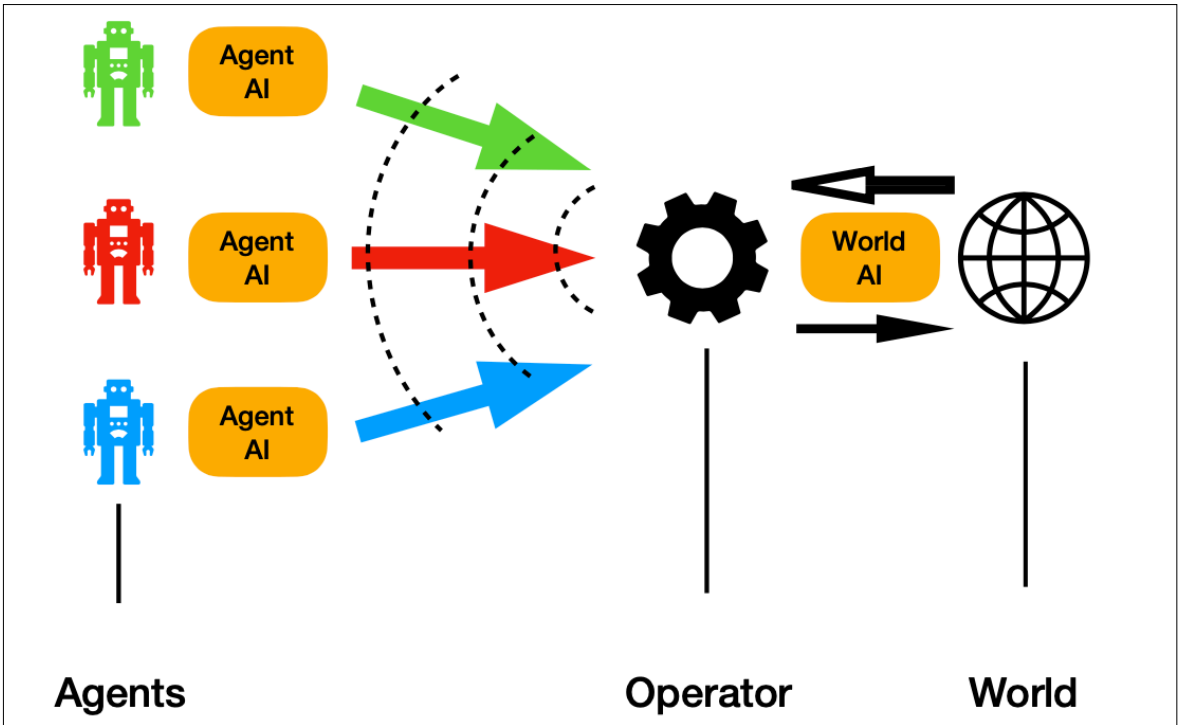

Figure 1. Schematics of the markets + AI idea. *World AI* learns the structure of the world and provides appropriate inputs to the operator. Operator takes these inputs and sends signals to the agents. *Agent AI* analyses these signals and interacts with the agents in a user-friendly manner. Its job is to learn enough about the agent's preferences that it can respond appropriately on behalf of the agent. The operator collects these responses and allocates resources appropriately. The signaling between the operator and the agents forms a market. The *World AI* observes these allocations and updates its predictions and inputs to the operator.

Project Proposal

AN END-TO-END FRAMEWORK FOR RESOURCE ALLOCATION AND PRICING

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MARKETS + AI

Resource allocation are market design are central problems for many economic activities. Although these have been studied for centuries the technological developments in the recent past have led to newer possibilities necessitating us to revisit these problems from a modern perspective. In particular, I am referring to the following breakaway technologies:

1. Digital revolution: It enhanced communications and computation technologies. The more compute power the more you can process at any given node
2. Internet of Things → Enhanced monitoring and data gathering
3. Artificial Intelligence → Enhanced data processing, learning, agent assisting through recommendation systems
4. Markets + AI → Interactive solutions for multi-agent systems to enhance decision making and resource allocation in multi-sided markets.

