Asian Deans' Forum 2026

THE RISING STARS

Women in Engineering Workshop

SEP 13 - 15 | HKUST, Hong Kong

THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

DEPARTMENT OF Industrial Engineering & Decision Analytics

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Optimizing Service Operations via LLM-Powered Multi-Agent Simulation

PROBLEM & CHALLENGES

Services Operations Dominate Modern Economics (China, U.S., ...)

- (c.f. Manufacturing) Human-centric: Intensive Interactions

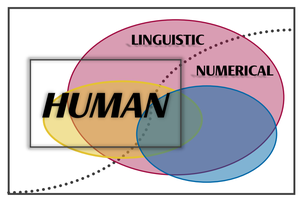
Designer's Decision-Making Problem: **System Design Optimization**

Systems	Supply Chains	Innovation Contests	Online Marketplaces
Designs	Sustainable Policies	Incentive Structures	Operational Levers
Participants	Multi-echelon Players	Contestants	Sellers, Consumers

Generic Task: Design Parameters → Participant Responses → Design Performance

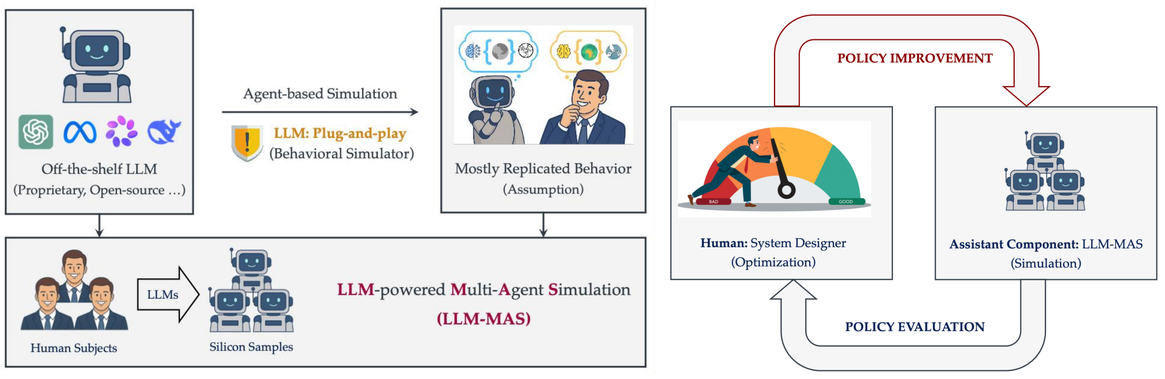
- Capturing **(Human) Behavior** Is Non-trivial!

Empirical Studies	Limited Data, Insufficient Granularity
Lab **Experiments**	Costly, Time-consuming, Hard to Scale
Analytical Models	Idealized Scenarios, Rigid Assumptions
LLM Simulations	Promising (Academia, Industry)



NOVEL FRAMEWORK: LLM-MAS

Our Contributions: Modeling – Algorithm – Empirics



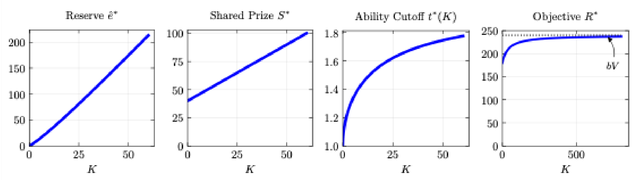
CONTRIBUTION: EMPIRICS

Innovation Contest Design: **Incentive Structure**

- c.f. Winner-Takes-All (WTA)
- Entry Fee, Reserve Threshold, Shared Prize

Traditional Approach: **Lab** Experiment

Traditional Approach: **Game-Theoretic** Analysis



Prize Allocation

$$\begin{cases} (V + NK, 0, \cdots, 0), & \mathcal{I} \neq \emptyset \\ (S^*, \cdots, S^*), & \mathcal{I} = \emptyset \end{cases}$$

$\mathcal{I} = \{i \in [N] : e_i > \hat{e}^*\}$

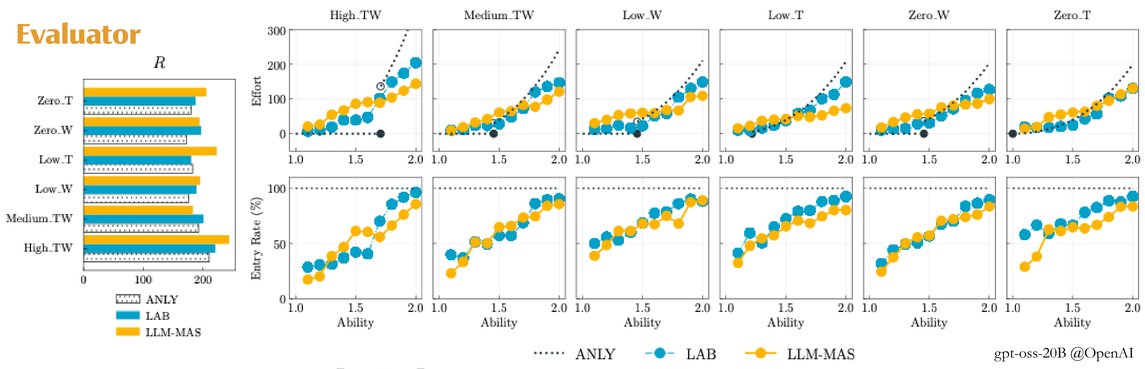
Individual-level Behavior

- Entry Rate 100%
- Low-ability: No, High-ability: Effort

System-level Performance

- Increasing (Limit)

