COL749: Computational Social Choice

Lecture 6 (Contd.)

Kidney Exchange

Jan 25, 2025 | Rohit Vaish

Housing Market

[Shapley and Scarf, *JME* 1974]

Housing Market

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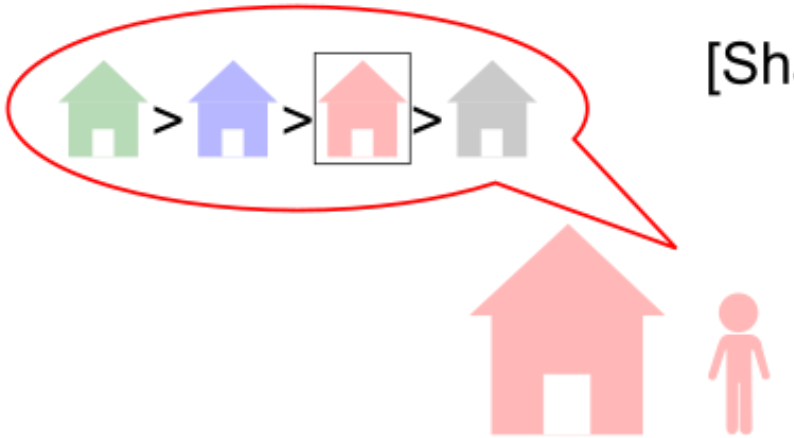

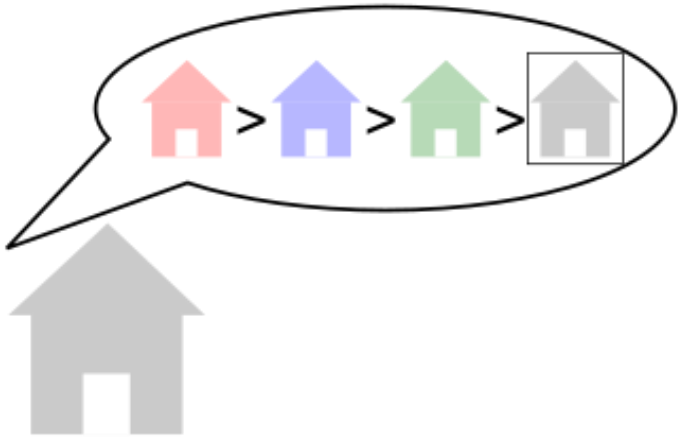

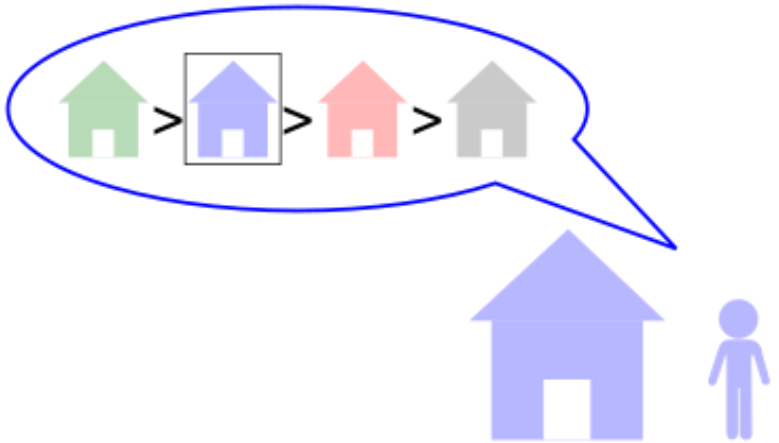

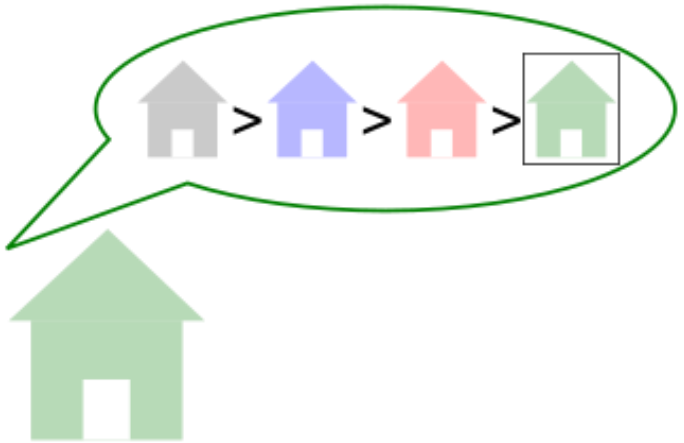

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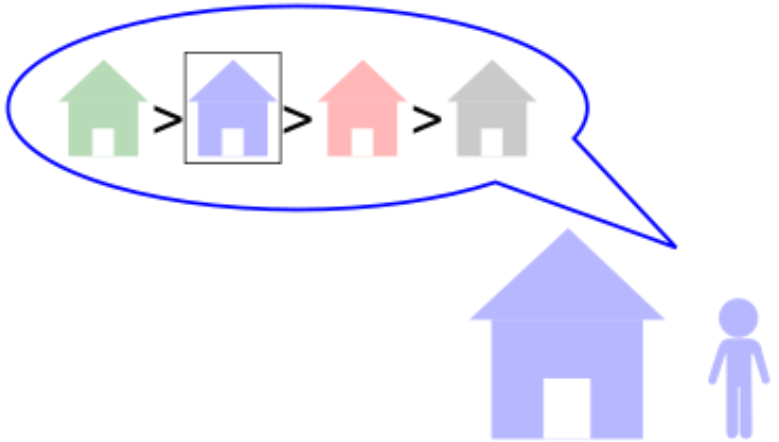
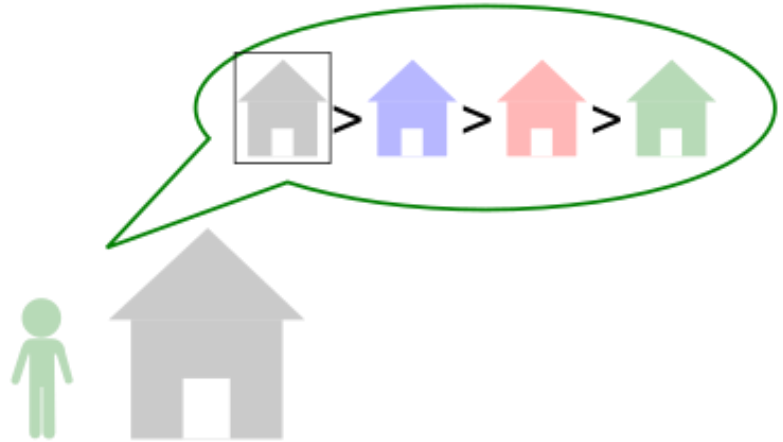




Is there a way to exchange houses to make the agents "maximally happy"?