PROBLEMS IN NETWORK ECONOMICS AND RESOURCE ALLOCATION CAN OFTEN BE SEPARATED INTO TWO PARTS: THE WORLD AND THE AGENTS.

Situation	World	Agents
Transportation networks	Infrastructure like roadways, railways, airways, etc.	Travelers and shipments
Communication networks	Infrastructure like routers, modems, base stations, etc.	Communicating agents such as people, computers, sensors, etc.
Advertising networks	Target audience and influence channels like media and social networks.	Advertisers, campaigners, influencers, etc.
Ride Hailing (+Last Mile Apps)	Matching and routing options	Drivers and riders
Supply chain management	Facilities like warehouses and transportation	Producers and consumers

Key features:

1. The world is generally a complex space and each agent has limited information about it as well as about the other agents in the system.
2. Each agent's preferences and beliefs (another complex space) are different and it's private information. The agents show a natural tendency to behave in their own best interests.

The Operator is a mediator between the Agents and the World that interacts repeatedly with them and performs the following tasks:

1. Monitors and collects data from the world and develops predictive models.
2. Learns agent preferences.
3. Allocates resources to fulfill certain system goals such as customer satisfaction, revenue generation, or fairness.

MARKETS + AI

Goals:

1. Design a market-based framework to enable a signaling protocol between the operator and the agents for optimal resource allocation.
2. Develop AI techniques to learn the world structure and the agent preferences from the data in order to facilitate the functioning of the market.
3. *These two designs should work in harmony with each other*.

Directions:

1. Markets have been studied in game theory, and operations management. Use ideas from Kelly's agent-operator decomposition and mechanism design to design the signaling scheme for the market.
2. World structure is studied in statistics, econometrics, and control systems. Combine it with ideas from ML/RL to design World AI.
3. Agent preferences and behavior are studied in psychology, decision analysis, and behavioral economics. Combine it with ideas from CPT, ML and RL to design Agent AI.

Examples

A. Real-time bidding for adverts
   Online ads, companies bid for AdWords, platforms like Google, Facebook, Yahoo show these ads to their users. Limited resource is the users attention. Companies are competing for it. Platform analyses user behavior and influence factor. Companies bid as per their preferences and needs. Platform charges the companies for optimally allocating the resource and generates revenue.

B. Internet bandwidth allocation
   More flexible bandwidth allocation with higher control from the users. Imagine you could signal how much bandwidth you need as simply as increasing or decreasing your device volume!

