$$

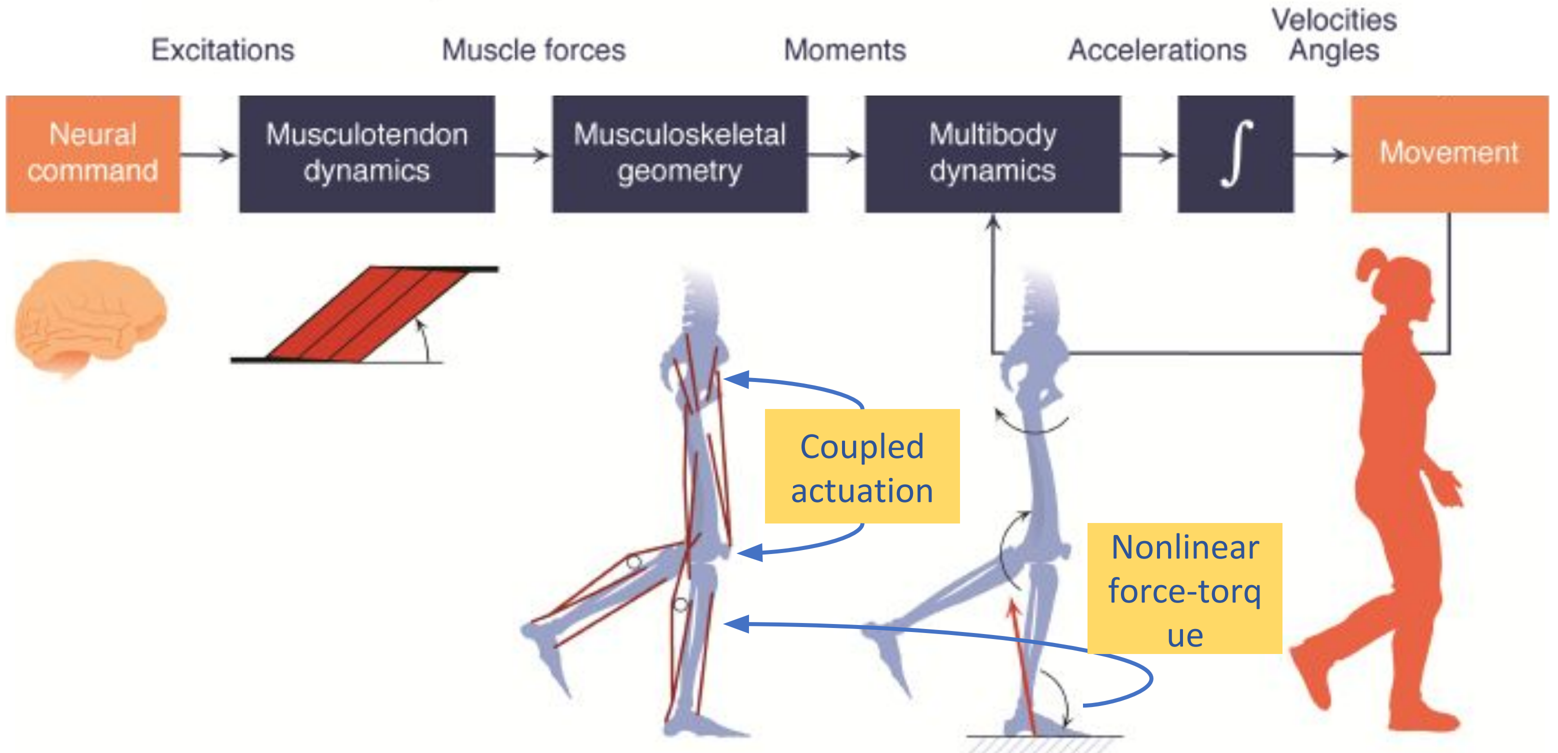
Khatib *et al.*, 2009

Image adapted from: Seth *et al.*, 2018



$$A(q)\,\ddot{q} + b(q, \dot{q}) + g(q) = L^T m$$

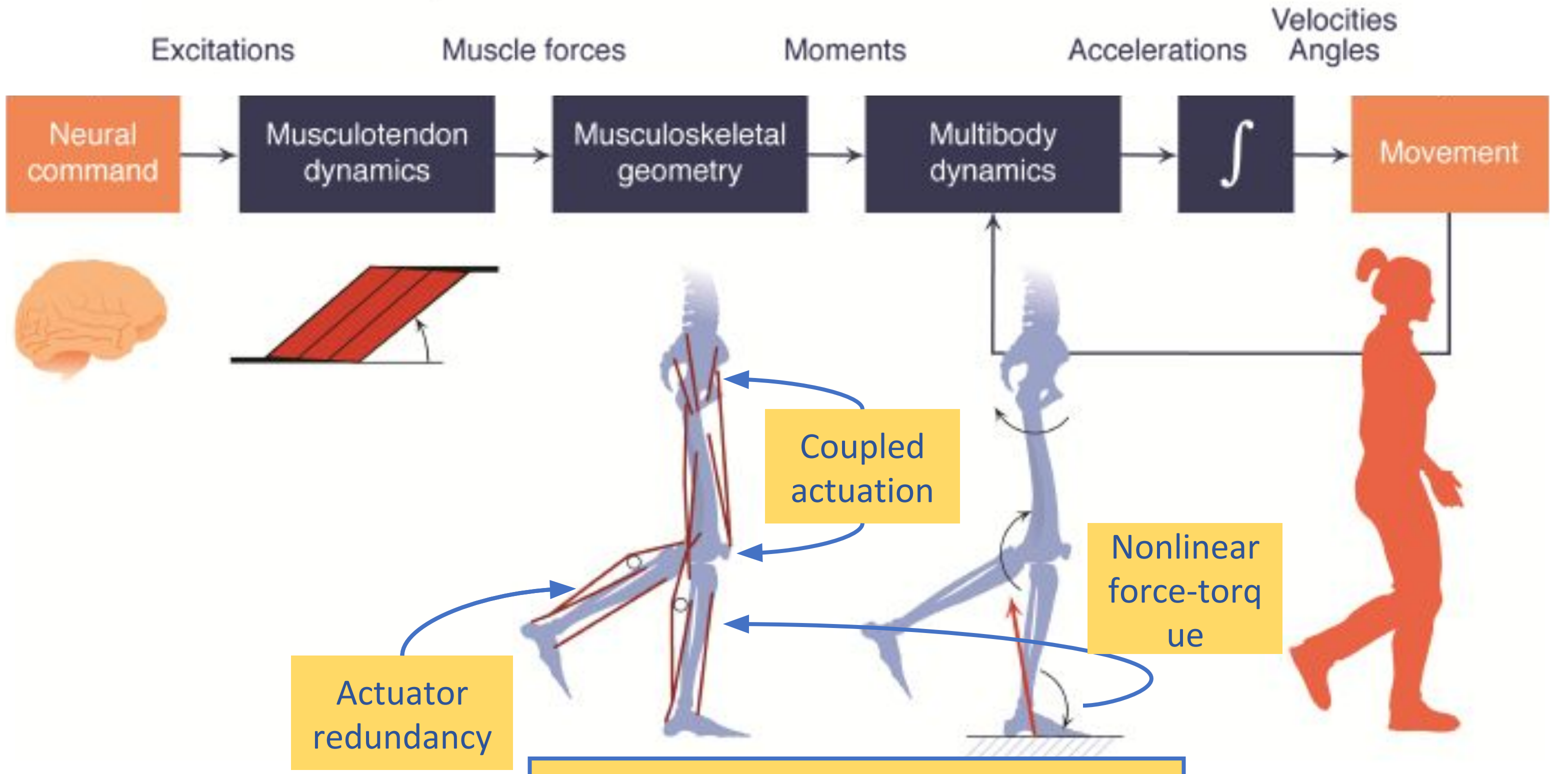
Image adapted from: Seth *et al.*, 2018



$$\mathbf{A}(\mathbf{q})\,\ddot{\mathbf{q}} + \mathbf{b}(\mathbf{q}, \dot{\mathbf{q}}) + \mathbf{g}(\mathbf{q}) = \mathbf{L}^T\mathbf{m}$$

