Dynamic Pricing Provides Robust Equilibria for Stochastic Ridesharing

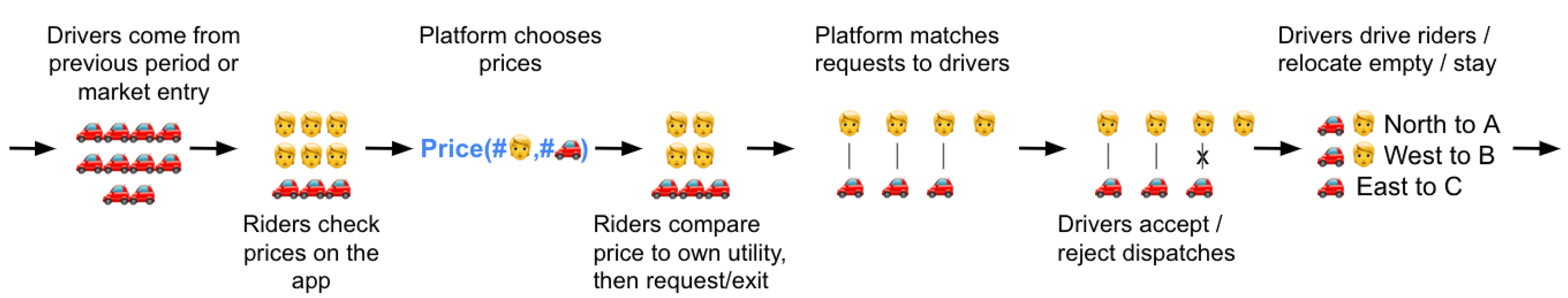
J. Massey Cashore, Peter I. Frazier, Éva Tardos

Cornell University

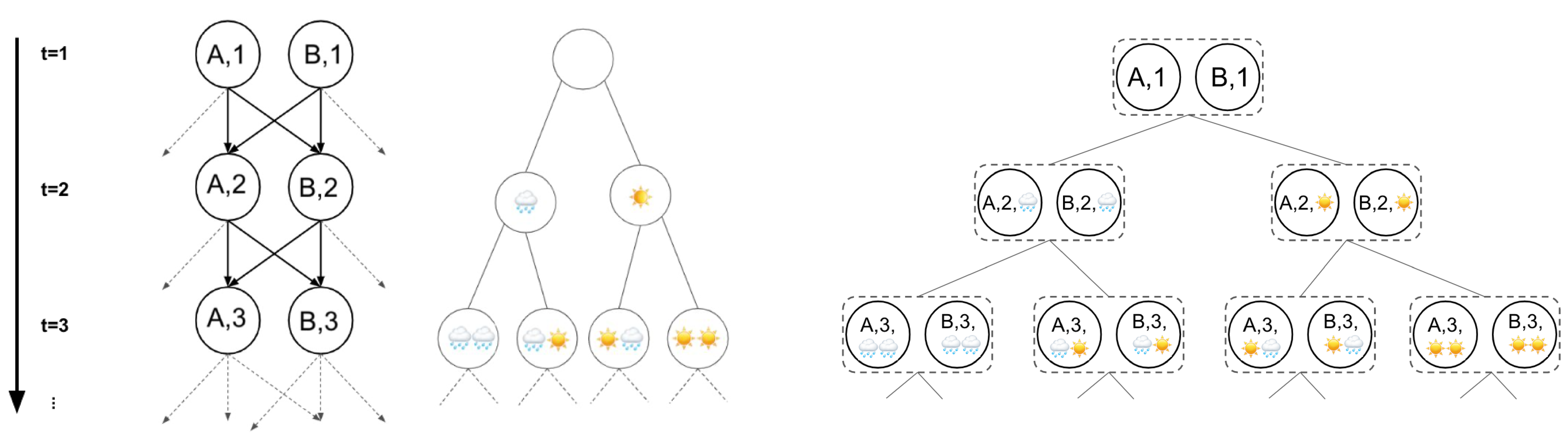
Model Description

- **Stochastic Two-Level Model:** Riders and drivers are discrete agents. Rider and driver decisions governed by *microscopic randomness*. High-level traffic patterns governed by *macroscopic randomness*.
- **Stochastic Fluid Model:** Large market limit of two-level model. Riders and drivers are deterministic, continuous agents. Top-level macroscopic randomness of two-level model is retained.