C. Cloud computing resource allocation
   Algorithms to prioritize jobs and users based on their need.

D. Traffic routing
   Option to choose alternative routes based on needs and incentives in the form of rewards.

E. Ride-hailing
   Improved implementation of these platforms by taking a principled approach.

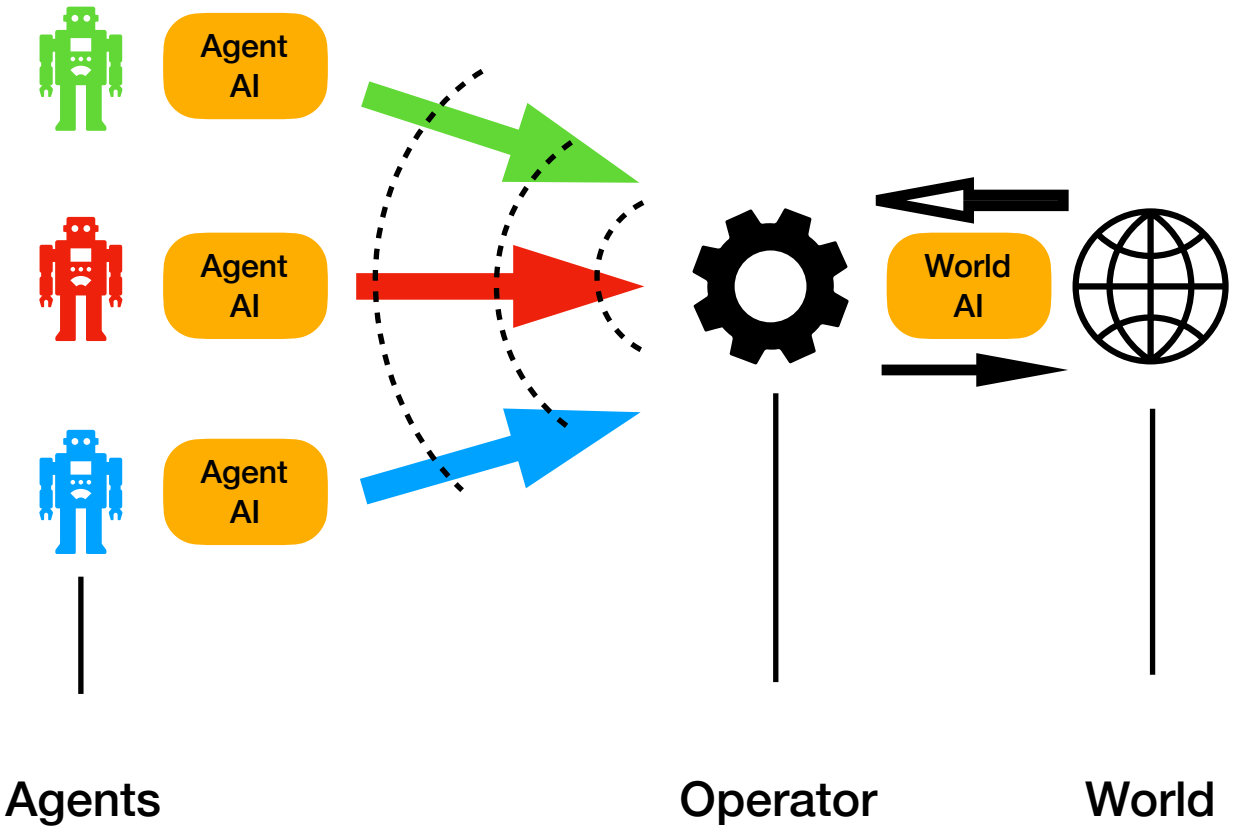
F. Delivery of goods
   Automating the role of middlemen in distribution tasks facilitating improved efficiency by taking advantage of data analysis and appropriately incentives allocations.

G. Labor markets
   Improved matching of workers to jobs.

H. Digital markets
Rich market for creation, sale, and consumption of goods and services over the Internet.

I. Telemedicine
Improved matching of doctors to patients.

J. Digital Education
Improved matching of teaching resources to students.



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Enhanced Market Design using AI

In this document, I will lay out a plan to carry out the research necessary for designing markets that are aligned with and takes advantage of the modern technological developments, namely, communication, computation, and AI in a principled manner. This will help in the design of systems of various types: those that match customers to professionals, today performed by companies such as Amazon, Uber, Doordash, etc.; those provide services to customers with varying preferences such as Xfinity, Verizon, logistic planning companies, CRMs; those which manage advertising and outreach or run social welfare campaigns.

I will describe a recipe to design markets. Key to this approach is a communication protocol inspired by Kelly's work in network bandwidth allocation that explains the functioning of Transmission Control Protocol (TCP) used all over the Internet. I will show that such an approach leads to a modular framework for designing markets that is amenable for AI based enhancements. This approach will provide clear guidelines to aid the design of objectives for AI methods with the ultimate goal that the markets function efficiently. I will be able to capture the typical goals of a system in the most abstract forms and result in efficiently functioning systems. Such as approach will definitely be beneficial in the long run.

The platform operations and algorithms run by these companies today are confidential and often pushed under the carpet. Unprincipled approaches can lead to randomly changing mechanics, be extremely unreliable, and thus of limited use. (The fact that many of these companies are loss making today doesn't bolster confidence in these methods either.) A principled approach will not only guide the design of these systems but also provide us concrete ways to assess the functioning of these systems. We will see that many of the practices followed today in e-commerce and digital markets will naturally arise from this approach and in some situations the theory will suggest valuable alternatives for improvements. It will also lead to metrics to evaluate the proper functioning of these systems.

