Computational motor control and learning: *a game theoretic approach*

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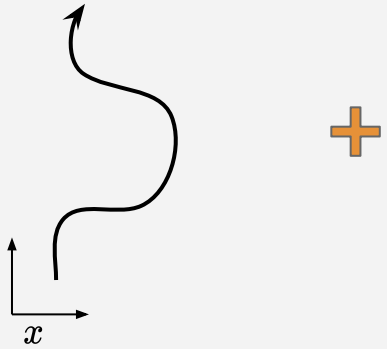
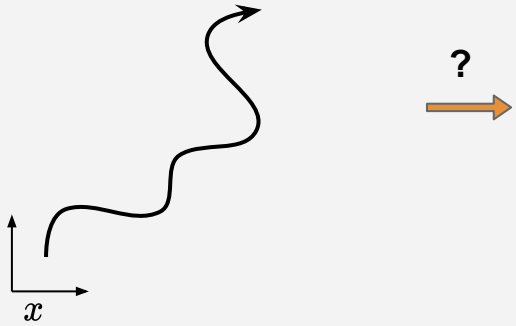
Motivation: Multi-agent Dynamics

Dynamical system $\dot{x} = f(x, u_1, u_2)$

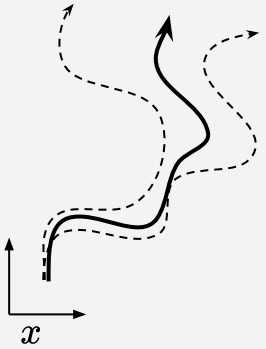
Player 1's optimal trajectory



Player 2's optimal trajectory



Coupled dynamics?



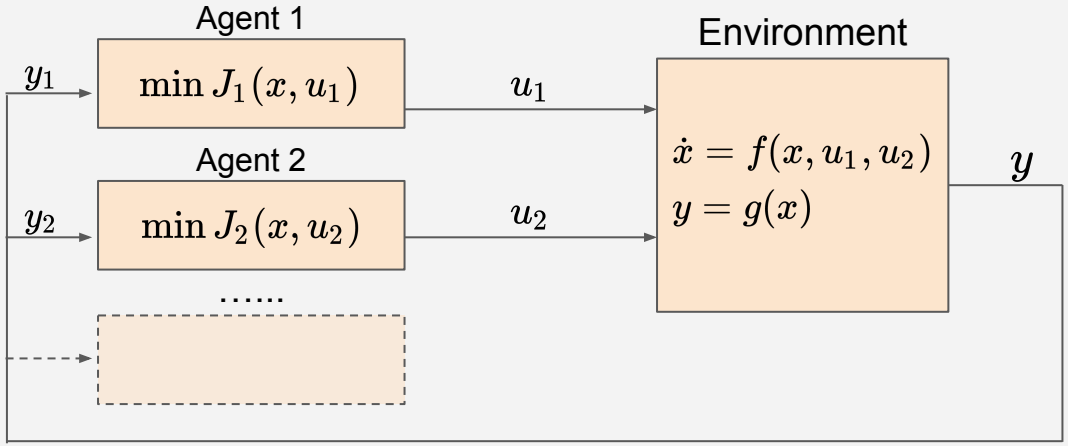
Mathematical Model

State: $x \in \mathcal{X} = \mathbb{R}^n$

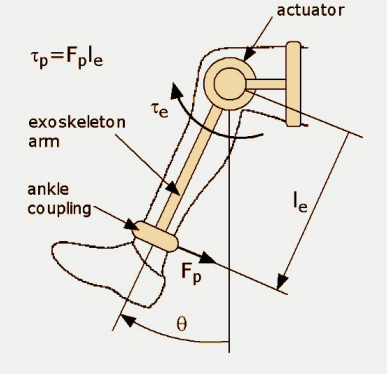
Actions: $u_i \in \mathcal{U}_i = \mathbb{R}^{m_i}$

Observations: $y_i \in \mathbb{R}^d$

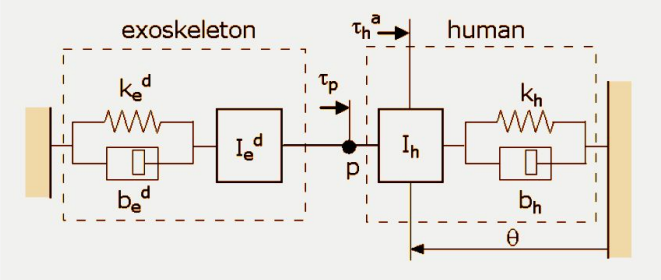
Costs: $J_i : \mathcal{X} \times \mathcal{U}_i \to \mathbb{R}$

