Task-Based Assistance for Software-Enabled Biomedical Devices

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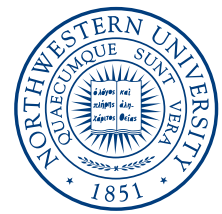

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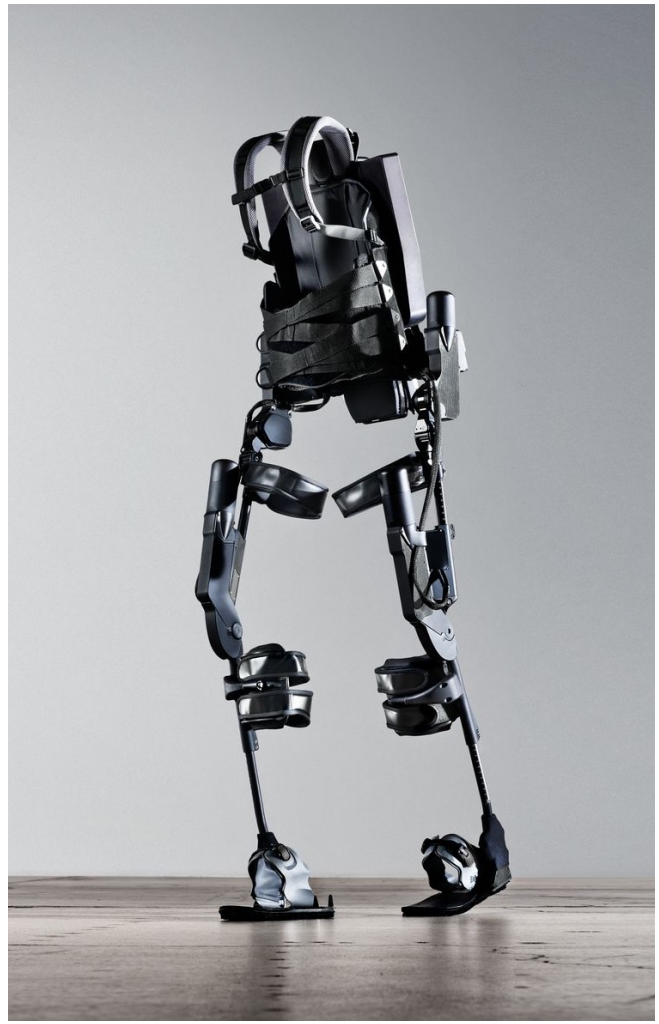
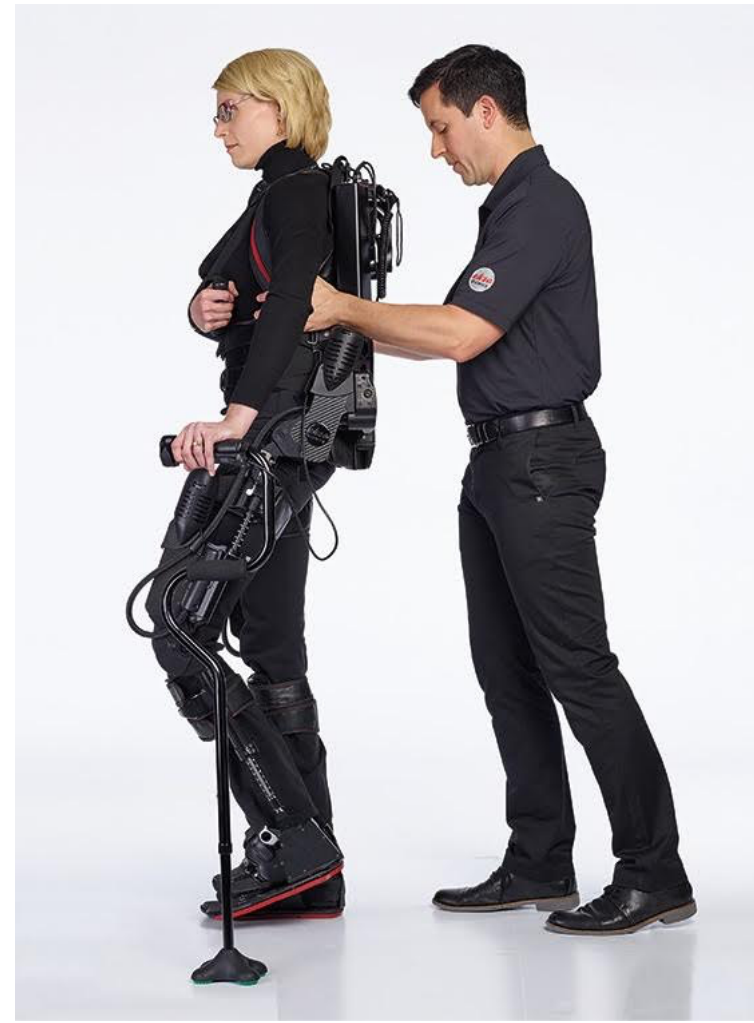
Task-Aware Assistance