Single Period Dynamics: Microscopic Randomness



Stochastic Spatiotemporal Network Structure: Macroscopic Randomness



- **Left:** Spatiotemporal network similar to previous work on deterministic ridesharing mechanism design.
- **Middle:** Stochastic scenario tree is a new ingredient we introduce to model macroscopic uncertainty.
- **Right:** Cross-product of spatiotemporal network and scenario tree defines a *stochastic flow network*.

Stochastic Fluid Optimization Problem

- Welfare-optimal plan solution to min-cost flow problem over stochastic flow network.
- Flow-conservation constraint associated with each (location, time, scenario) node.
- Decision variables determine relocation trips and dispatch trips along each (orig, dest, time, scenario) arc.
- Objective function: expected social welfare over remainder of the planning horizon.

Dynamic Pricing Algorithm for Stochastic Ridesharing Networks

- At beginning of each time period: *re-solve* fluid problem, incorporating realized driver locations.
- Set prices based on re-computed optimal dual variables.

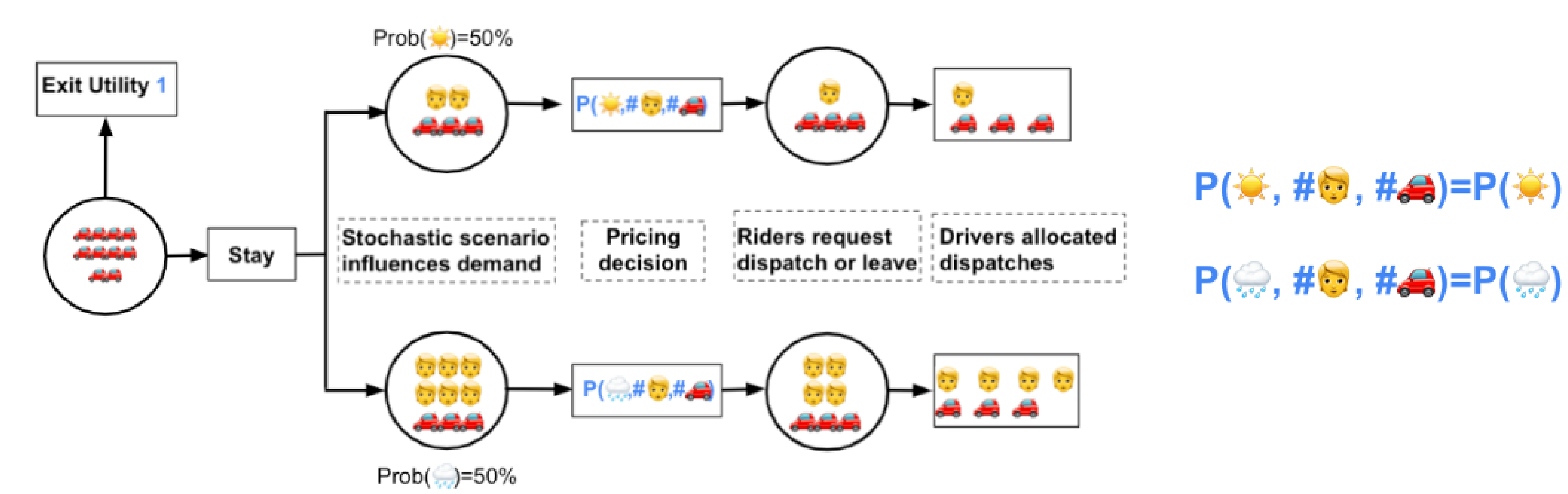
Results

Strategy profile is an *approximate subgame-perfect equilibrium* if, from any market state, approximately every driver has approximately no incentive to take a different trip.

Under our dynamic pricing algorithm, in a large-market limit of the two-level model:

- *(Incentive-Compatibility)* Welfare-optimal trips are an approximate subgame-perfect equilibrium.
- *(Welfare-Robustness)* Every approximate subgame-perfect equilibrium is approximately welfare-optimal.

Example: The Need for Driver-Aware Prices



- Scenario-aware prices can achieve incentive-compatibility, but not robustness.
- In stochastic fluid model, equilibrium strategy is not unique: **Utility(exit) = Utility(stay)**.
- In two-level model, small probability of not getting a dispatch: **Utility(exit) > Utility(stay)**.

Takeaways

- Novel model for ridesharing markets combining tractability and realism.
- New robustness property: every approximate equilibrium is approximately welfare-optimal.
- New insights into dynamic pricing in ridesharing markets and re-solving in stochastic optimization.