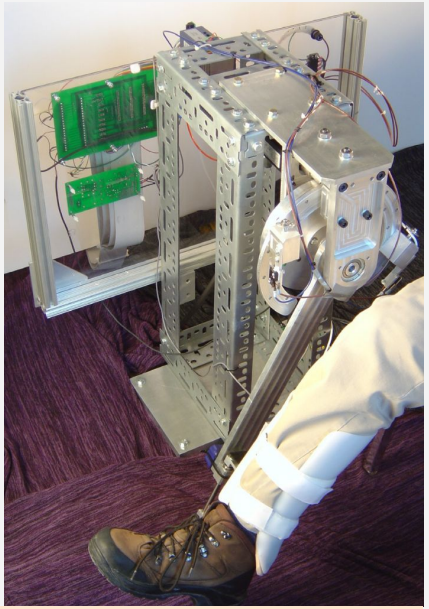


Mechanical Human/Agent Example



$$\dot{x} = f(x, u_1, u_2)$$





Reed, Peshkin (2008)

Prior work

Adaptive Control *(Slotine, 1980s …)*

Learns unknown system parameters

Inverse optimal control (*Levine, Abbeel, Ng, etc, 2000s …)*

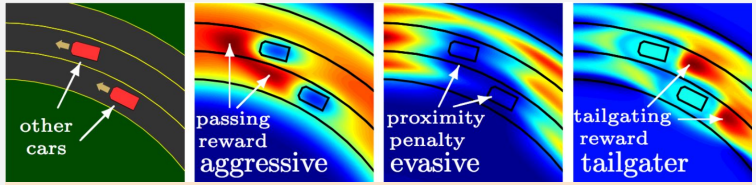
Learns control law from trajectory

Dynamic noncooperative games *(Başar, Olser, 1999 …)*

Theoretical framework for analyzing dynamic games

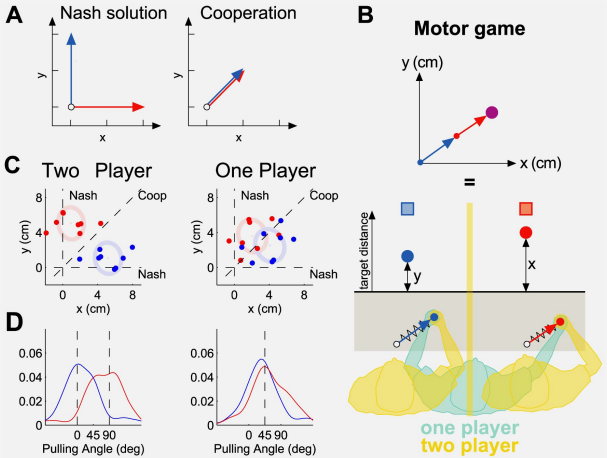
Motor games (*Wolpert, 2009 …)*

Cooperation vs nash equilibrium in motor games



Levine, Vladlen (2012)

Lavretsky et. al (2003)



Braun, Pedro, Wolpert (2009)

Our contribution

- Dynamical system

  $$\dot{x} = f(x, u_1, u_2, \cdots)$$

- Non-cooperative agents

  $$\min J_1, \min J_2, \cdots$$

- Online adaptive controllers

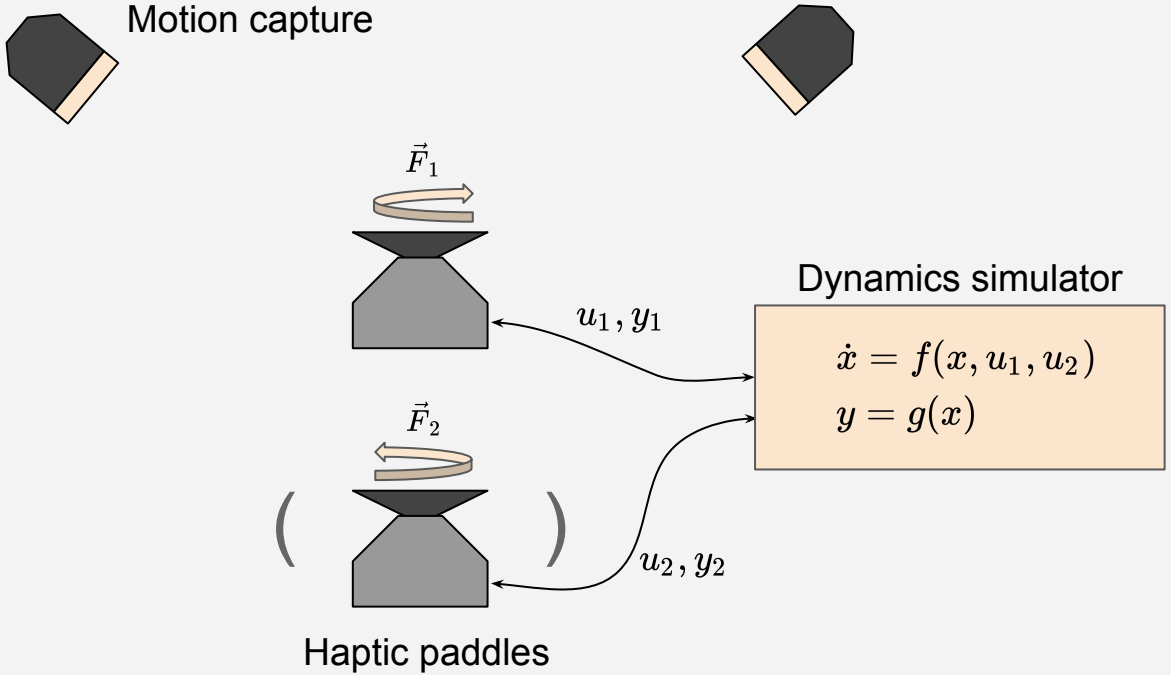
  Learns unknown parameters/control law of other agents

- Game theoretic insights

  Nash equilibria, stackelberg equilibria, information patterns…

- Experimental validation of theory

Experimental setup



Questions?