Ekso Bionics Exoskeleton

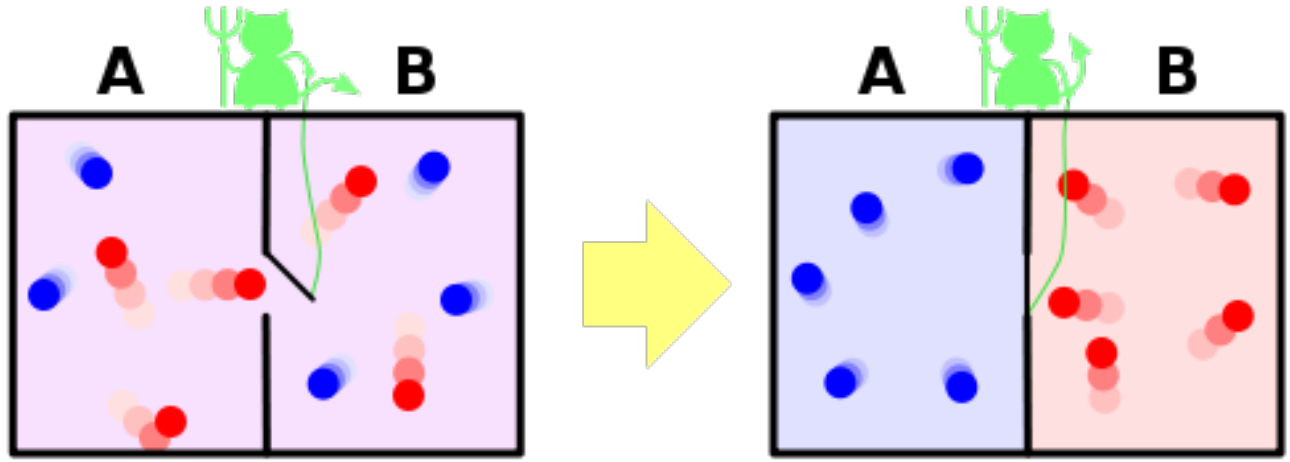
How should we design task-based assistive algorithms?

