



Tutorial on Advances in Simulation Technology for Web Applications

– *The Web Conf 2023*

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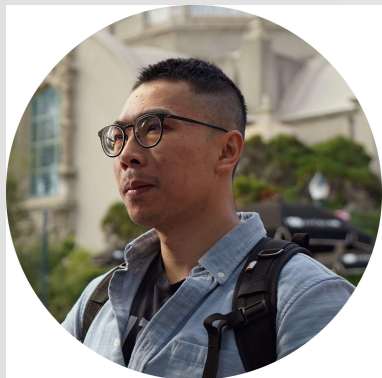
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Tutorial Webpage: <https://foundation4recsys.github.io/Tutorial-WWW23/>

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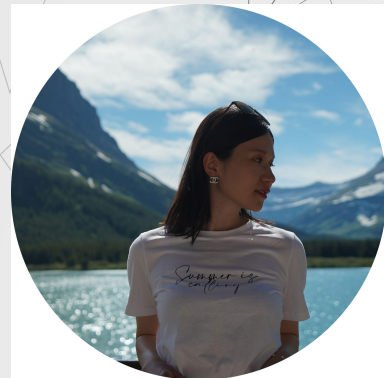
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Opening remark

Motivation, Introduction & Scope

01

Overview

Agent-based Simulation for
Modern Web Applications

02

For Information Retrieval

Web search engine
Conversation System

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For Recommender System

Personalized Recommendation

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For Marketing and Advertising

Bidding, Pricing, Ads Allocation

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Summary and future directions

Landscape
Interpretation, evaluation
Generative AI, LLM



Q&A will be held at the end of the tutorial

01

Opening Remark

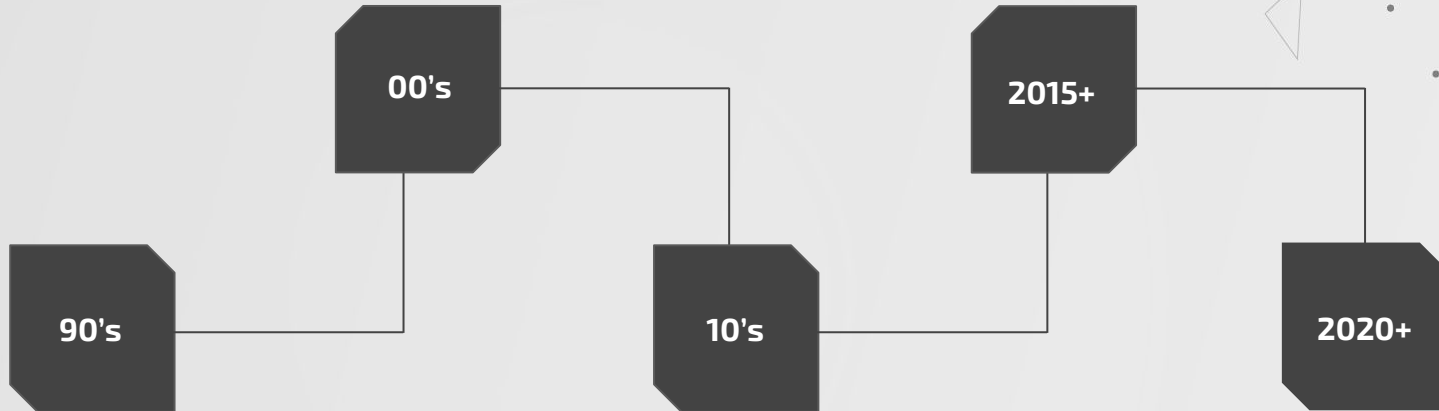
Overview, Motivation, Introduction & Scope



Milestones

Use more fine-grained stochastic and physical models that reflect particular user behaviors to evaluate and understand simpler phenomena of the system

Incorporate the counterfactual and sequential interaction nature of Web systems and combine them with the tools and ideas developed from reinforcement learning to drive realistic long-term simulations



Simulation with simple physical models (with differential equations) discovered the Internet Service Provider (ISP) marketing model – no monthly fee + advertising – the foundation of modern IT companies' business model

Employ ideas from causal structure modeling to account for prior knowledge and other more complex aspects of real-world mechanisms for evaluating and studying system behaviors

Generative-AI-driven simulation where system components and transactions will be dominated by generative AI agents

Rough Numbers on the Percentage of Major Data Mining and Recsys Conference Publications that Have Simulation Study*

<2%

10 YEARS AGO

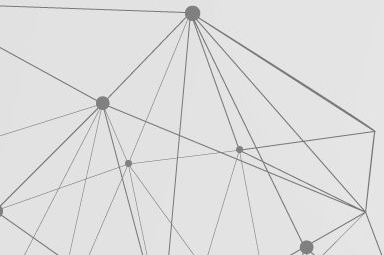
~4%

PAST 10 - 3 YEARS

~7%

PAST 3 YEARS

* We use the term 'simulation study' as the indicator for doing our web-crawler-based survey, which is subject to missingness and bias