Top-Trading Cycle Algorithm (TTCA)

[Shapley and Scarf, *JME* 1974 (attributed to David Gale)]

While there is a remaining agent:

- Each remaining agent points to the owner of its favorite house.
- There must be a cycle (include self-loops). Do the cyclic exchange.
- Remove the agents and houses involved in the above exchange.

The Core

An allocation is in the core if no coalition blocks it.

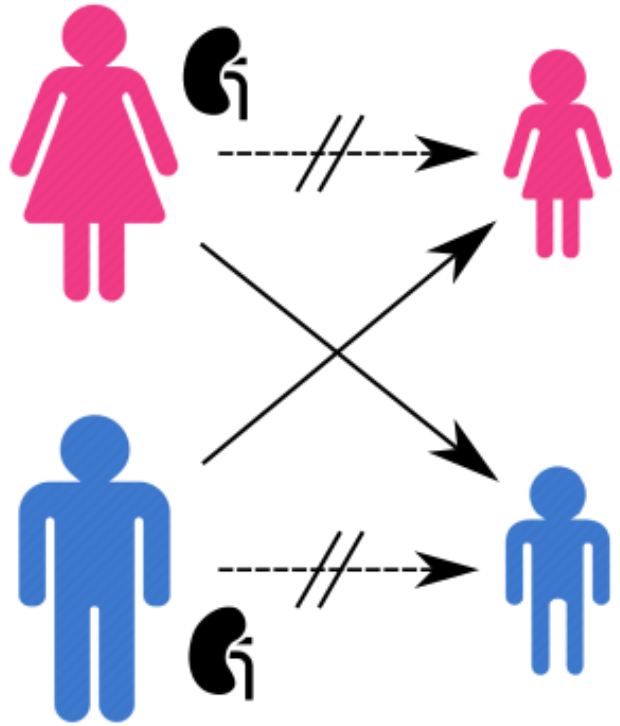
A coalition of agents blocks an allocation A if:

they can redistribute their **endowed houses** among themselves such that, compared to A, none of them is worse off and at least one of them is strictly better off (i.e., redistributing endowments is a Pareto improvement over A).

Awesome Properties of TTCA

- Polynomial running time
- (Group) strategyproof
- Core
- Pareto optimal

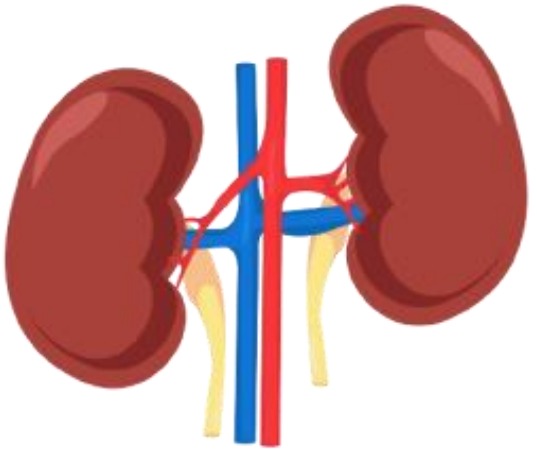
Application of TTCA



Kidney Exchange

Kidney Exchange

Many people suffer from kidney failure
(waiting list in US: ~90,000; in India: ~200,000).



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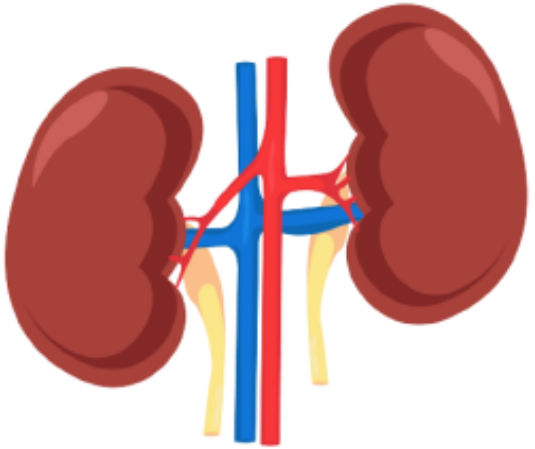

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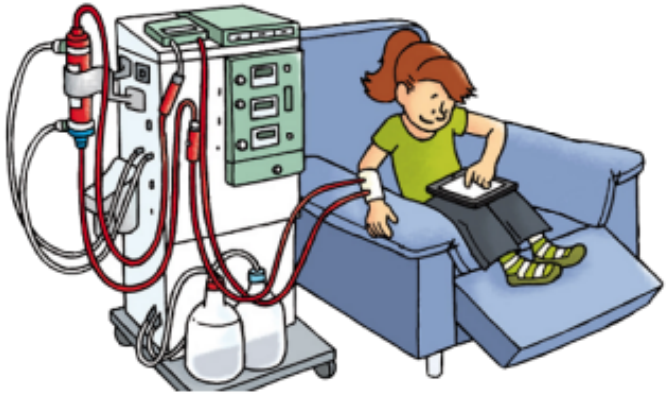
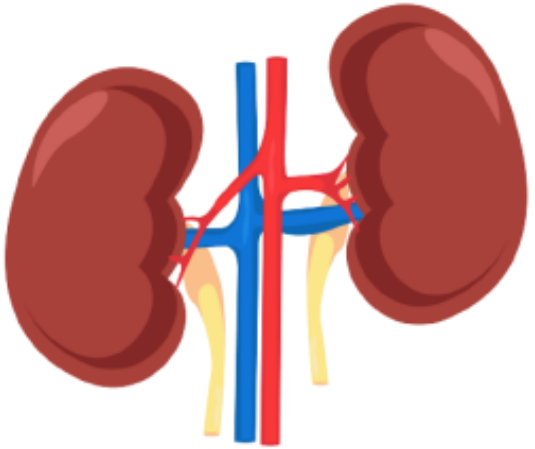


Dialysis

Kidney Exchange



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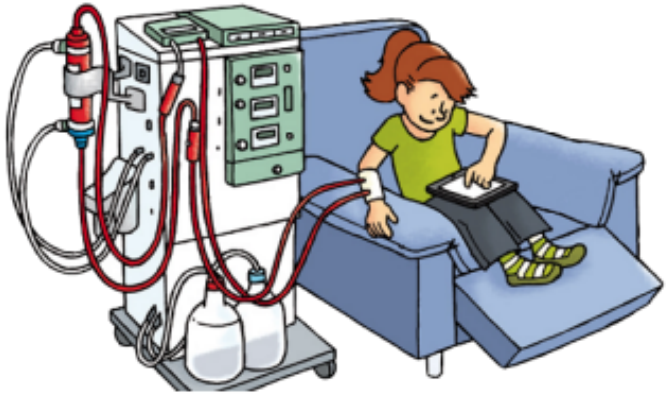