Task-Based Interfaces

Collaboration with Ekso Bionics

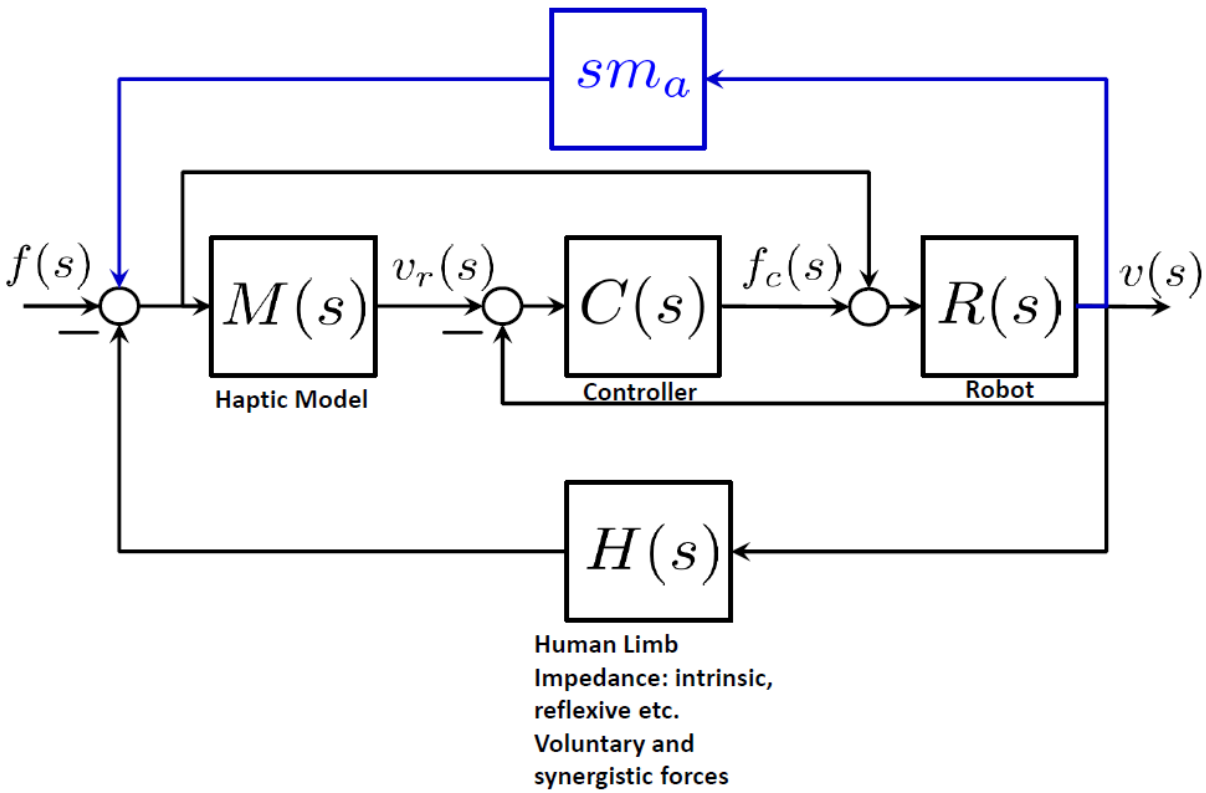
Interfaces and Maxwell's Demon

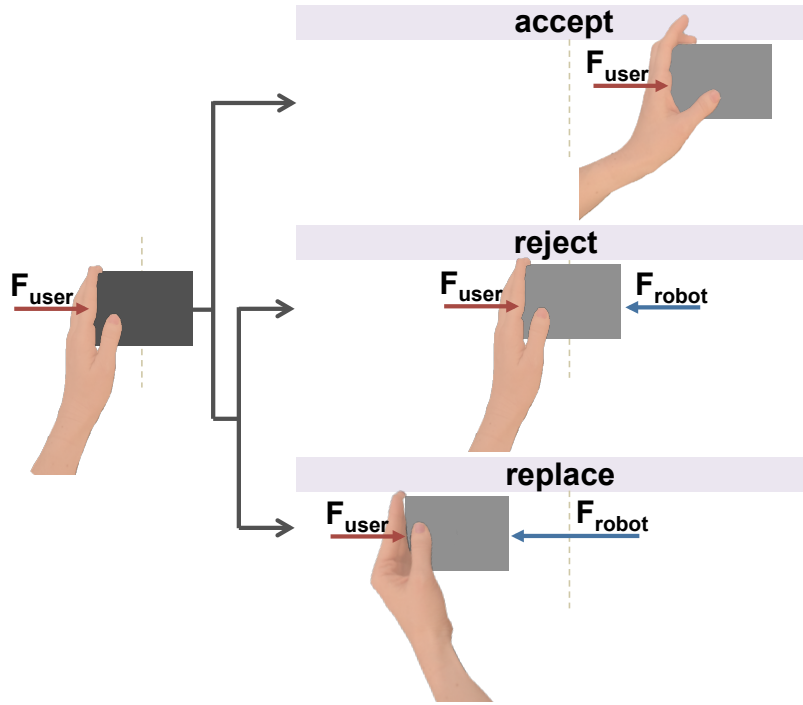
- How do we use control to create a task-specific interface?
- The Maxwell's Demon Paradox considers using a switch to segregate a fluid into a hot liquid and a cool liquid



- We use this as an interface principle; whenever someone's input is in the same 'direction' as a control vector, we apply the user control to the system. Whenever their input is not in that half plane, we reject the input. We call this the Maxwell's Demon Algorithm (MDA).

