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## Case Studies Nonlinear Optimization

# Open Cast Mining

Midterm Presentation

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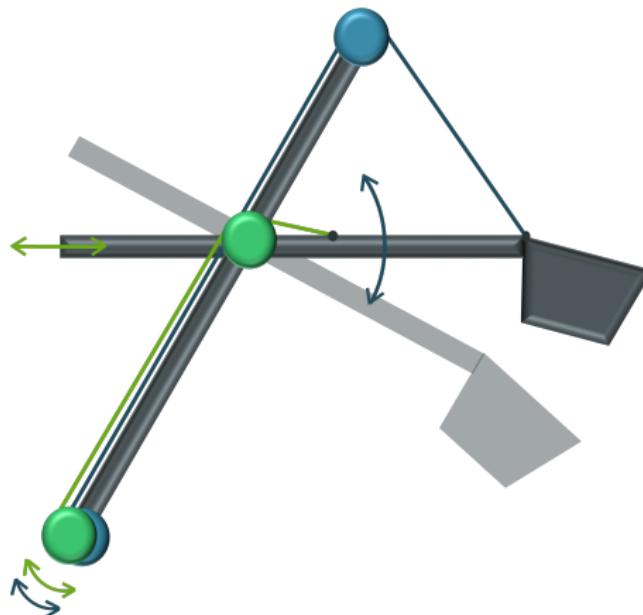
4 Summary



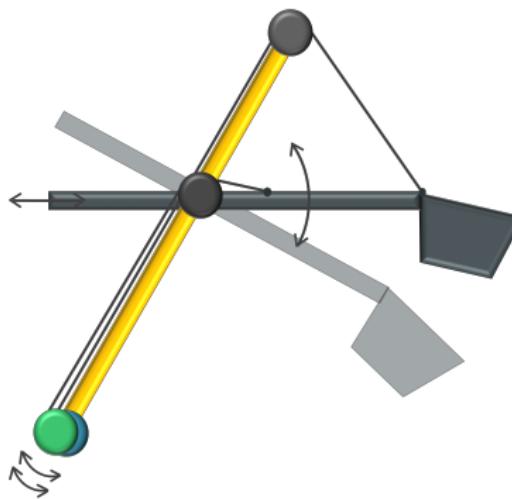
originally posted to Flickr by FAndrey at <http://flickr.com/photos/43301444@N06/4141786255>

- Goal: **optimization of model parameters**
- Models of technical system = physical properties + control properties

# Problem Setting

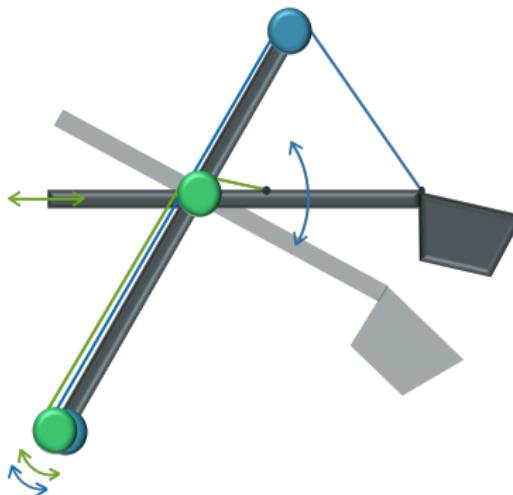


# Problem Setting



- arm element fixed to base
- cannot be moved w.r.t. the base

# Problem Setting



- green shovel motion **back and forth**
- blue shovel motion **up and down**

# Main Problems

## 1. Physical Modelling

- Modelling rope properties
- Determining information needed for calibration of model

## 2. Parameter Optimization

- Optimizing parameters for a complex, unknown model (black box)

# Physical Modelling

Why?

Building an accurate  
model



Good description of  
the effects of control  
and motion

To consider:

- Friction in cable reels
- Deformation of ropes
- etc.

# Parameter Optimization

What are parameters?

- Friction coefficients
- Mass
- Inertia

Why?