- L is not diagonal

Image adapted from: Seth *et al.*, 2018



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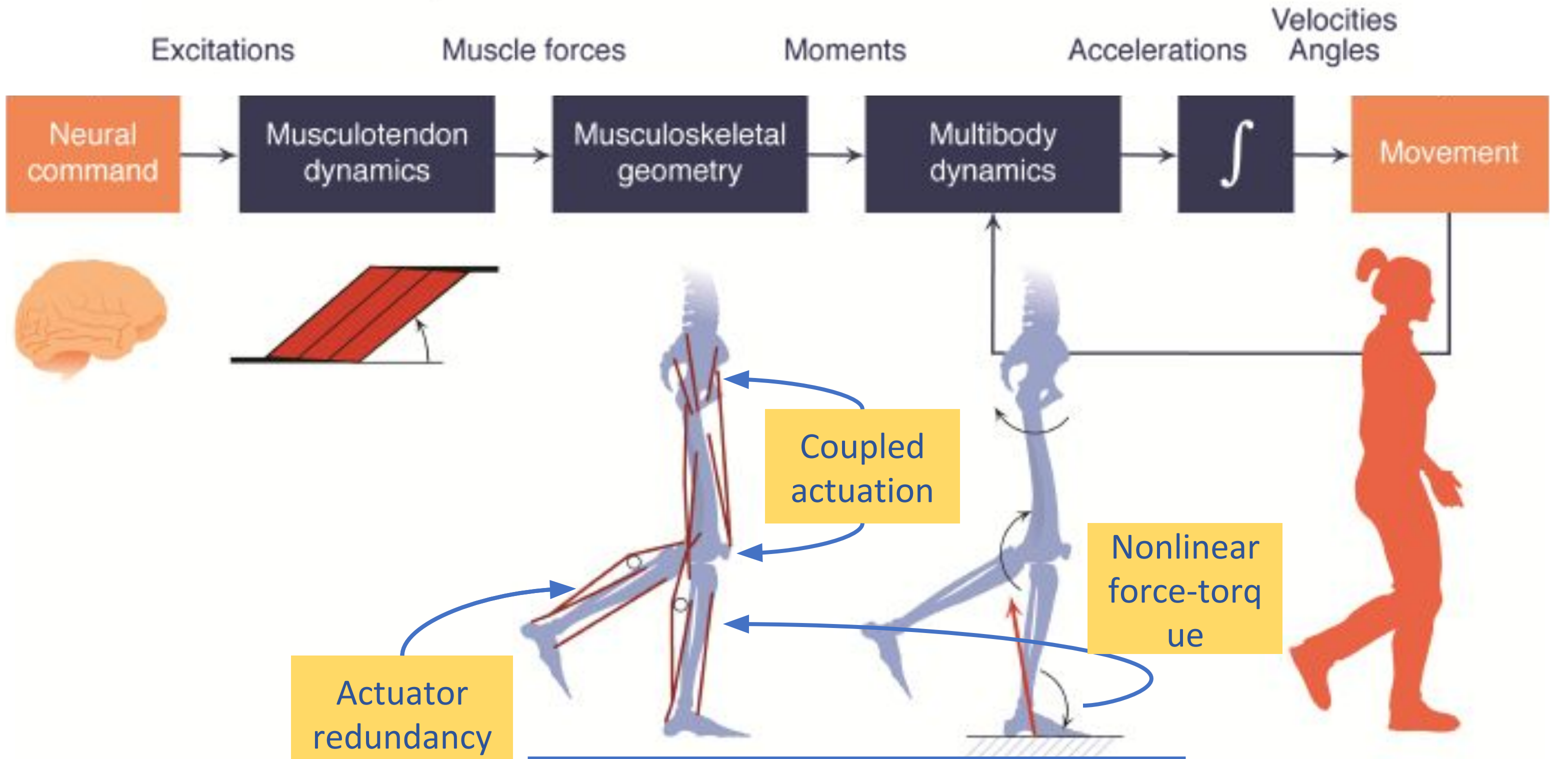
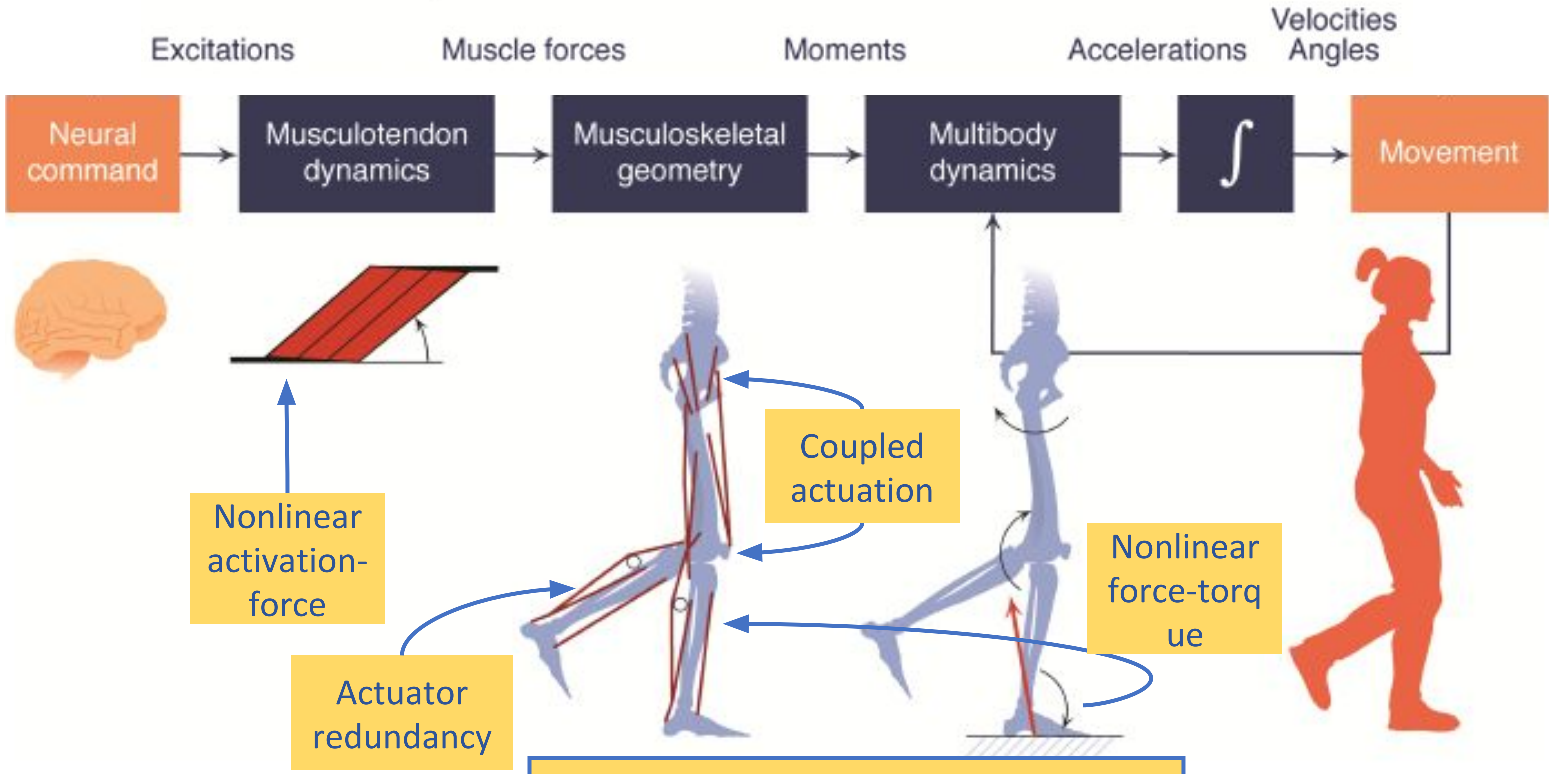


$$\mathbf{A}\,(\mathbf{q})\,\ddot{\mathbf{q}} + \mathbf{b}\,(\mathbf{q}, \dot{\mathbf{q}}) + \mathbf{g}\,(\mathbf{q}) = \mathbf{L}^T\mathbf{m}$$