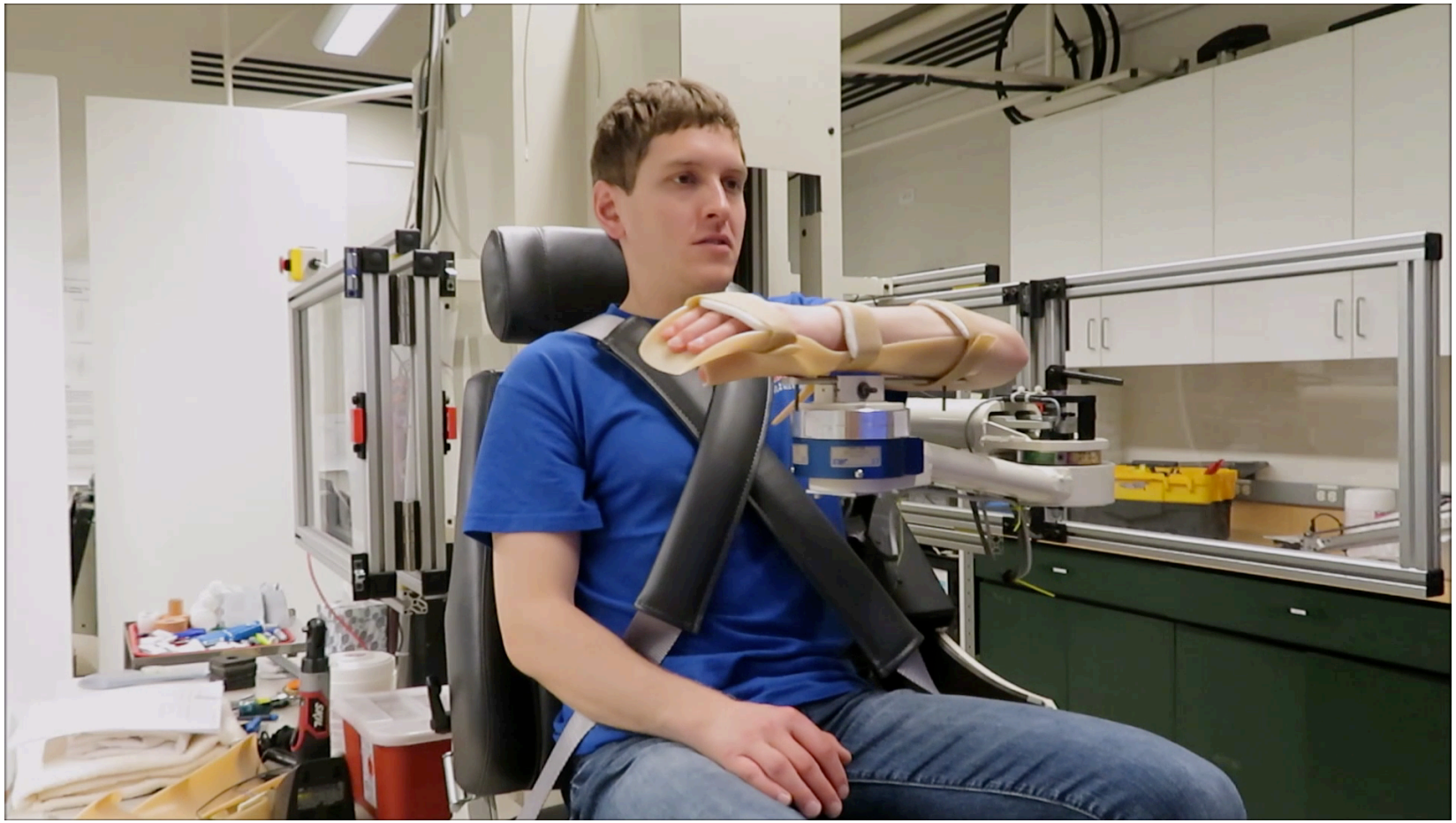
NACT-3D Experiment





- f(s) is included in control of NACT-3D based on MDA Boolean variable
- Protocol:
  - 53 subjects completed two sessions one week apart
  - Each session was 30 trails either with MDA or without it
  - Three groups (NoAssist➔NoAssist,NoAssist➔Assist, Assist➔NoAssist)