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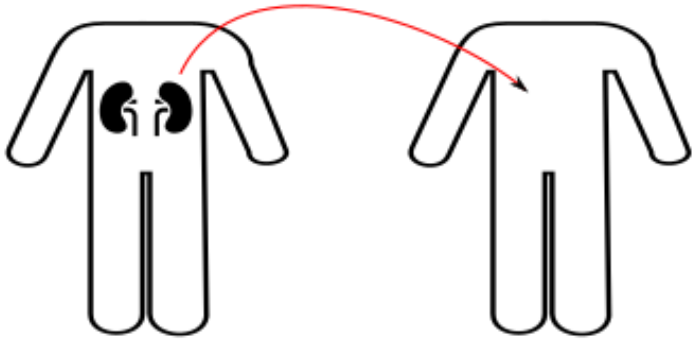
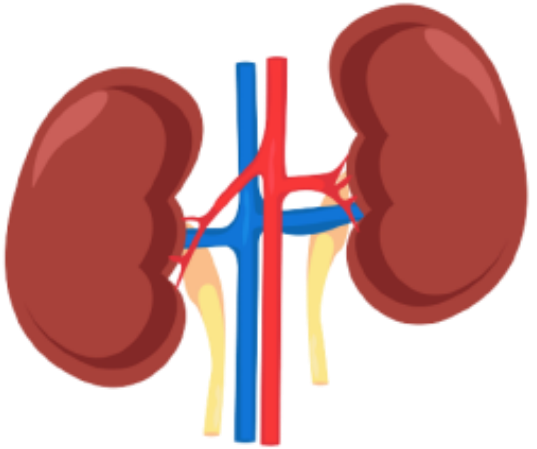


Transplant

Kidney Exchange



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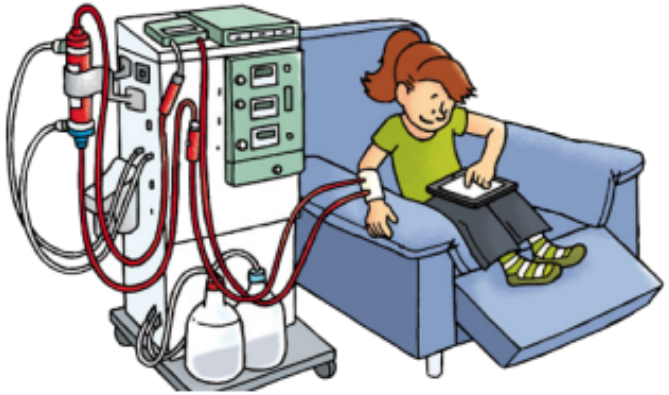
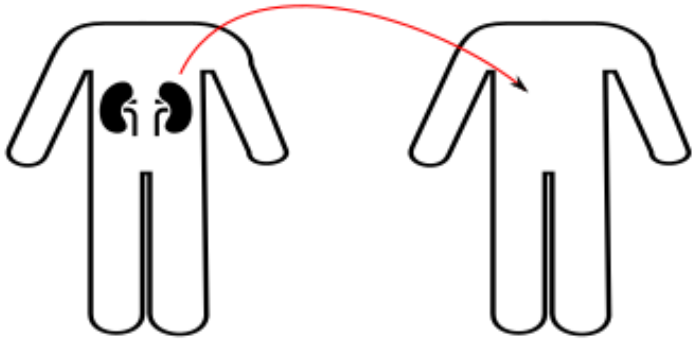




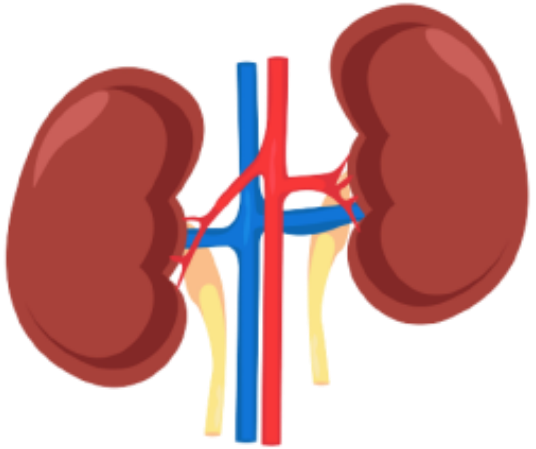
Dialysis

Poor quality of life
High cost

Transplant

Better life quality
Lower cost

Kidney Exchange



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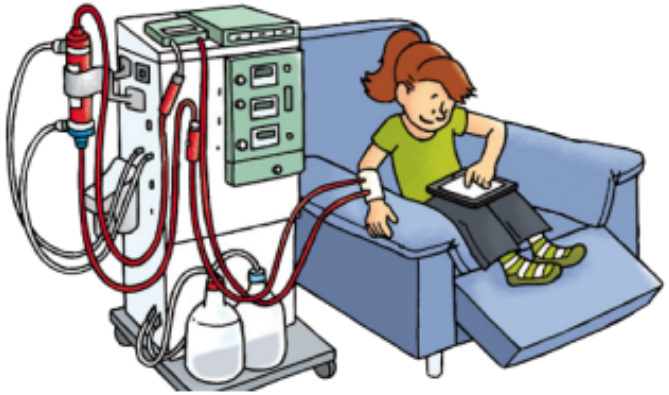

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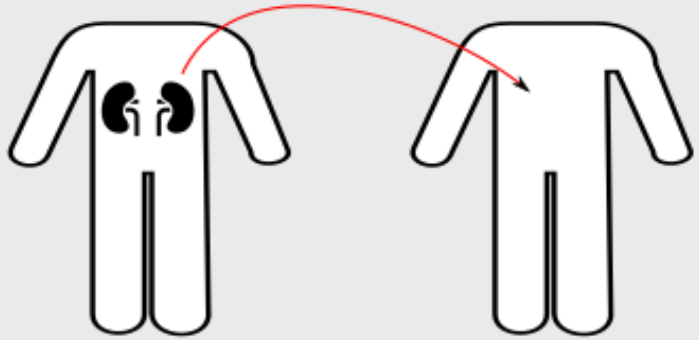

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- From a deceased donor
- From a living donor

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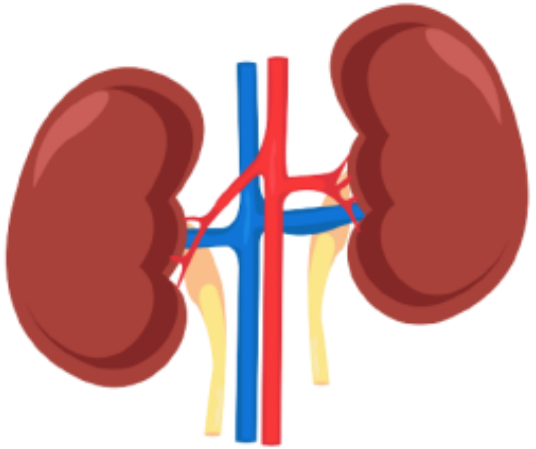