References

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Braun, Daniel A., Pedro A. Ortega, and Daniel M. Wolpert. "Nash equilibria in multi-agent motor interactions." *PLoS computational biology* 5, no. 8 (2009): e1000468.

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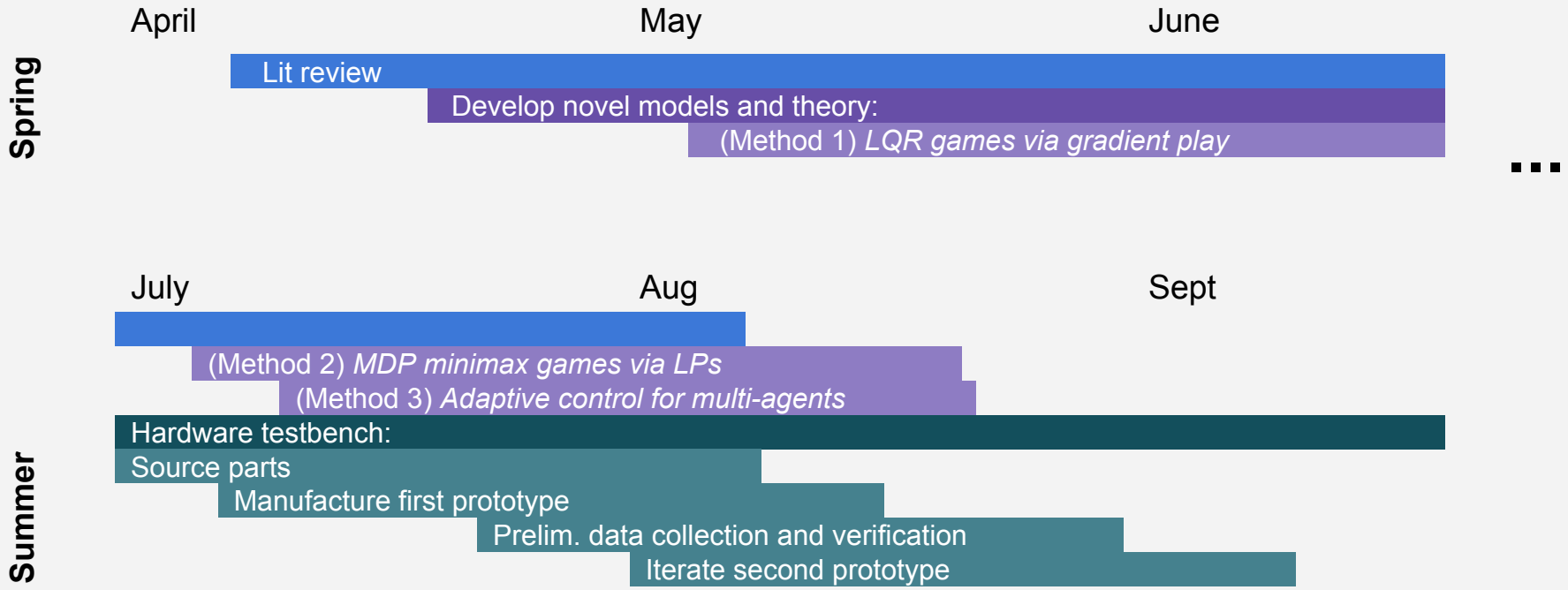
Slotine, Jean-Jacques E., and Weiping Li. *Applied nonlinear control*. Vol. 199, no. 1. Englewood Cliffs, NJ: Prentice hall, 1991.

Project Timeline



Summer deliverables

✓ Completed
◎ In progress

Theory

- **LQR games via gradient play**
  - Convergence guarantees ✓
  - Prelim simulations ✓
- **MDP minimax games**
  - Problem formulation with constraints ✓
  - Prelim. simulations ◎
- **Adaptive control with multi-agent SI**
  - *Novel* multi-agent approach ◎
  - Inverse optimal control
  - Shift nash of cost minimizing agents
  - Prelim. simulations

Experimental

- **Modular testbench:** series-elastic haptic paddle
  - Design first prototype ✓
  - Source parts ✓
  - Print and assemble ◎
  - Simple PID controller ◎
- **Validation experiments**:
  - Adaptive controller detects sys. params. ◎
  - Reproduce Wolpert motor games
- (Stretch goal) **Novel experiments**
  - Characterize nash of two-player dynamic games
  - Inverse reinforcement learning via adaptive control
- (Stretch goal) **Extend modular hardware setup**
  - Hopper games
  - Balance games