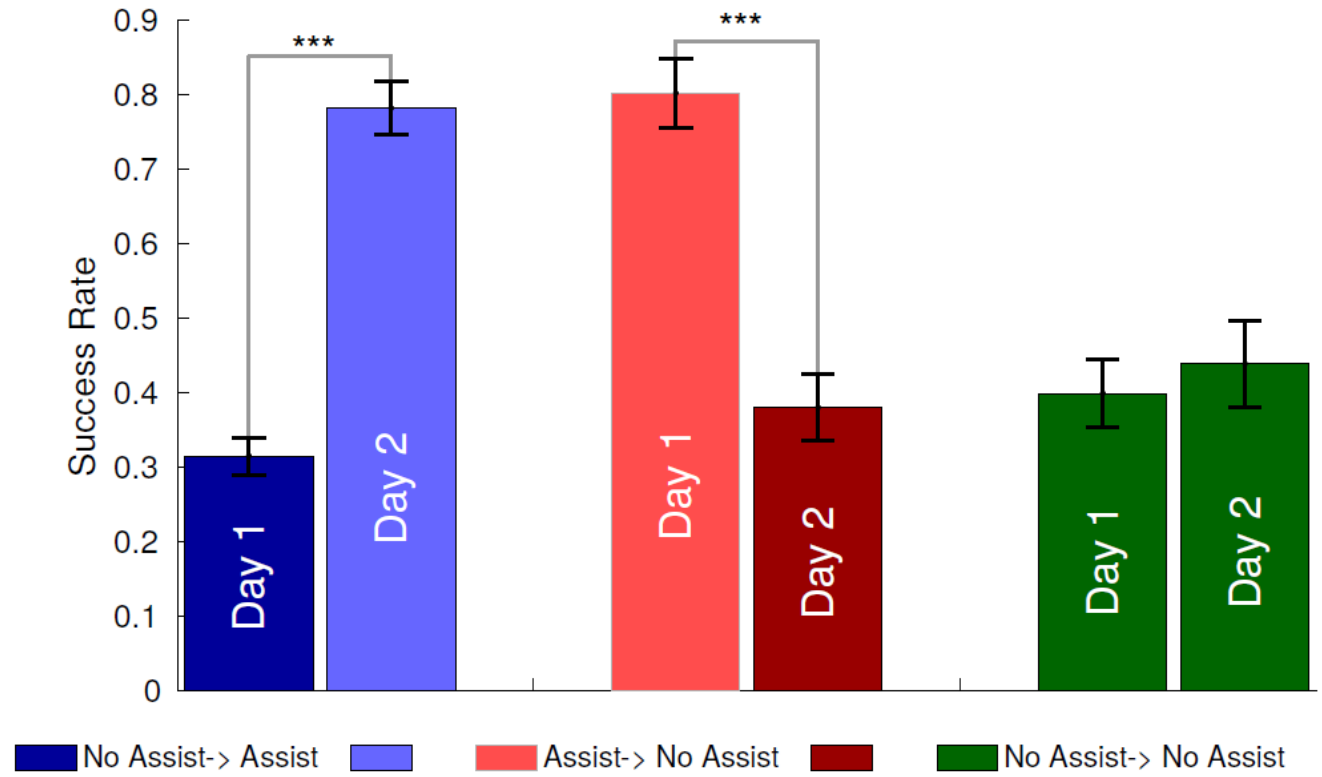
Interfaces and Maxwell's Demon



- We tried this with several interfaces, including touchscreen, haptic devices, and clinical research robots
- Works very well for "drive by wire" interfaces like touch screens
- Works, but less well, when rejection of input is physically interactive