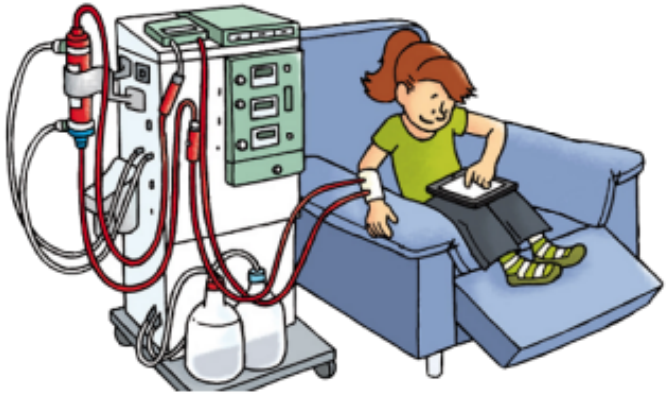

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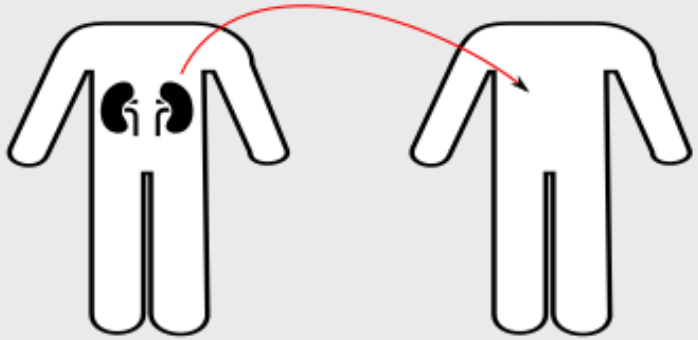

Transplant

Better life quality
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- From a deceased donor

- From a living donor

E.g., first-degree relatives, spouse etc.

Kidney Exchange

Simply having a willing donor is not enough.

The organ must be medically compatible.

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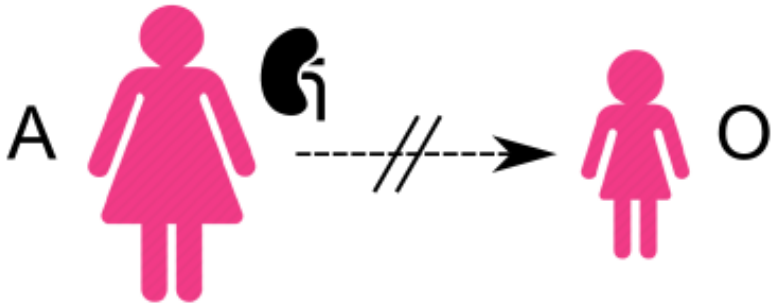
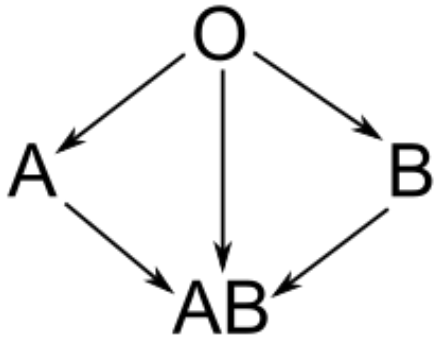


Blood-type incompatibility



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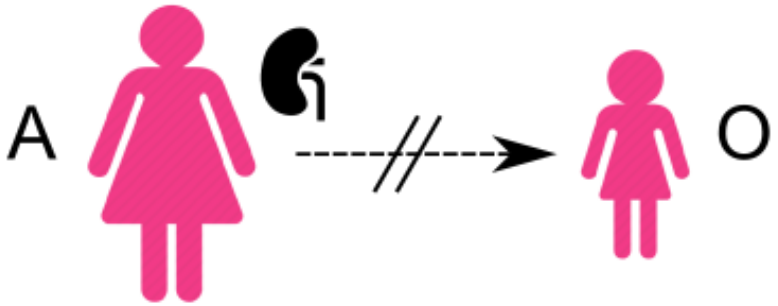

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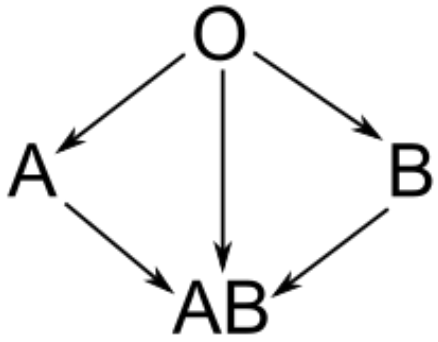
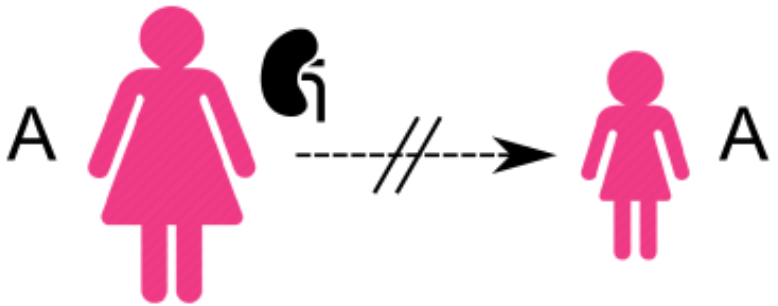


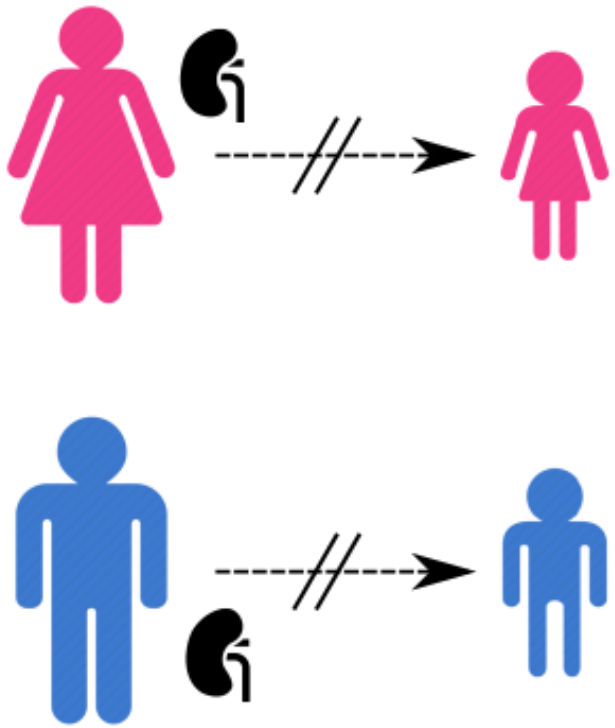


Tissue-type incompatibility

Sensitized patients with antibodies that will attack a foreign tissue (often due to prior exposure during blood transfusion, pregnancy, previous transplants).