Accurate and realistic  
parameters



Better prediction and  
planning of motion

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# Lagrange Formalism

Method to describe dynamics of an accelerated system

T kinetic energy

V potentials

F non-conservative external forces

r points of actions of forces

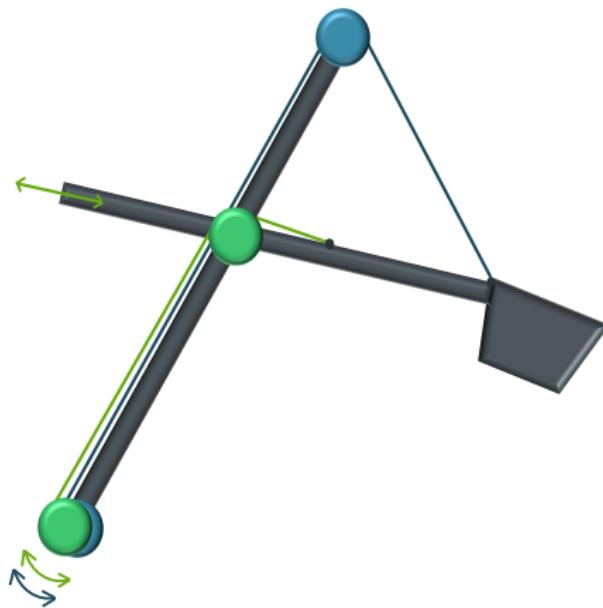
q free variables

Q generalized forces

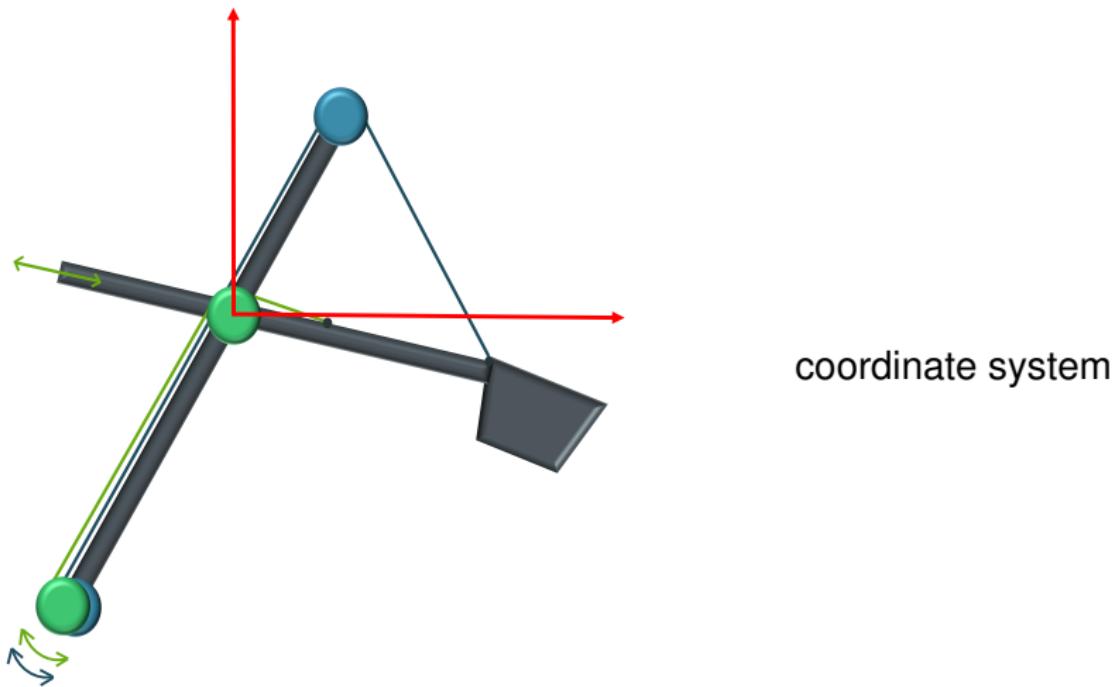
$$\frac{d}{dt} \left( \frac{\partial T}{\partial \dot{q}_i} \right) - \frac{\partial T}{\partial q_i} + \frac{\partial V}{\partial q_i} = Q_i$$