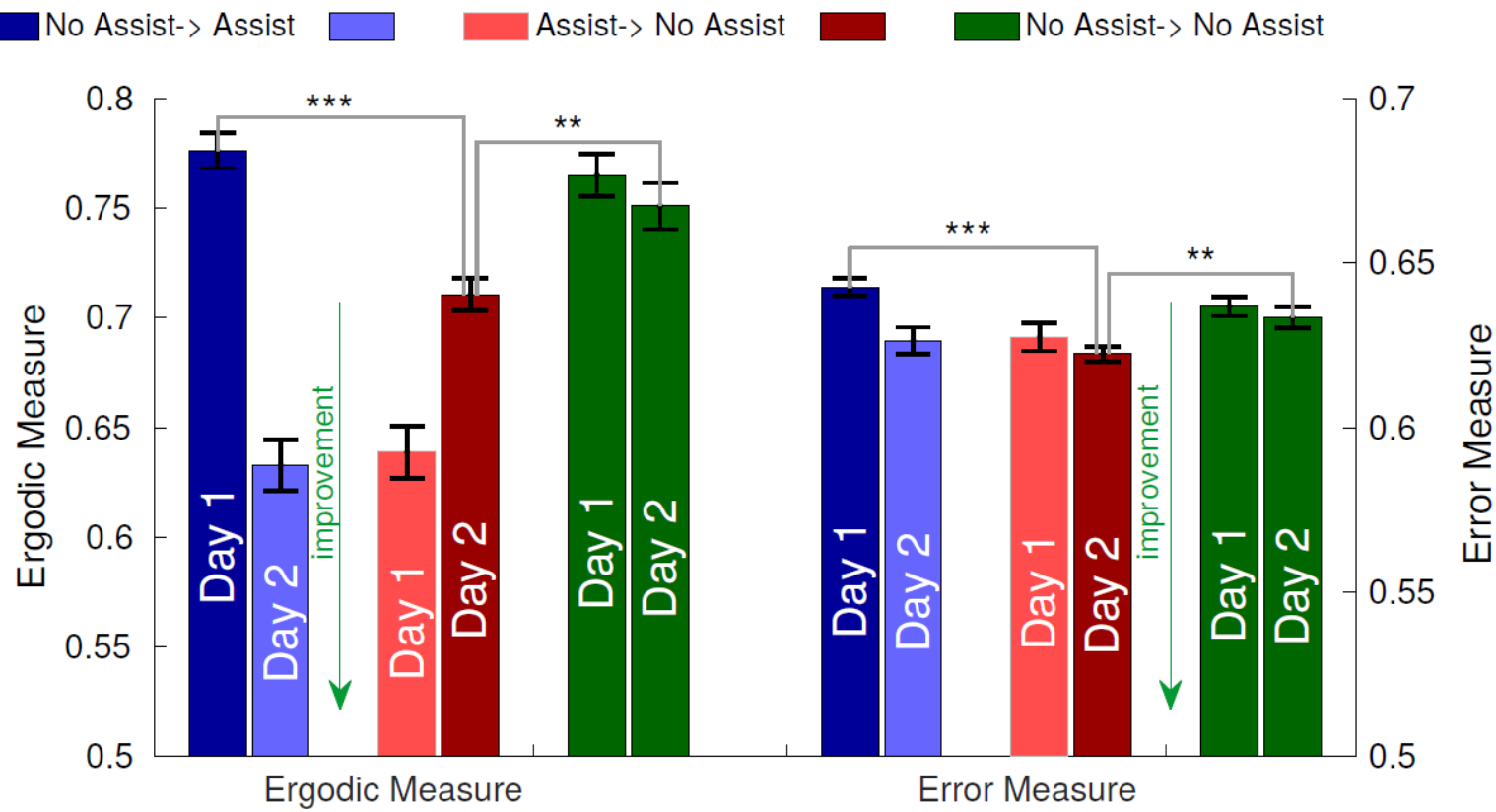
K. Fitzsimons, E. Tzorakoleftherakis, and T. D. Murphey, "Optimal human-in-the-loop interfaces based on Maxwell's demon," in *American Controls Conf. (ACC)*, 2016.

