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A Unified Approach to Dynamic Matching and Barter Exchange

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The exchange of indivisible goods without money addresses a variety of constrained economic settings where a medium of exchange---such as money---is considered inappropriate. Participants are either matched directly with another participant or, in more complex domains, in barter cycles and chains with many other participants before exchanging their endowed goods. This thesis addresses the design, analysis, and real-world fielding of dynamic matching markets and barter exchanges.

We present new mathematical models for dynamic barter exchange that more accurately reflect reality, prove theoretical statements about the characteristics and behavior of these markets, and develop provably optimal market clearing algorithms for models of these markets that can be deployed in practice. We show that taking a holistic approach to balancing efficiency and fairness can often practically circumvent negative theoretical results. We support the theoretical claims made in this thesis with extensive experiments on data from the United Network for Organ Sharing (UNOS) Kidney Paired Donation Pilot Program, a large kidney exchange clearinghouse in the US with which we have been actively involved.

Specifically, we study three competing dimensions found in both matching markets and barter exchange: uncertainty over the existence of possible trades (represented as edges in a graph constructed from participants in the market), balancing efficiency and fairness, and inherent dynamism. For each individual dimension, we provide new theoretical insights as to the effect on market efficiency and match composition of clearing markets under models that explicitly consider those dimensions. We support each theoretical construct with new optimization models and techniques, and validate them on simulated and real kidney exchange data. In the cases of edge failure and dynamic matching, where edges and vertices arrive and depart over time, our algorithms perform substantially better than the status quo deterministic myopic matching algorithms used in practice, and also scale to larger instance sizes than prior methods. In the fairness case, we empirically quantify the loss in system efficiency under a variety of equitable matching rules.

Next, we combine all of the dimensions, along with high-level human-provided guidance, into a unified framework for learning to match in a general dynamic model. This framework, which we coin FutureMatch, takes as input a high-level objective (e.g., ``maximize graft survival of transplants over time'') decided on by experts, then automatically (i) learns based on data how to make this objective concrete and (ii) learns the ``means'' to accomplish this goal---a task that, in our experience, humans handle poorly. We validate FutureMatch on UNOS exchange data and make policy recommendations based on it.

Finally, we present a model for liver exchange and a model for multi-organ exchange; for the latter, we show that it theoretically and empirically will result in greater social welfare than multiple individual exchanges.

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Thesis Summary: <http://jpdickerson.com/proposal.pdf>