Kidney Exchange

[Rapaport, *Transpl. Proc.* 1986; Ross et al. *NEJM* 1997]



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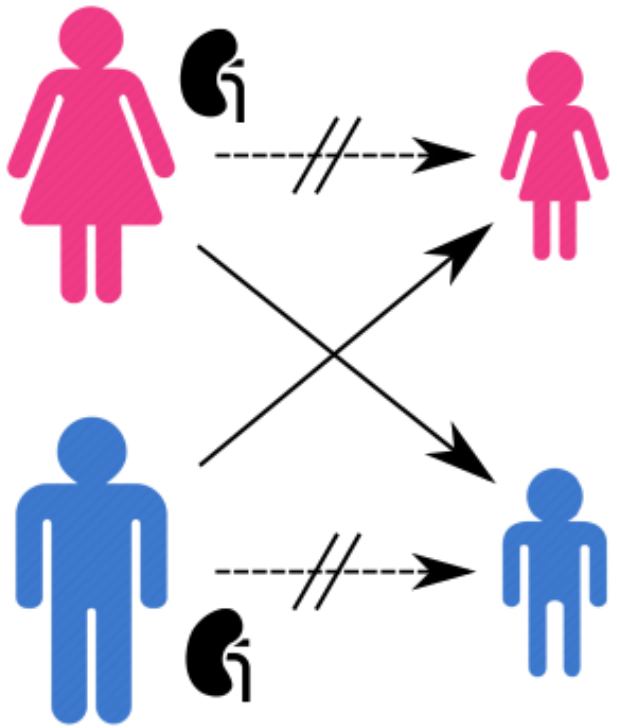

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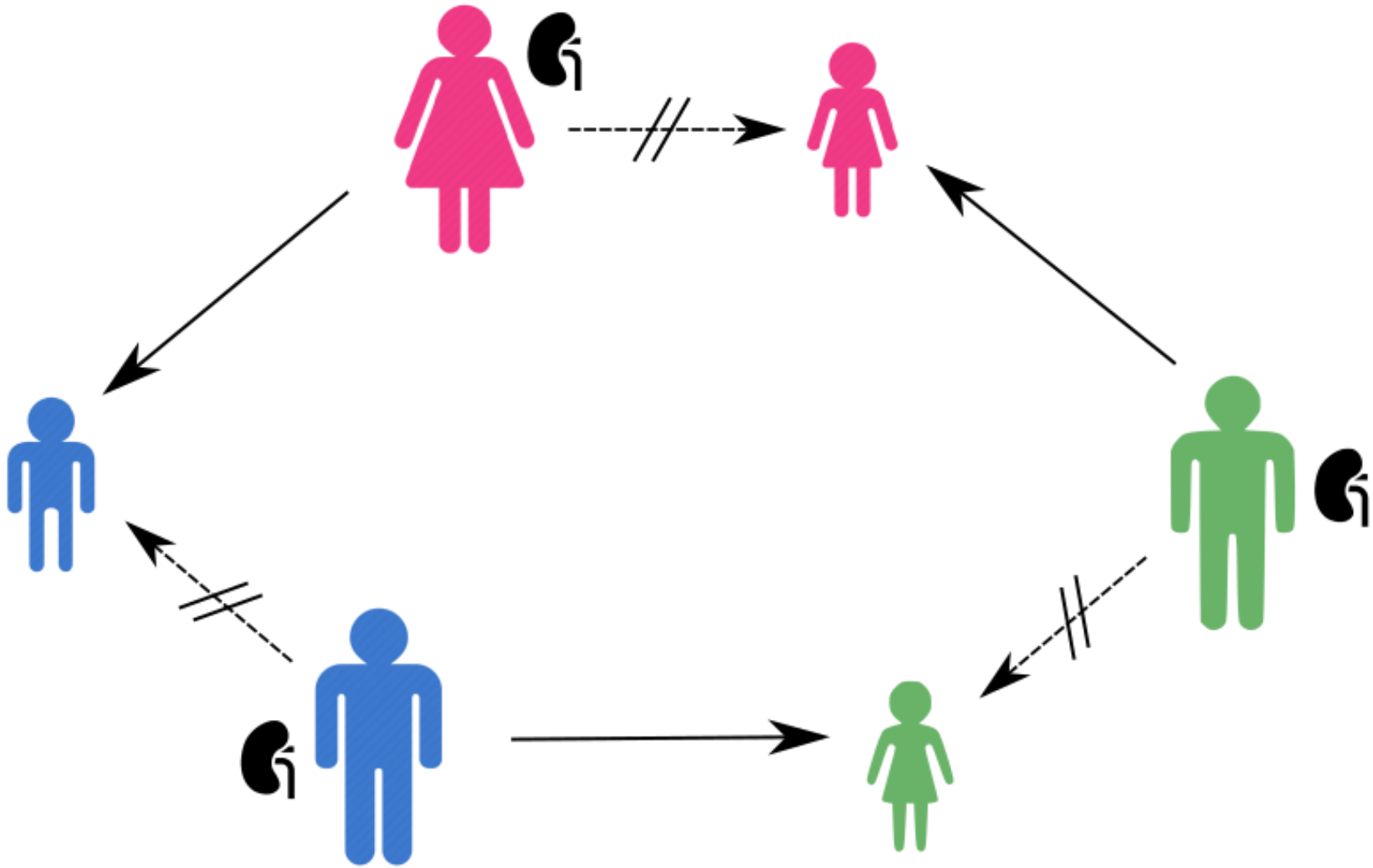