Results: Success Rate



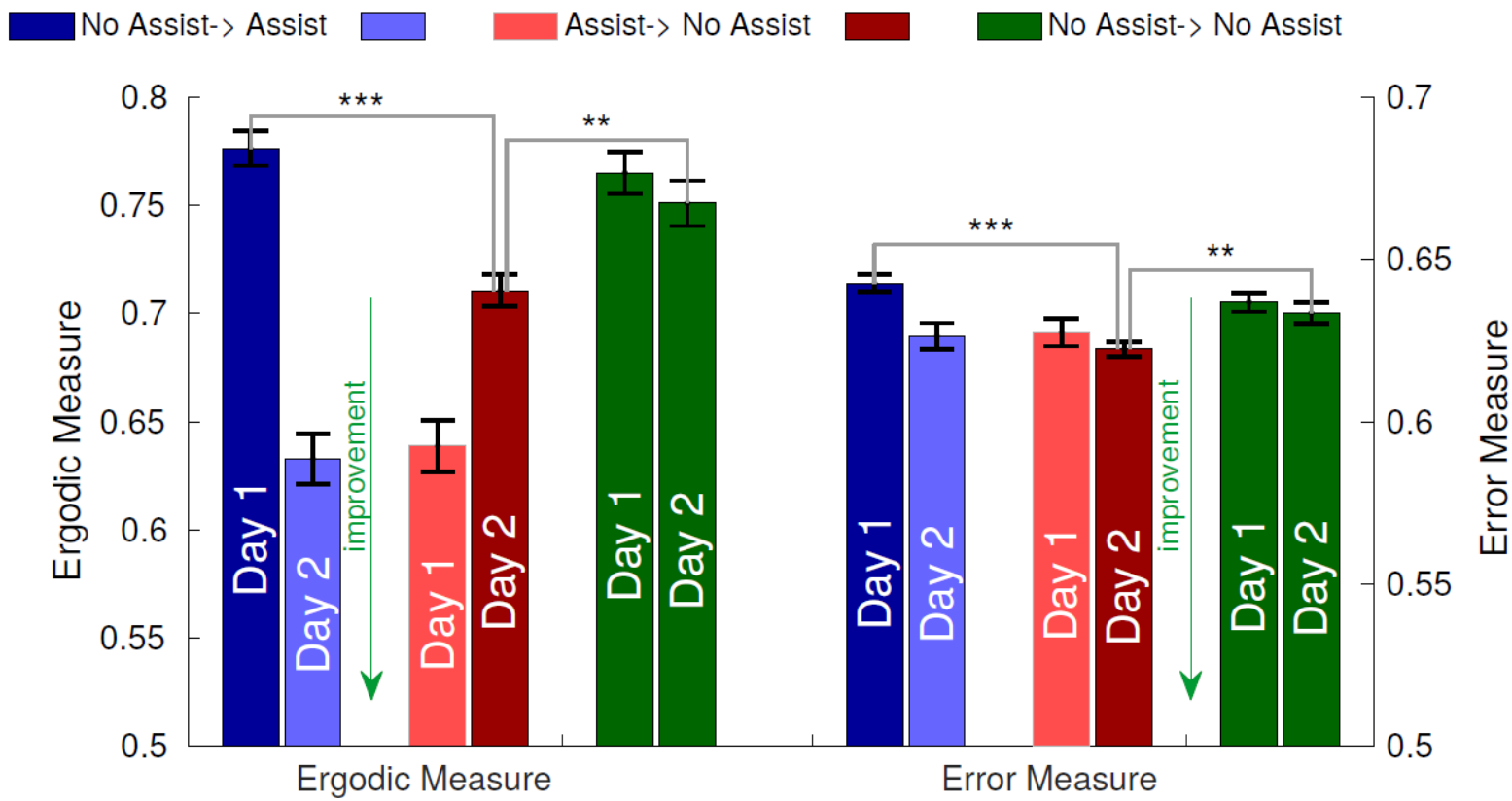
- MDA assistance has large impact on success rate
- MDA assistance also has large impact on balance time and time to success

Results: Ergodic/RMS Measures



- MDA improved NoAssist Day 2 outcomes
  - relative to the NoAssist to NoAssist group
  - using both RMS error and the ergodic measure.