- **L** is not diagonal
- **L** is not square

-- so **L** is not invertible

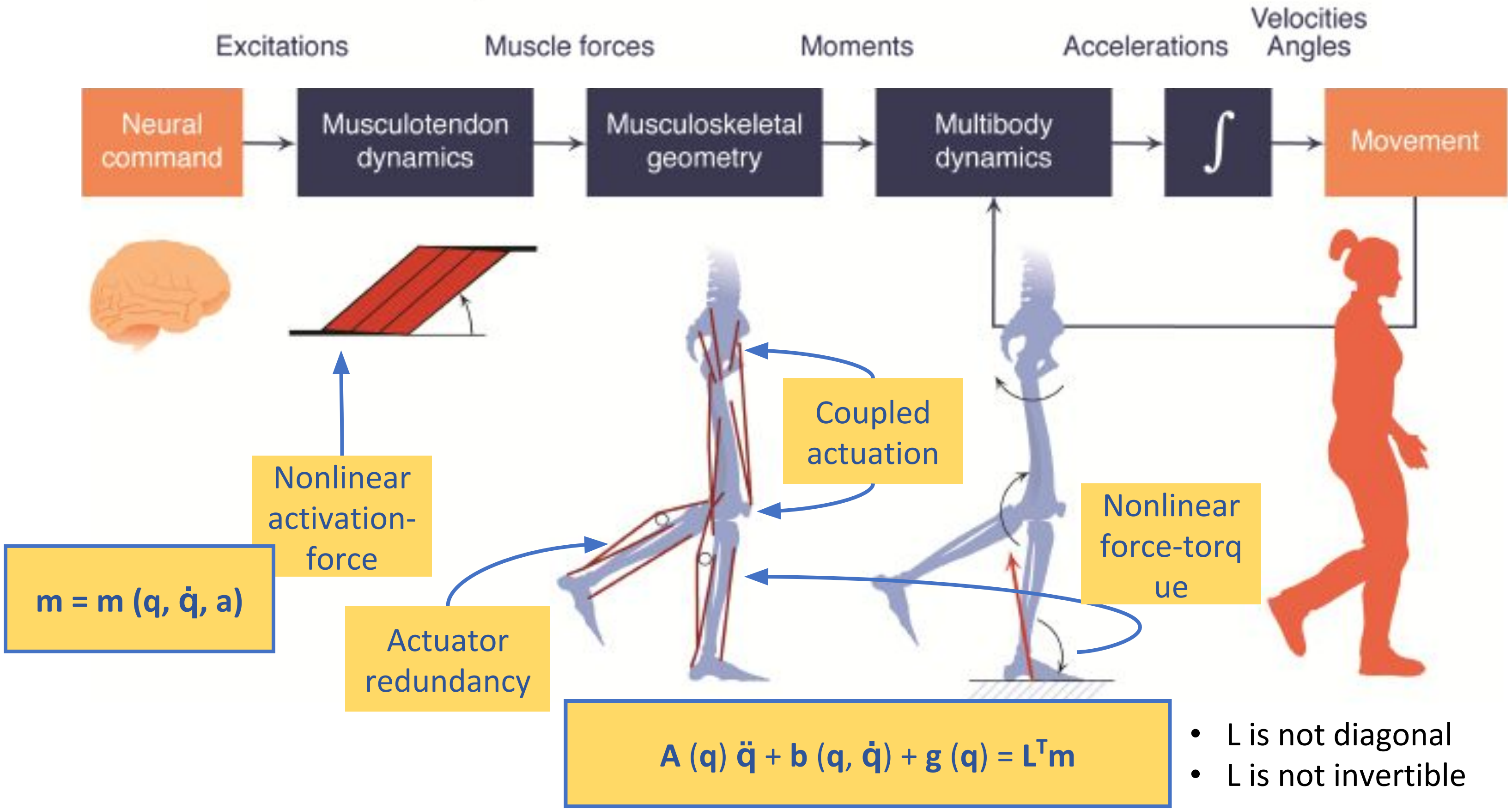
Image adapted from: Seth *et al.*, 2018



$$\mathbf{A}\ (\mathbf{q})\ \ddot{\mathbf{q}} + \mathbf{b}\ (\mathbf{q},\ \dot{\mathbf{q}}) + \mathbf{g}\ (\mathbf{q}) = \mathbf{L}^{T}\mathbf{m}$$

- L is not diagonal
- L is not invertible

Image adapted from: Seth *et al.*, 2018



- L is not diagonal
- L is not invertible

Image adapted from: Seth *et al.*, 2018

2

Analysis

$$A(q)\,\ddot{q} + b(q, \dot{q}) + g(q) = L^T m(q, \dot{q}, a)$$

How do we deal with underdetermined systems in robotics?

Analysis

$$A(q)\,\ddot{q} + b(q, \dot{q}) + g(q) = L^T m(q, \dot{q}, a)$$

How do we deal with underdetermined systems in robotics?