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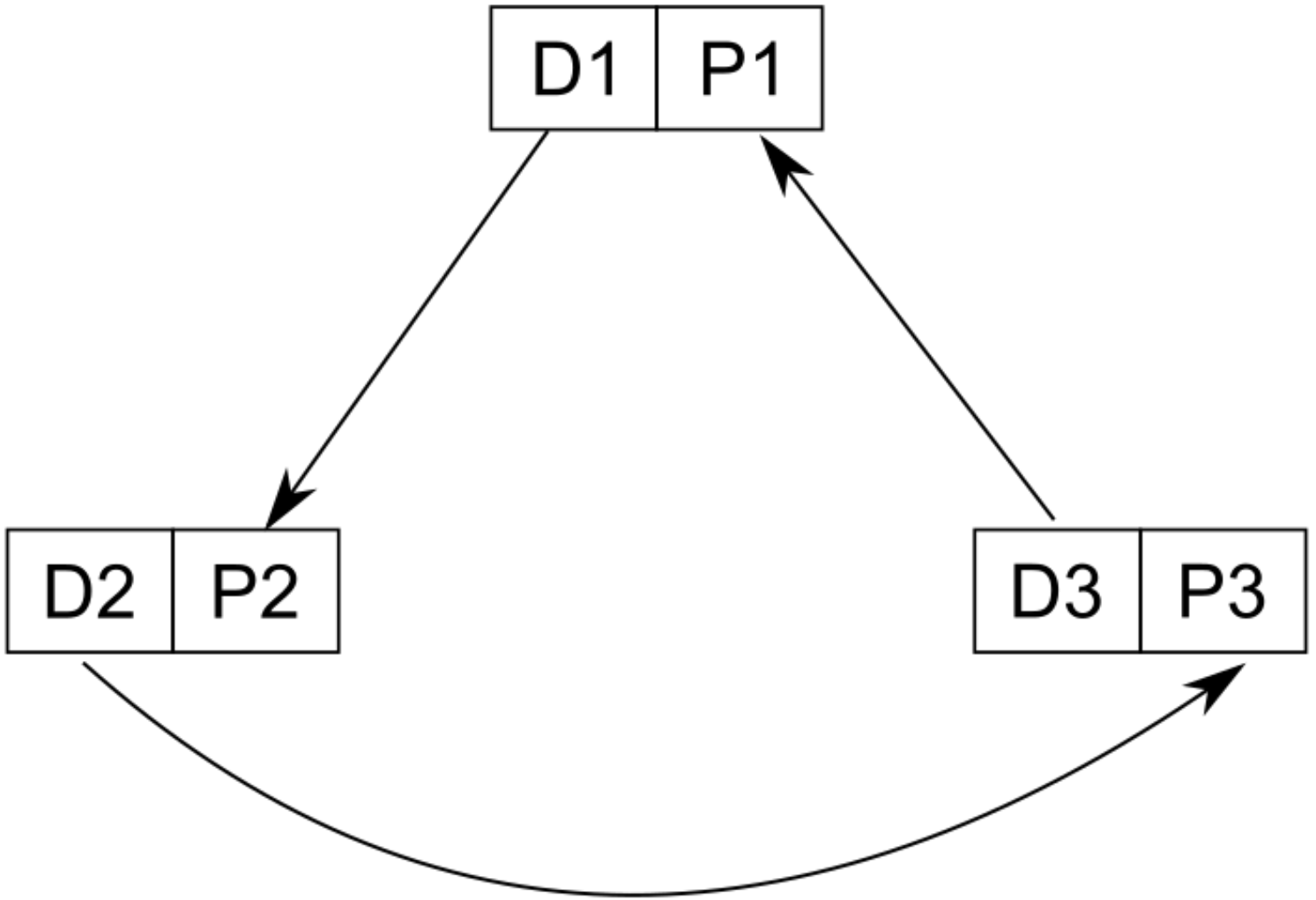

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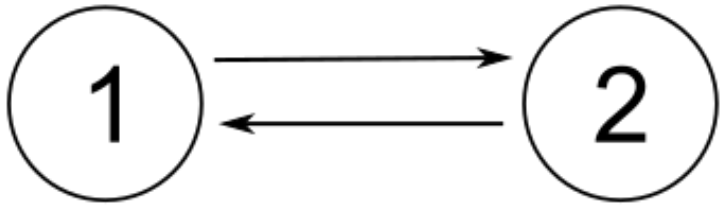

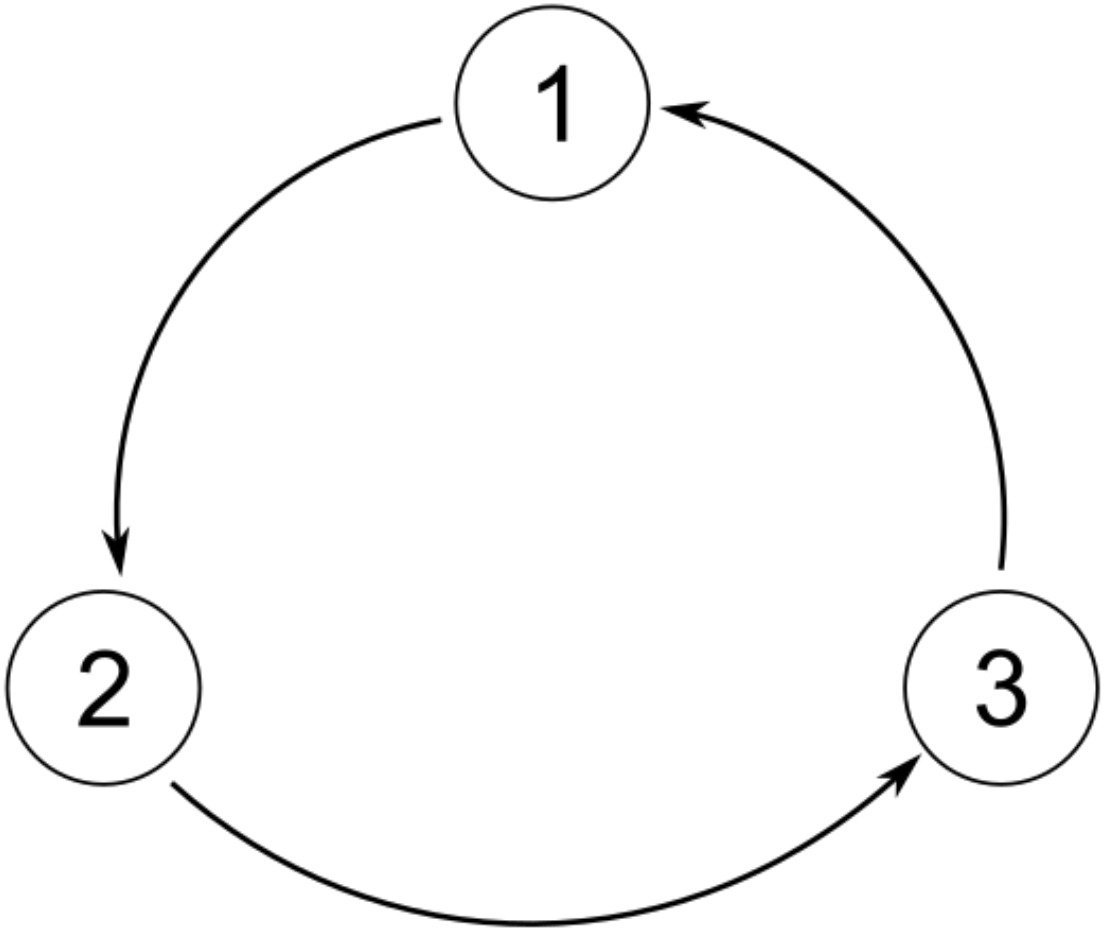

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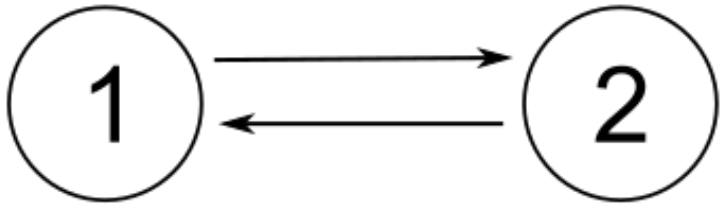