Results: Ergodic/RMS Measures

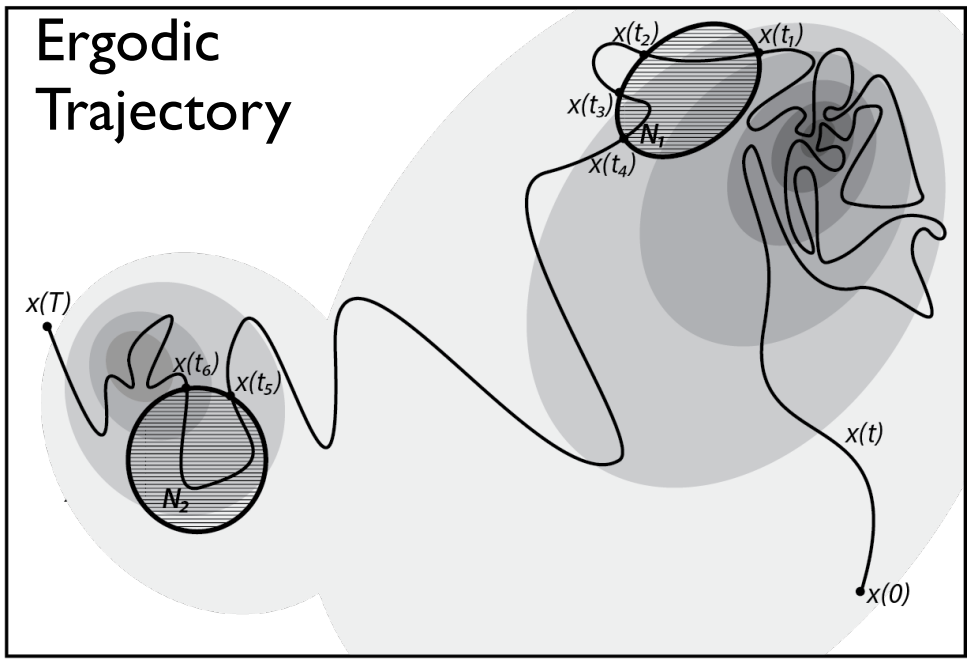


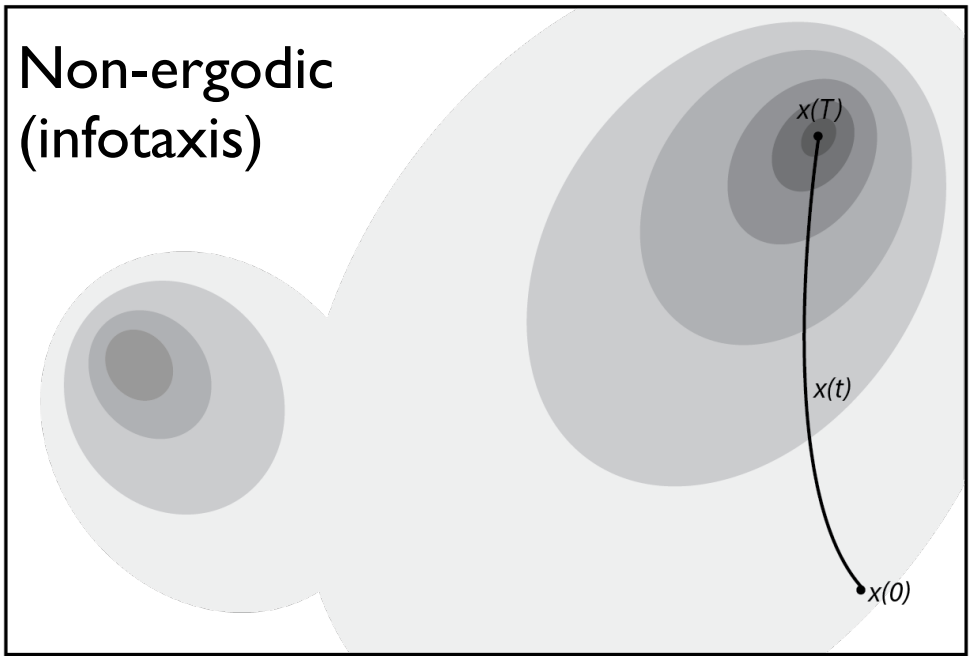
- RMS error *did not* detect the removal of assistance in Day 2, but the ergodic measure did
- ANOVA showed ***no*** main effects or interaction effects on RMS error
  - Interpretation: error does not allow one to discriminate day or group in this study

Ergodic Processes

Ergodicity can be used to relate the time-averaged behavior of a trajectory to the spatial statistics of a the expected information distribution.

One can think of ergodicity as the generalization of Kullback-Leibler divergence to trajectories.





- Ergodicity can be used as a goal for a system, allowing one to specify a system's behavior in terms of its spatial statistics instead of its temporal behavior.

G. Mathew and I. Mezic, "Metrics for ergodicity and design of ergodic dynamics for multi-agent systems," *Physica D: Nonlinear Phenomena*, vol 240, no. 4-5, pp. 432-442, 2011.

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Conclusions

- Traditional robots focus on moving to achieve a particular state
- During assistance, robots should potentially move only to negate bad decisions, rather than move for a subject
- Measuring effectiveness depends on measures, and ergodicity—as a measure of information—appears to outperform state error in detecting assistance and learning
- Other results, including integrating machine learning into task-based assistance, can be seen at our poster