To help appreciate this approach, I will use the example of a food delivery service platform to explain the key ideas and stages in designing markets. However, these ideas are applicable in most of the settings discussed above and many others. Imagine that we are running a platform that matches diners with restaurants for food delivery. Explain how this works typically. Explain the user interface. What sort of algorithms, methods are used today? What is it lacking?

Recipe to design markets in food delivery business

Step 1. Identify the primary agents. Here we have customers (or the diners) who want to order food and the suppliers (or the restaurants) who want to complete these order requests. Besides, there are the drivers who fulfill these delivery orders. We will treat this as a multi-sided market, each side having multiple agents. Here we have three sides in this market: diners, restaurants, and drivers. Set up some notation here for different sides of market. Include a diagram.

Step 2. What is important to the primary agents? The different sides of a market are roughly based on what the different agents care about. For example, the diners care about the quality of service such as where they get their food from and how long it takes to receive their delivery. The restaurants care about the number of orders

they get through the delivery platform. Too little orders and they are losing money due to idling. We can assume that the restaurants do not have preferences over who orders from them. The drivers care about how far they need to travel to fulfill the delivery and which areas they need to travel. Although all the different sides of the market have preferences on different outcomes, these are all linked to each other. Explain. Notation needed. Diagram needed.

Step 3. System constraints: The number of orders that the restaurant can complete is limited. Too many orders and the restaurant will not be able to complete them in the required time. Thus increasing the delay. The drivers available for delivery are limited. The traffic conditions are external factors not within the control of the system. All these affect the delay and thus the QoS of the diners. In contrast to simply trying to recommend a user what restaurant she might like the most, a smart system would also take into account the effects related to delay and suggest accordingly. Suggesting many users a single restaurant in not ideal because this will increase the delay for these users thus bringing down their satisfaction. Market forces are essential in balancing out these effects and improve restaurant recommendations and resource allocations. We wish to focus on these aspects.

Behavioral considerations: Different agents have different preferences. Note that the different agents in a single side of the market will have different preferences even if they care about similar things. Besides, the agents can show behavioral features like biases and heuristics in making decisions. We want to framework to be as robust as possible to these features. Examples. CPT, etc.

Learning problem: We will call the things that an agent cares about as the outcome domain. The possible preferences of an agent over her outcome domain is a huge class. Notice that the number of restaurants is large and the users can have different preferences on them based on the delays. We will need to use learning techniques from AI and ML to facilitate this. Explain how collaborative filtering is used here. Explain how our approach is going to tackle this is a different way.

Also, knowing the system constraints exactly is not always possible. This gives rise to an RL problem on the network side. This has natural ties with the TCP wind based management idea. You allocate resources, observe the resulting delays and adjust the allocations. Explain how the logarithm based objective function is inspired from Kelly network problem with additional costs based on the capacity constraints.

Practicality considerations: Communication between the system and the agents is a costly business. This should be designed very carefully. This will help in learning the agent preferences.

Sources of information: External sources such as restaurant features are agent features can be used to assist the learning problem. Typically used to alleviate problems such as “cold start” etc.

Timescale considerations: The fact that the demand and supply is a dynamically changing aspect, the prices should change dynamically and adjust appropriately. This is the main reason why we need real-time systems based on Kelly type process as compared to traditional economic markets that allow certain sides in the market to set the prices and let the market forces to stabilize the system. In the markets that we are interested in, we need to assist the agents to make these decisions due to the vastness of the markets and their tendency to change

rapidly. The user optimizers in Kelly decomposition can be seen as assistants that work on behalf of the agents and help in price discovery as well as recommendations from the vast options available to these agents.

Part A: One-sided markets

Stage I: Non-integrated model-based learning approach

Stage II: Integrated model-based learning approach

Stage III: Integrated model-free learning approach

Part B: Two-sided markets

Stage I: Non-integrated model-based learning approach

Stage II: Integrated model-based learning approach

Stage III: Integrated model-free learning approach

Part C: Multi-sided markets

Stage I: Non-integrated model-based learning approach

Stage II: Integrated model-based learning approach

Stage III: Integrated model-free learning approach