$$Q = \left( \frac{\partial r}{\partial q} \right)^T F$$

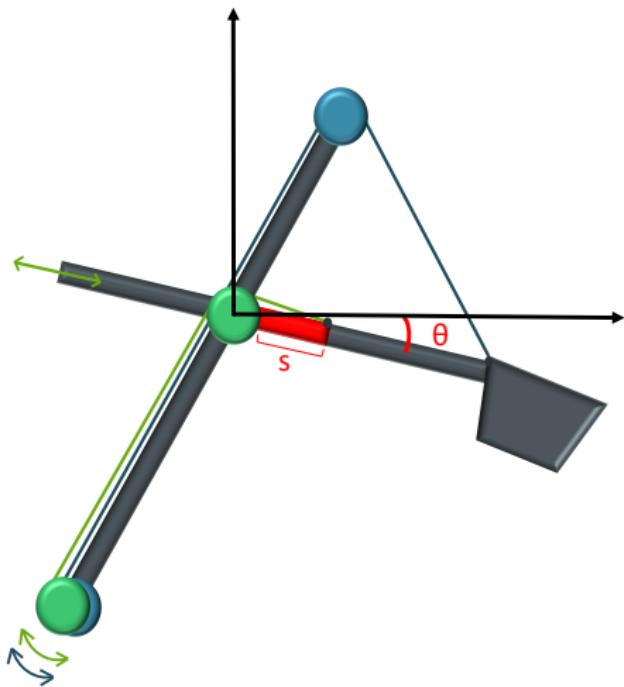
# Physical Model of Excavator



# Physical Model of Excavator



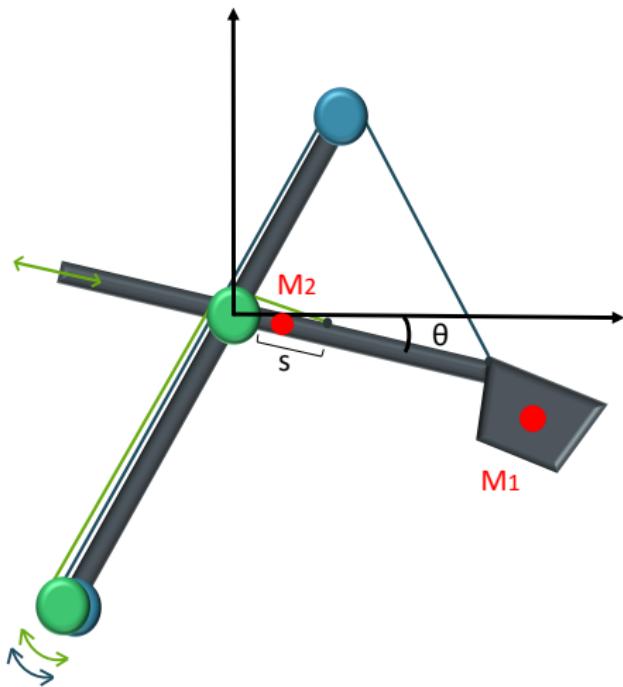
# Physical Model of Excavator



degrees of freedom

- length  $s$
- tilt angle  $\theta$

# Physical Model of Excavator



movable centers of  
gravity of

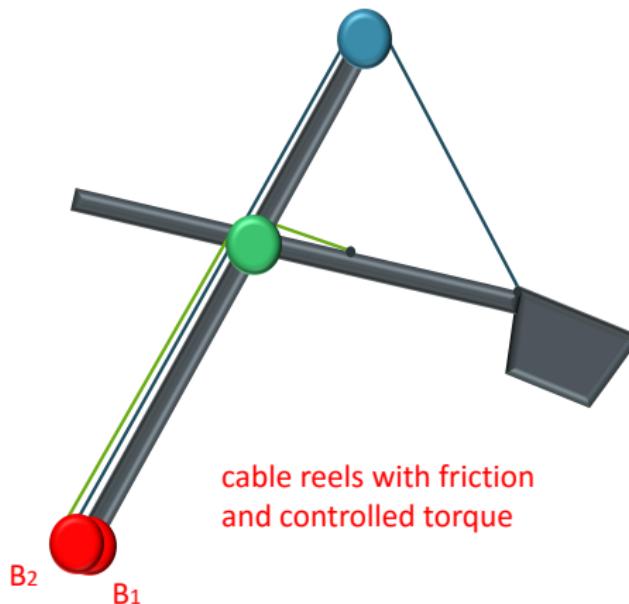
- shovel  $M_1$
- arm  $M_2$

# Physical Model of Excavator

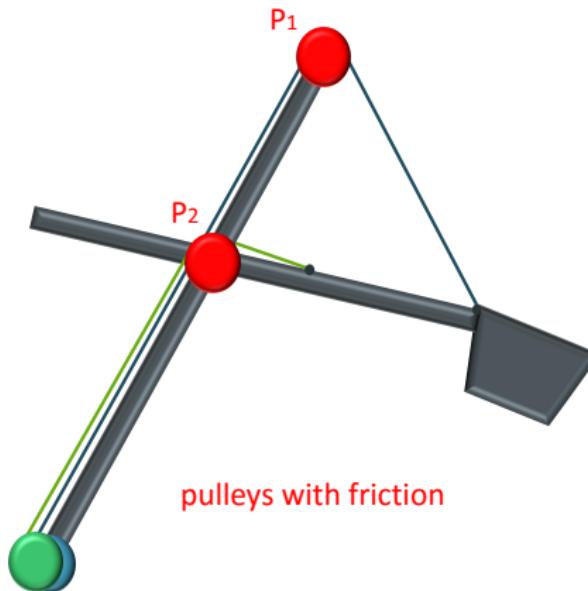
Assumptions to the model:

- no mass for the ropes
- shovel as point mass
- no slack/friction between ropes and cable reels