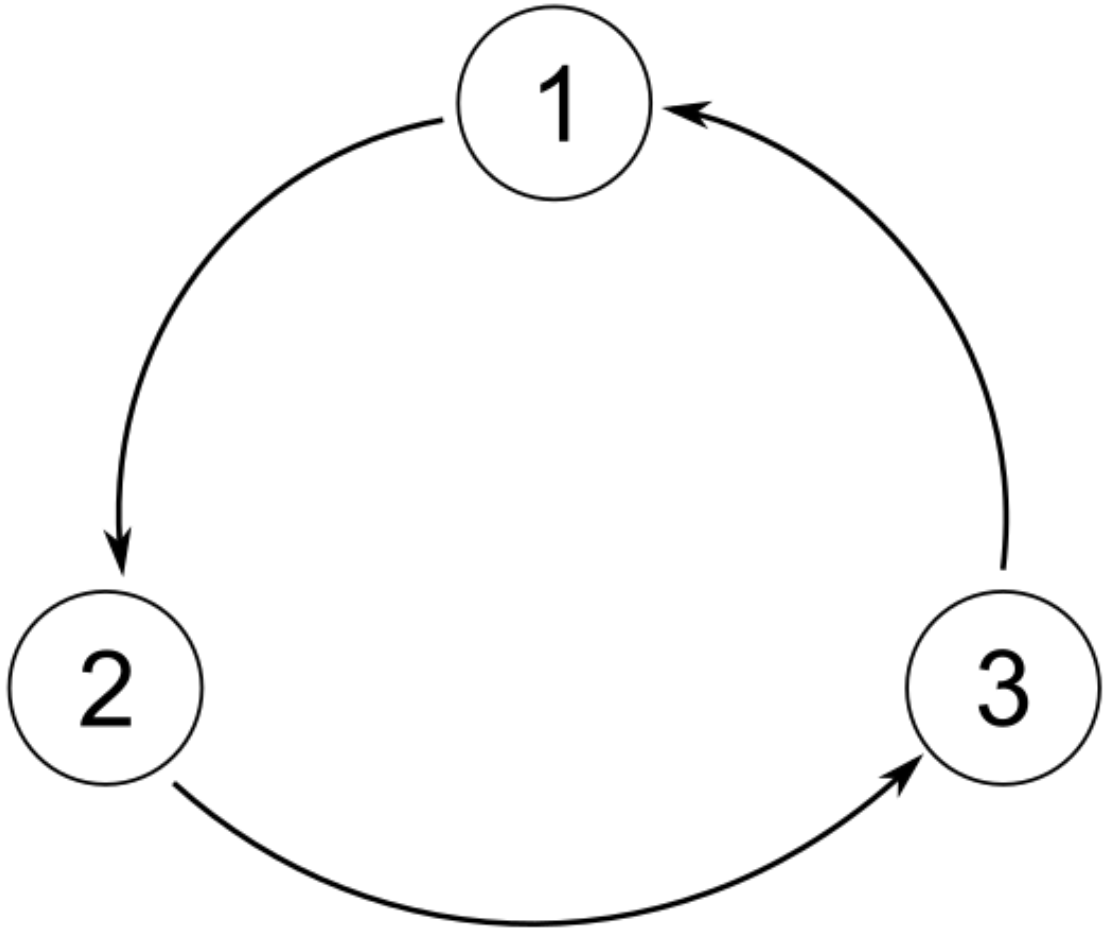

Intuitively, having more and more of such willing-but-incompatible pairs will create more opportunities for an exchange.

History [edit]

Year	Event
1986	KPD first suggested by Rapaport[14]
1991	First KPD program started in South Korea by Dr. Park[8]
1999	First European KPD transplants performed in Switzerland[8]
2000	First KPD transplants performed in USA at the Rhode Island Hospital[8]
2001	Hopkins completes KPD transplants and begins first KPD program in USA[15]
2004	Dutch established first national KPD program[8]
2007	NEAD chain started by APD utilizing first bridge donor[16]
2007	Charlie Norwood Living Organ Donation Act clarifies legality of KPD in USA [17]
2008	National Kidney Registry organizes its first transplants on Valentine's Day[18]
2009	Hopkins leads first 16 patient multicenter Domino Chain [19][20]
2010	UNOS organizes its first KPD transplants[8]
2012	National Kidney Registry completes largest chain involving 60 participants[6]
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Early Proposals for Kidney Exchange

Proposal 1

Using TTCA

Proposal 2

?

Proposal 1: Kidney Exchange using TTCA

[Roth, Sönmez, and Ünver, *QJE* 2004]

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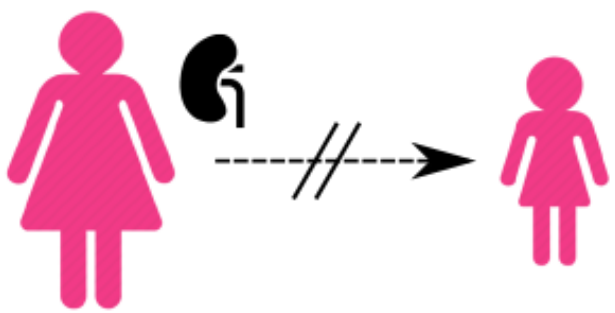

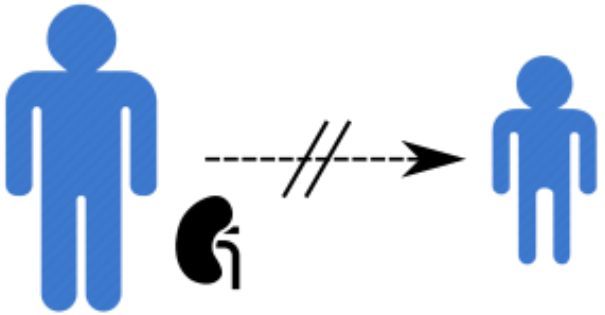

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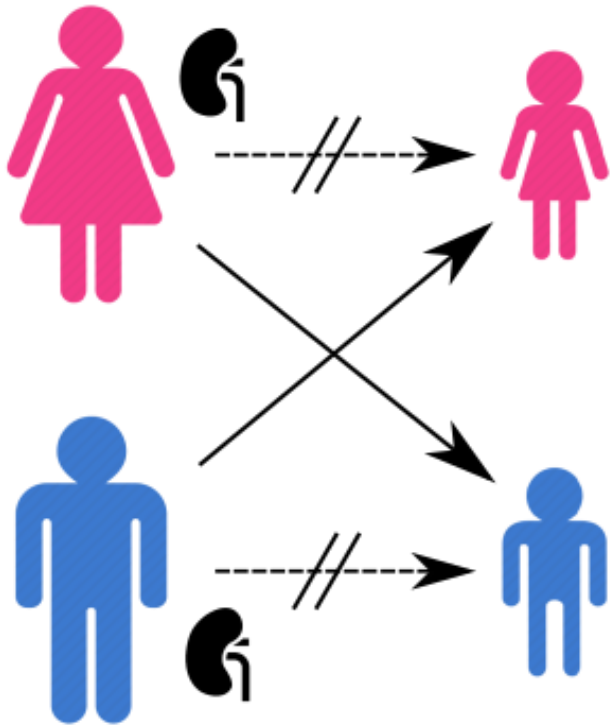