Static optimization methods

- Minimize $E = \Sigma c_i m_i^2$ (Khatib *et. al*, 2009)
- Minimize $f = \Sigma\, c_i\, a^2_i$ *
- Minimize $g = \Sigma\, \sigma^2_i$ *

* For examples, see Erdemir *et. al*, 2007

2

Analysis

$$A(q)\,\ddot{q} + b(q, \dot{q}) + g(q) = L^T m(q, \dot{q}, a)$$

How do we deal with indeterminate systems in robotics?

Static optimization methods

- Minimize $E = \Sigma c_i m_i^2$ (Khatib *et. al*, 2009)
- Minimize $f = \Sigma\, c_i\, a^2_i$ *
- Minimize $g = \Sigma\, \sigma^2_i$ *

* For examples, see Erdemir *et. al*, 2007

Dynamic optimization methods

- Minimize $\int E(t)\, dt$
- Minimize $\int f(t)\, dt$
- Minimize $\int g(t)\, dt$

and so on (see Dembia *et. al*, 2019)

Extending Computed Torque Control to Computed Muscle Control (Thelen *et al.*, 2003)

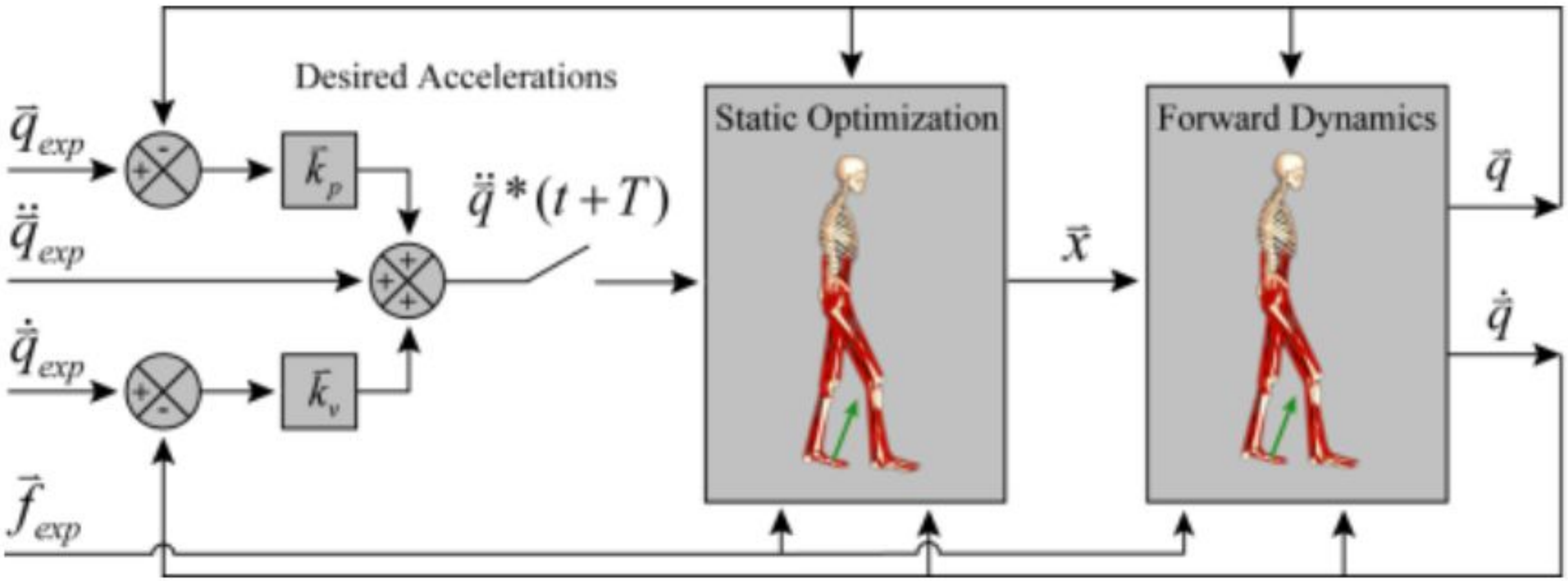


Image source: Thelen *et al.*, 2003

Prediction

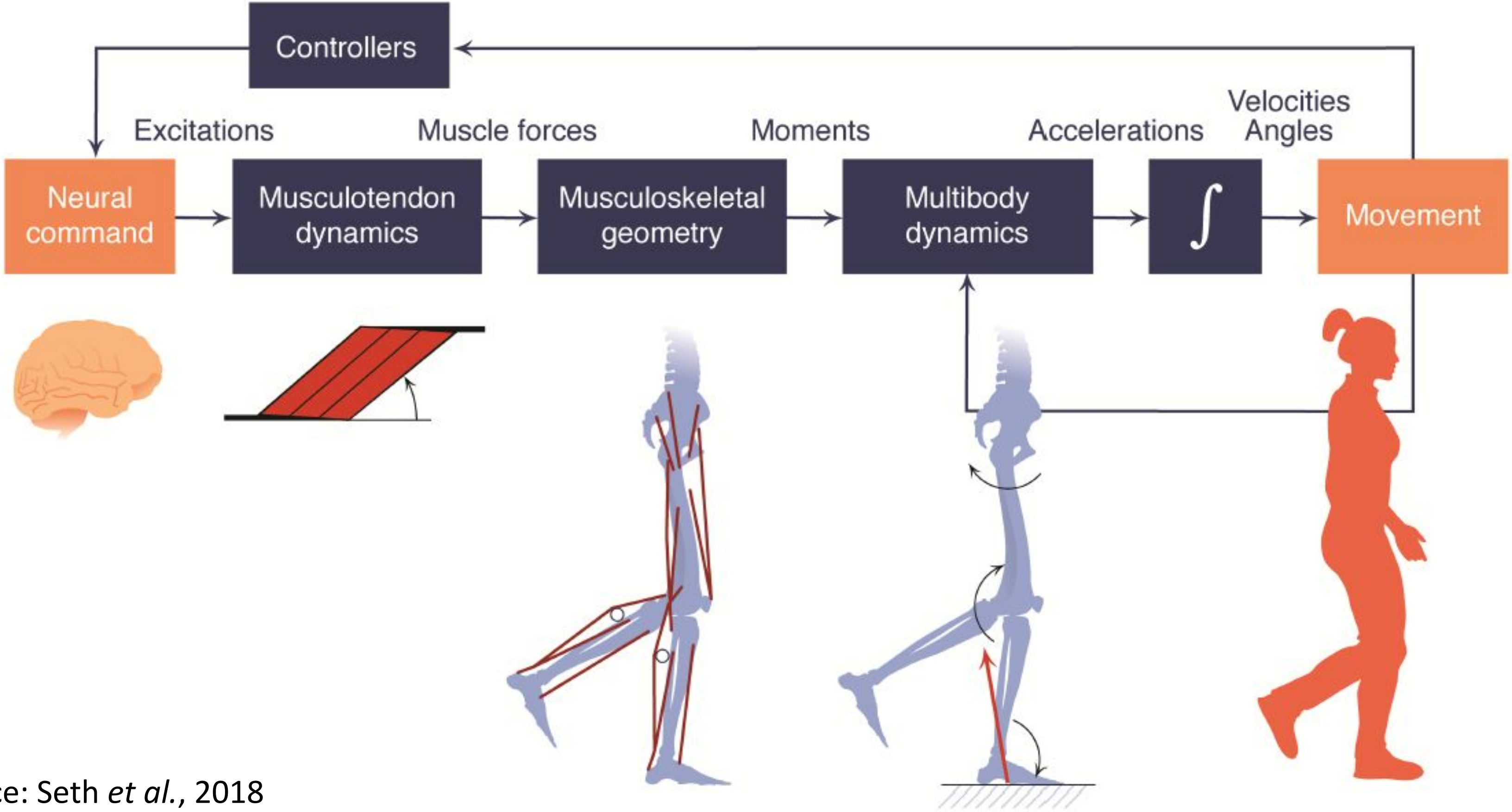
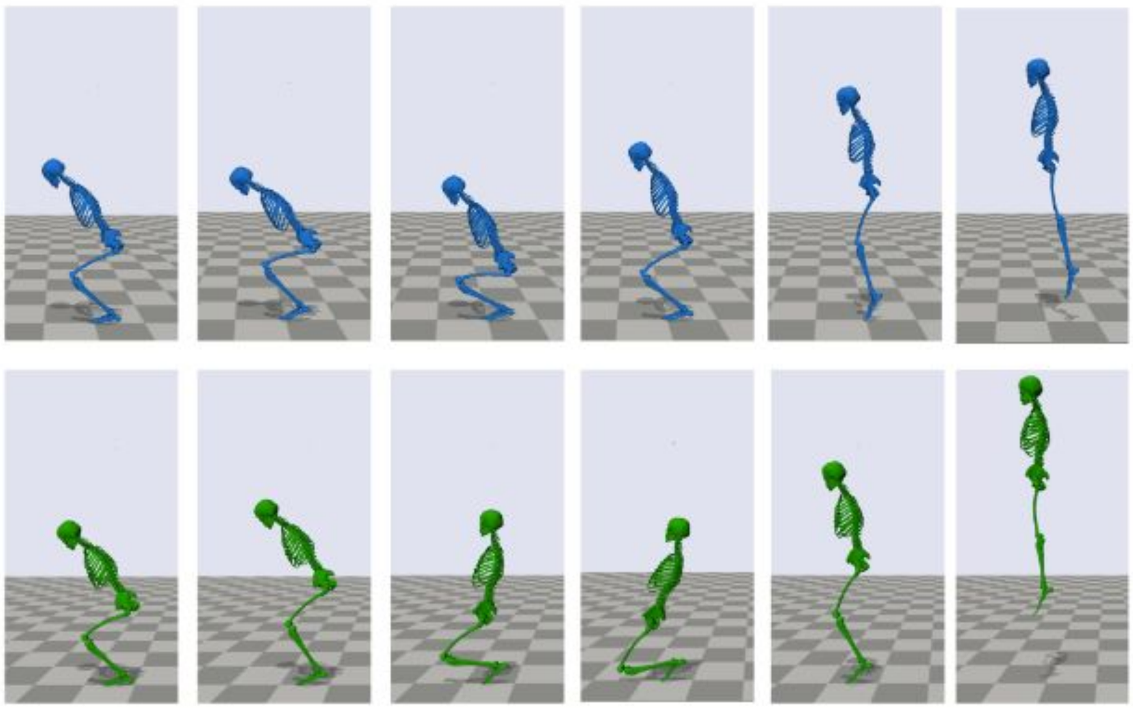