Motivation

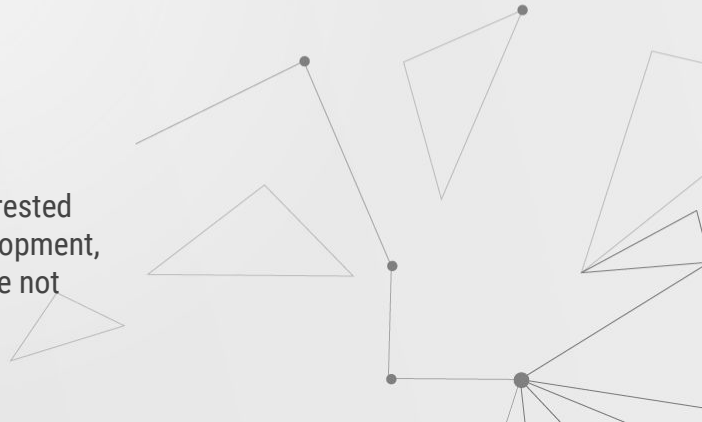
Aim to provide a systematic review for the growth and advancement of a technology that is becoming progressively crucial in the research and development of algorithms and systems for Web applications, with high relevance to both academia and industry

Introduction

Many simulation technologies that have emerged in the past 20 years can be encapsulated by the concept of agent-based simulation, which holds significant implications as we venture into the era of generative AI. We present and contextualize this concept with concrete design and realization patterns in the fields of information retrieval, recommender system, and advertising.

Scope

Since this is a 1.5 hr tutorial, we focus more on the conceptual aspects and point interested readers to the references for detail. Our discussion revolves around supporting the development, refinement, analysis and comparisons of algorithms and systems. Our discussions are not supposed to reflect the full extend of real-world behaviors.





02

Overview

Agent-based Simulation for Modern Web Applications

Agent-based Simulation

A Mindset More
than Technology

- Provide a natural description of the system
- Provide a visible pathway from **Hypothesis to Action**, bring algorithms out of the lab
- Fine-grained control over **environment complexity, reality faithfulness, and manipulability** for studying phenomena

Benefits

- Interactions are often **complex, non-linear, discontinuous**, and the state and action spaces are not fixed
- Emergent and interesting phenomena arises from agent interactions
- Often **heterogeneous** and exhibit such as network effects and delayed feedback

Agent interactions

- TL;DR: Creating system of agents and the relationships between them

- Can exhibit **complex memory** and **path dependencies**
- Hysteresis, temporal correlations
- Can have complex behaviors such as **learning** and **adaptation**

Agent Decision

- The population is rarely homogeneous, and can often characterized as mixture of clusters or hidden factors
- Aggregation smooths out fluctuations and masks heterogeneous behaviors

Beyond Average Analysis

Agent-based Simulation for Web Applications

Domain knowledge
Real-world constraints

Information Retrieval (Example: SimIR)

- (A). User type and topic model, search context pool, query and document generator, search engine
- (B,C). CSM (Complex Searcher Model, memory-aware)
- (D). Markovian environment and stopping criteria

Description of the System

- A. **Agent model & feature (state)** for such as user, item, document, ...
- B. **Agent choice model** (e.g. preference, interaction, stopping)
- C. **Transition model**
- D. **Environment** (reward, constraints, properties,...)

Recsys (Examples)

- (A). Real-world user and item (e.g. **MarsGym**)
- (B, C). Task- and User-type specific models (e.g. **PyRecGym**)
- (D). Organic + Bandit E-commerce sessions (e.g. **RecoGYM**)
SlateQ environment (e.g. **RecSim**)

Marketing & Ads

- (A). Open box auction simulation (**Genie**)
- (D). Bandit learning for bidding strategies (**AuctionGym**)

Major Scenarios for Using Agent-based Simulation in Web Applications



System Evaluation

Take advantage of the full observability and unlimited horizon of simulation environments to examine algorithms, off-policy evaluation and learning methods, long-term properties of the system, etc

Take advantage of the manipulability of simulation to design purposeful and controlled environments to verify hypothesis, detect patterns, and explore interesting phenomena

Opportunity Identification



Stylized Analysis

Take advantage of the flexibility to create stylized models and environments that are more targeted and simpler to analysis than real-world systems, to investigate, identify and understand the process and mechanisms underlying the phenomena of interest

On Designing Agent-based Simulation



Reality

- Designed to identify, understand or address real-world problems
- Simplified, abstract, reusable, and externally valid components
- Complete 'sim-to-real' is often unnecessary



Assumption

- On agent models, states, interactions, transitions, and environment
- On initial conditions and behavior trajectory
- On objective and visible pathway between simulation outcome and hypothesis



Intervention

- Purposefully taking actions on the simulation environment
- Explore consequences, understand causal pathways
- Draw connection and test hypothesis



Faithfulness

Faithfulness to the real-world counterpart of the problem



Complexity

Complexity of the assumptions and hypothesis



Manipulability

Degree of freedom and level of constraints for the acting ability

The tradeoffs are delicate and should be carefully weighing in for different use cases in order to ensure feasibility and draw plausible conclusion.

How to get buy-in from reviewers, clients, colleagues, leadership

