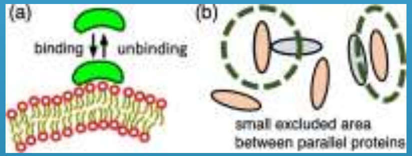
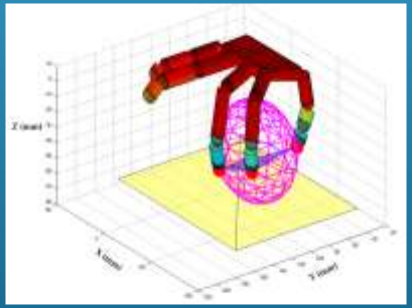
Bio-inspired Robotics: Adaptive Object Handling Through Cellular Mechanics and Artificial Intelligence

Background and Current Goals

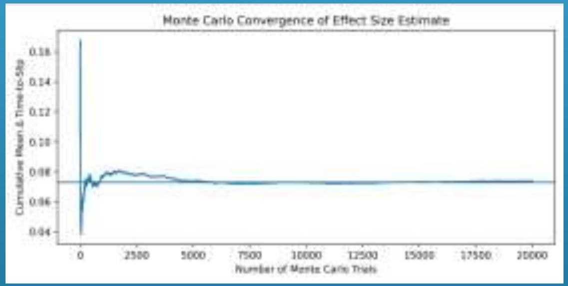




- Cells use a mechanism of binding and unbinding depending on force displacement. Allows for adaptable grip strength
- Fixed forced grippers use predefined parameters, leading to crushing the object or letting the object slip due to a lack of force
- The goal is to instate real-time adaptation inspired by cells into adaptive robotic grippers

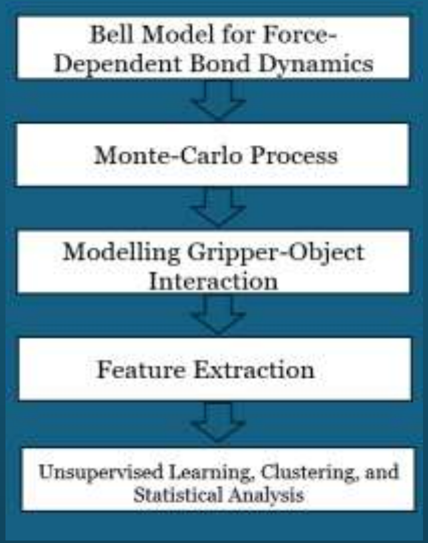
Statistical Analysis and Results

- Across 20,000 Monte Carlo trials, the adaptive controller increased time-to-slip relative to baseline methods. Nonparametric permutation testing and bootstrap confidence intervals confirmed statistical robustness.



- The convergence analysis shows that the estimated effect size stabilizes as simulation count increases, indicating that results are not driven by small-sample variability.

Methods and Project Design



- Developed a simulation-based clutch-inspired control framework using Bell model force-dependent bond dynamics and stochastic Monte Carlo state transitions.
- Modeled gripper–object interaction via series spring mechanics and evaluated performance across 20,000 trials using time-to-slip as the primary stability metric.

Conclusion and Future Work

- The clutch-inspired adaptive controller significantly improved time-to-slip relative to fixed-force control and demonstrates that stochastic adhesion dynamics can be translated into structured robotic force regulation under mechanical uncertainty

Comparison	Mean Δ Time-to-Slip	95% CI	p-value
Adaptive vs Fixed	+0.073	[0.048, 0.099]	5×10^-5
Adaptive vs PID	+0.021	[-0.003, 0.046]	0.06

- Future work will implement the framework on hardware platforms with real-time sensing and extend it to soft robotic manipulation and dynamic material classification through closed-loop mechanical property estimation.