Image source: Seth *et al.*, 2018

3

Prediction

If the objective functions are known, we can do predictive simulation



Jiang *et al.*, 2019

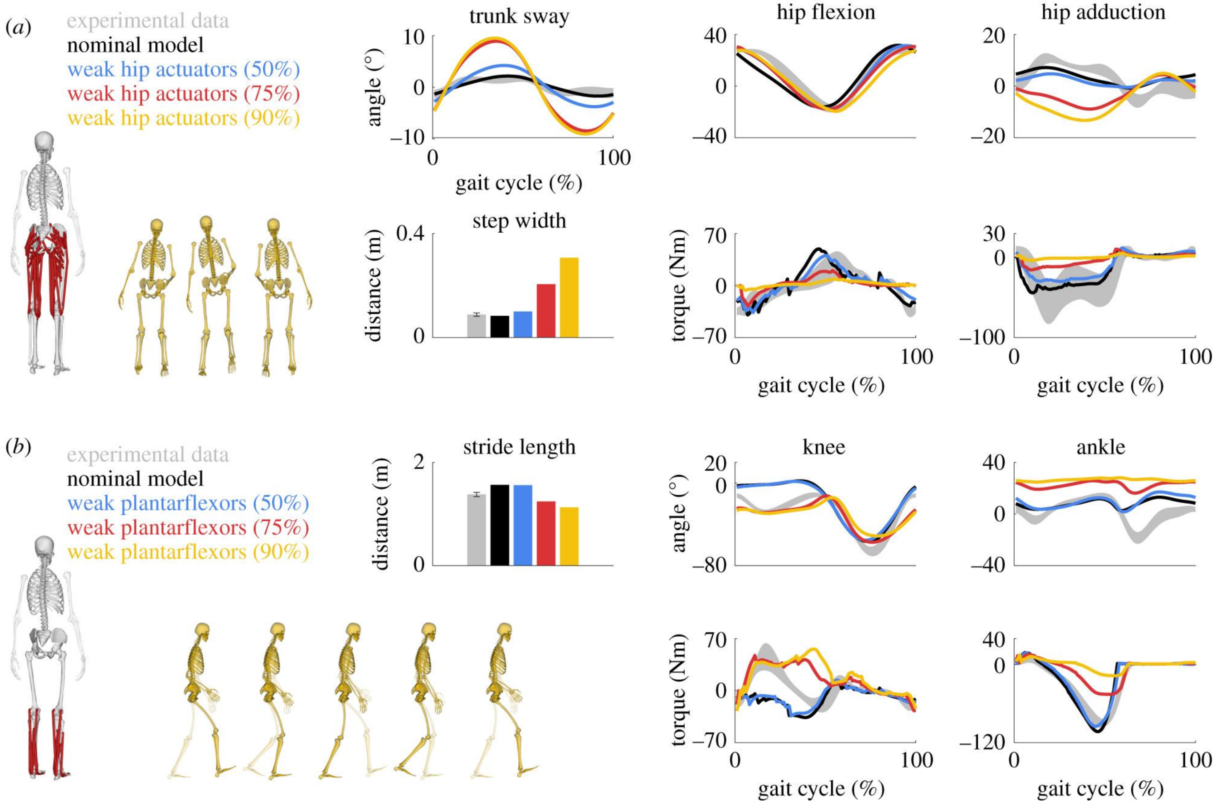
Maximize jump height with joint-torque control by learning pose-torque relationships

Compared to using torque limits that are independent of pose

Image source: Jiang *et al.*, 2019

Prediction

If the objective functions are known, we can do predictive simulation



Falisse *et al.*, 2019

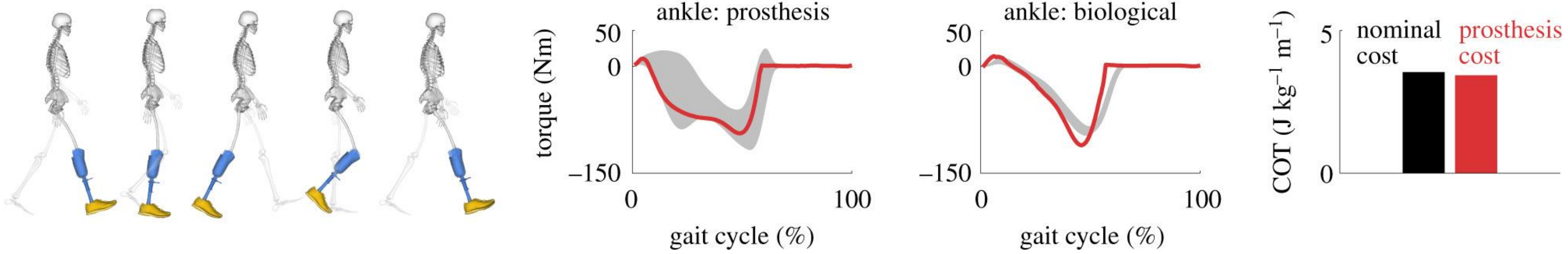
Minimize

- Metabolic energy expenditure
- Muscle activity
- Joint accelerations
- Passive torques
- Arm excitations