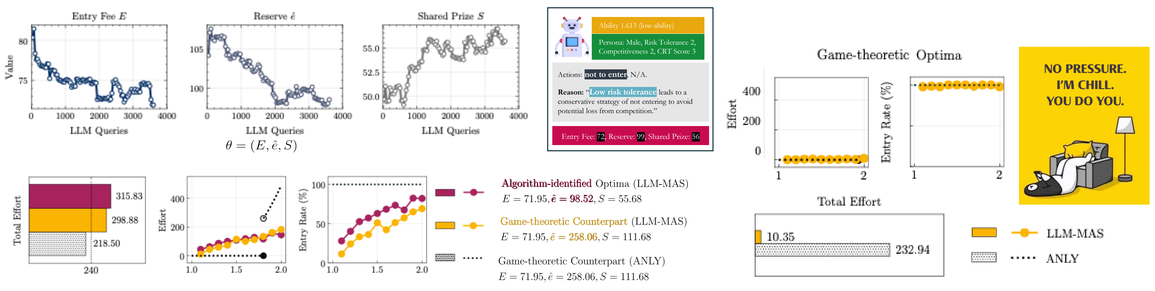
Our Approach: **LLM-MAS**



Explorer

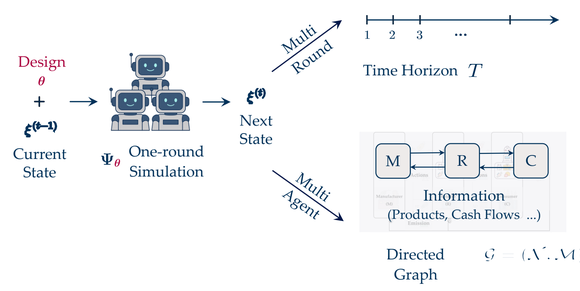
$$\max_{\theta \in \Theta} \mathbb{E}_{\xi \sim \mu_\theta} \left[\sum_{i=1}^{N=12} e_i \right] \qquad \xi = (e_1, \ldots, e_N)$$

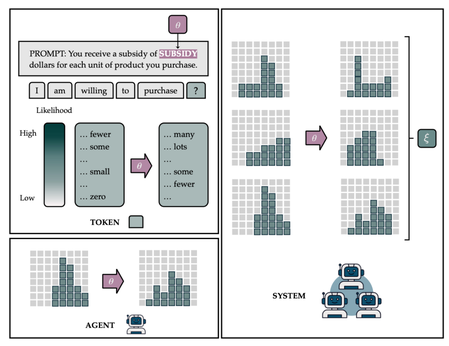
Opt-out of "Rat Race"!



CONTRIBUTION: MODELING

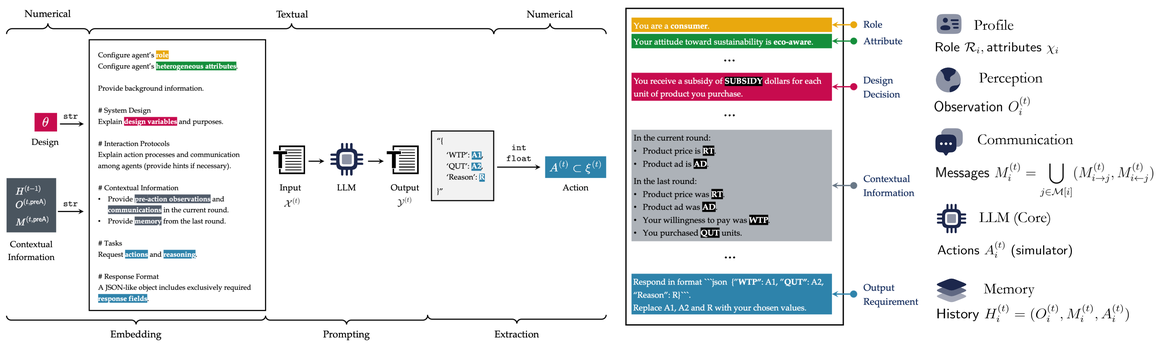
Multi-Round, Multi-Agent Simulation $\langle \mathcal{G}, \Psi_\theta, T \rangle$