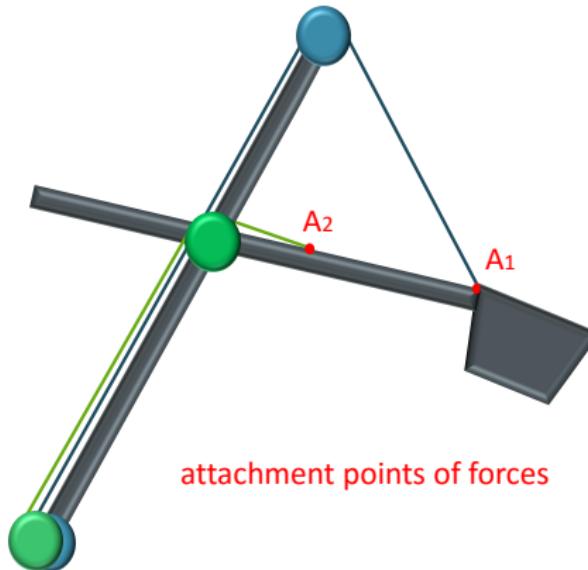
# Involved Forces



# Involved Forces



# Involved Forces



# Lagrange Formalism

$$\frac{d}{dt} \left( \frac{\partial T}{\partial \dot{s}} \right) - \frac{\partial T}{\partial s} + \frac{\partial V}{\partial s} = Q_s$$

$$\frac{d}{dt} \left( \frac{\partial T}{\partial \dot{\theta}} \right) - \frac{\partial T}{\partial \theta} + \frac{\partial V}{\partial \theta} = Q_\theta$$

## Resulting ODE

Second order ODE from Lagrange Formalism:

$$A(x, p) \begin{pmatrix} \ddot{s} \\ \ddot{\theta} \end{pmatrix} = b(x, u, p)$$

Transformed into first order ODE:

$$\frac{d}{dt} \begin{pmatrix} s \\ \theta \\ \dot{s} \\ \dot{\theta} \end{pmatrix} = \begin{pmatrix} \dot{s} \\ \dot{\theta} \\ A^{-1}(x, p)b(x, u, p) \end{pmatrix} = f(x, u, p)$$

state  $x = (s, \theta, \dot{s}, \dot{\theta})^T$

control  $u = (\tau_1, \tau_2)^T$

parameters  $p = (p_1, \dots, p_k)^T$

## Discretization of the ODE

Discretize time interval:

$$[0, T] \rightarrow \{0 = t_0, t_1, \dots, t_{m-1}, t_m = T\}$$

Discretize state and control:

$$x_n = x(t_n)$$

$$u_n = u(t_n)$$

## Discretization of the ODE

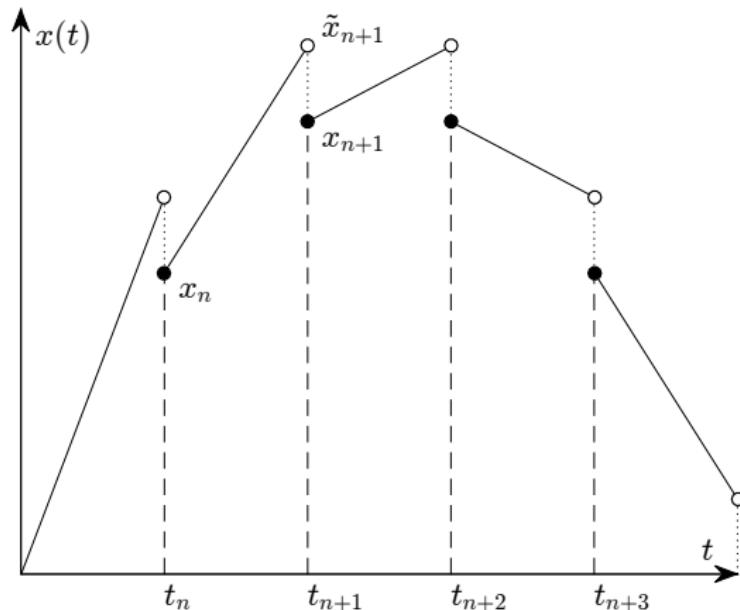
Explicit Euler for every time step  $h_n = t_{n+1} - t_n$ :

$$x_{n+1} \approx \tilde{x}_{n+1} = x_n + h_n f(x_n, u_n, p)$$

Discrete constraint:

$$0 = x_{n+1} - \tilde{x}_{n+1} \quad \forall n = 0, \dots, m-1$$

# Discretization of the ODE



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# Parameters

Examples:

- Friction coefficients  $\mu_{B_1}, \mu_{B_2}, \mu_{P_1}, \mu_{P_2}$
- masses  $M_1, M_2$
- inertia  $I_{B_1}, I_{B_2}, I_{P_1}, I_{P_2}$

Why do we need parameter optimization?

- hard to measure
- may change over time

## Blackbox Model

- contains a realistic model from Siemens
- confidential information

tba

# Parameter Optimization

- black box  $\Rightarrow$  derivative-free optimization
- need own model for testing

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# Results