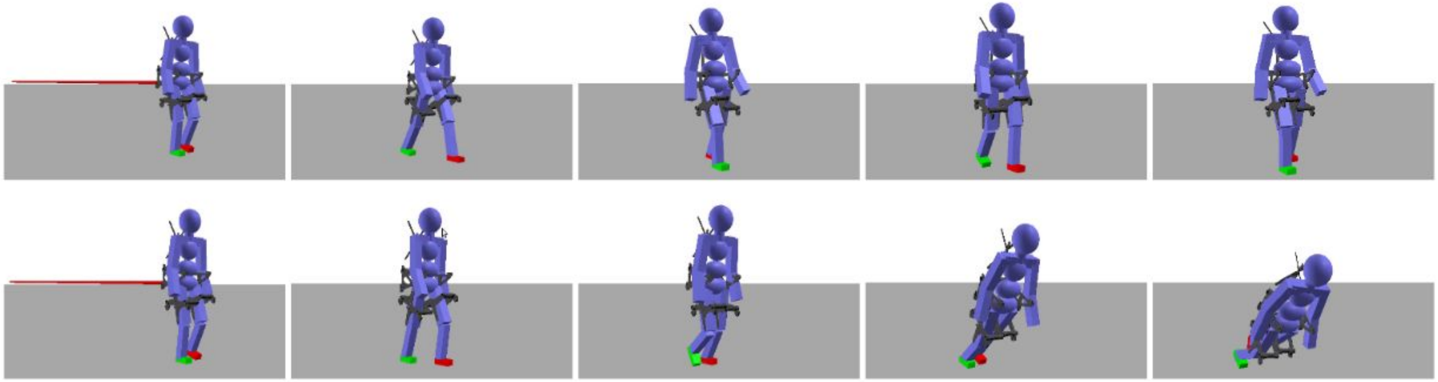
to predict walking

Image source: Falisse *et al.*, 2019

Design

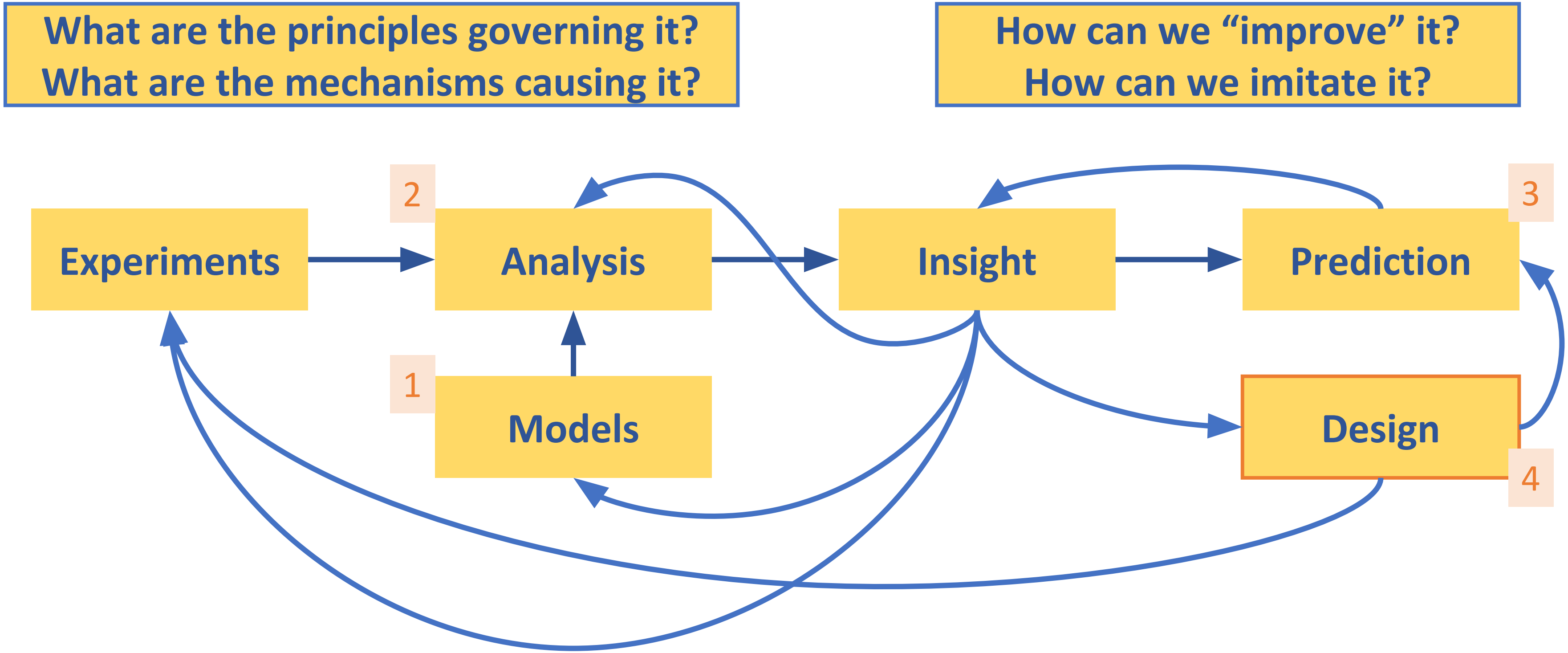


Falisse *et al.*, 2019



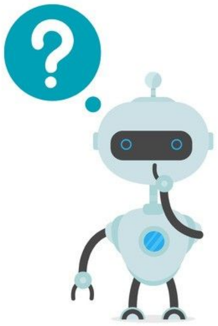
Kumar *et al.*, 2019

Some questions about human movement



Thank you

Questions?



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Record of the discussion for future reference

Comment from Oussama:

Humans are slow at closing the sensing loop but good at prediction,

Comment from Gabriela

Motion primitives can help get there

Comment from Oussama

Yes like playing tennis