LLM Prompting

$$\underbrace{\left(\theta, H^{(t-1)}, O^{(t,\text{preA})}, M^{(t,\text{preA})}\right)}_{\text{contextual information}} \xrightarrow{\text{embedding}} \underbrace{\mathcal{X}^{(t)} \to \text{LLM} \to \mathcal{Y}^{(t)}}_{\text{prompting}} \xrightarrow{\text{extraction}} \underbrace{A^{(t)}}_{\text{action}}$$



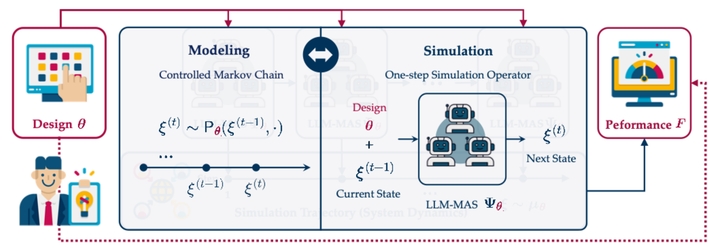
Controlled Markov Chain

- System Dynamics

Stochastic Optimization

- Decision-dependent uncertainty

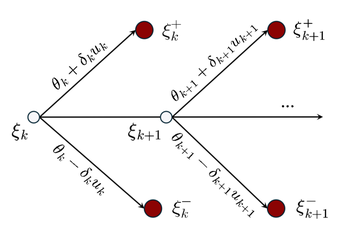
$$\min_{\theta \in \Theta} \left\{ f(\theta) := \mathbb{E}_{\xi \sim \mu_\theta}[F(\theta; \xi)] \right\}$$



CONTRIBUTION: ALGORITHM

On-Trajectory Learning (OTL) Tackles LLM Deep Coupling, High Inference Latency

I. Zeroth-Order Approach



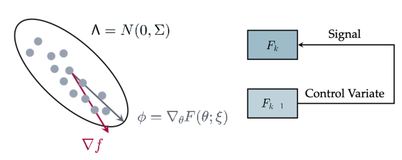
(Random Perturbation) $\begin{cases} u_k \sim N(0, d^{-1} I_d) \\ \xi_k^\pm = \Psi(\xi_k | \theta_k \pm \delta_k u_k) \end{cases}$

(Gradient Estimation) $G_k = G(\theta_k; \xi_k^\pm, u_k, \delta_k)$

(Parameter Update) $\theta_{k+1} = \Pi_\Theta(\theta_k - \eta_k G_k)$

(State Update) $\xi_{k+1} = \Psi(\xi_k | \theta_k)$

II. Variance Reduction



Guided Perturbation $\nabla_\theta F(\theta; \xi) \neq 0$

Residual Feedback $\nabla_\theta F(\theta; \xi) = 0$

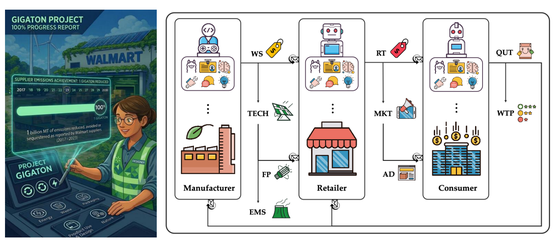
THEORETICAL GUARANTEE

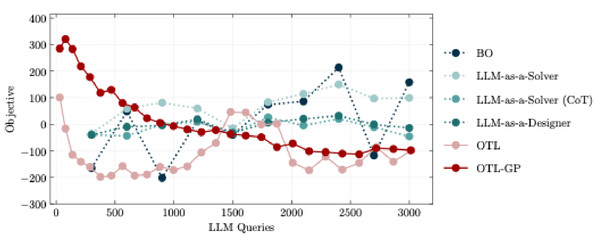
Almost-Sure **Convergence** of **OTL** Iterates $\{\theta_k : k \in \mathbb{N}_+\}, \theta_\infty \in \Theta_0$

A1.	Objective: Lipchitz Continuous Feasible Set: Compact, Convex	A2.	Markov Kernel: Smooth, Geometric Mixing
A3.	Transient Gradient: Bounded	A4.	Poisson Equation Solution: Smooth
A5.	Step-size: Two-timescale		

RESULTS & IMPLICATIONS

Prototyping Example: Walmart's Project Gigaton

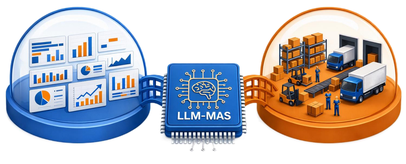




R1. OTL **Outperforms** Baselines!

R2. LLM-MAS **Complements** Traditional Approaches!

FUTURE RESEARCH WORKS



Potential Directions of **LLM-MAS&O**

01.	Refined **Theory**	04.	**Efficient** Deployment
02.	**High-Fidelity** Alignment	05.	**Scalable** Deployment
03.	**Robust** Deployment	06.	Boarder **Applicability**

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