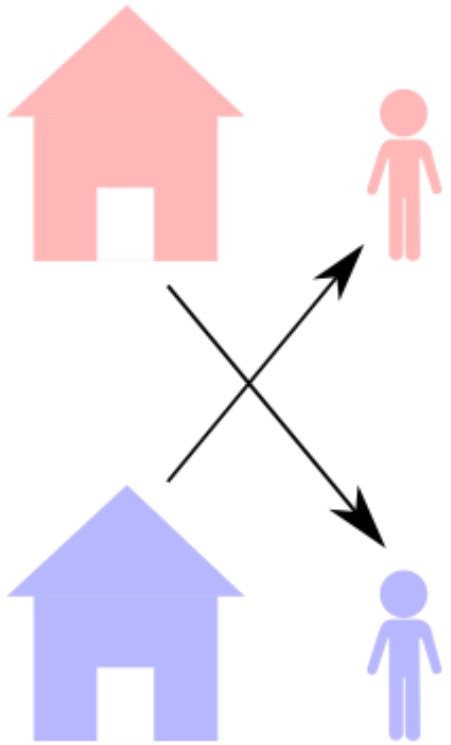

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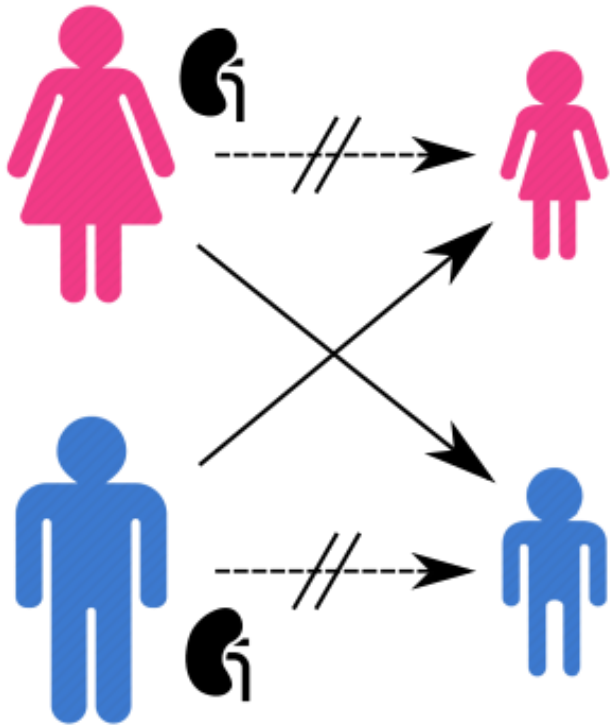
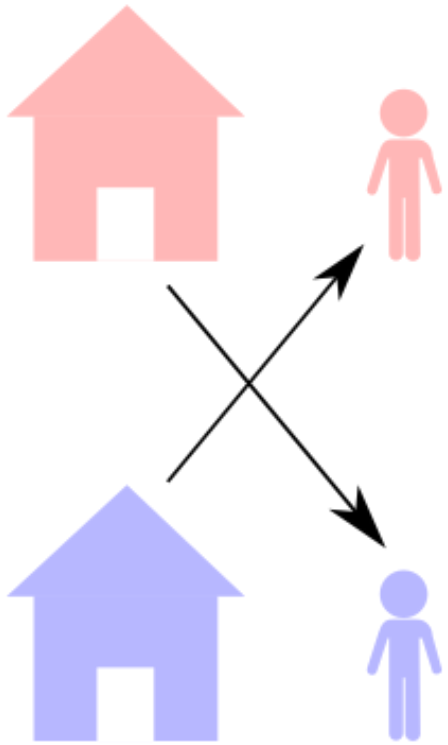


Each patient has a
strict ranking of donors.



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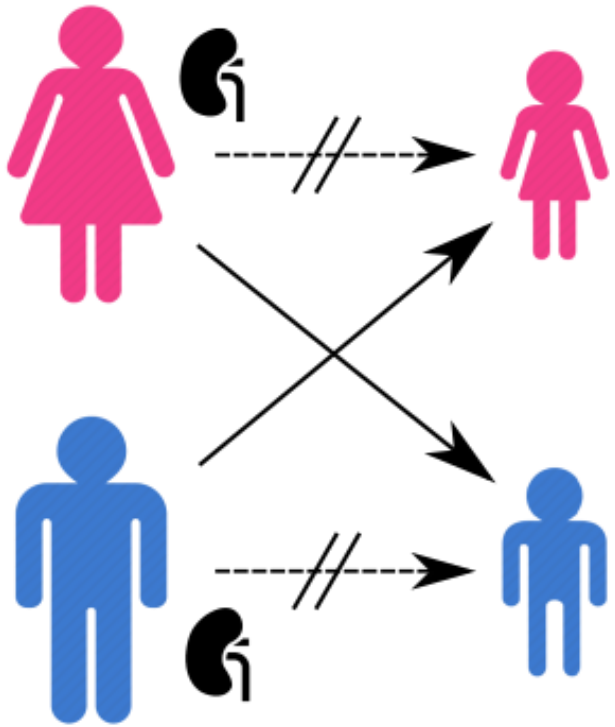

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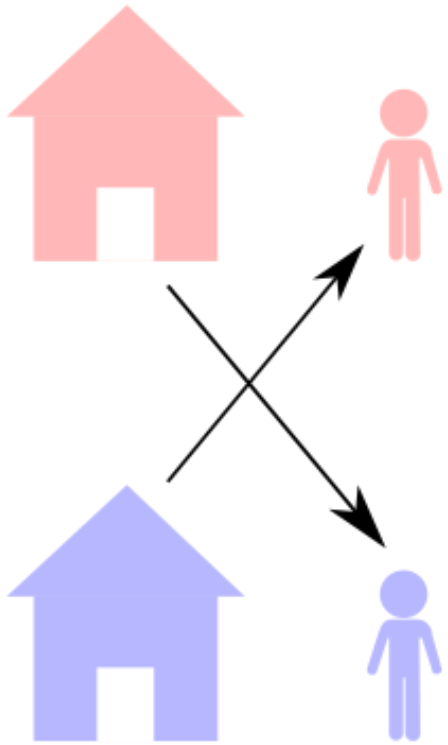

Each agent has a
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(idiosyncratic)

Advantages of Kidney Exchange using TTCA

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No group of patients can strictly improve
by reallocating donors among themselves.

Every patient is (weakly) better off than before.

Polynomial time.

Limitations of Kidney Exchange using TTCA

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In practice, there may be:

- patients without a donor ("agents without a house")
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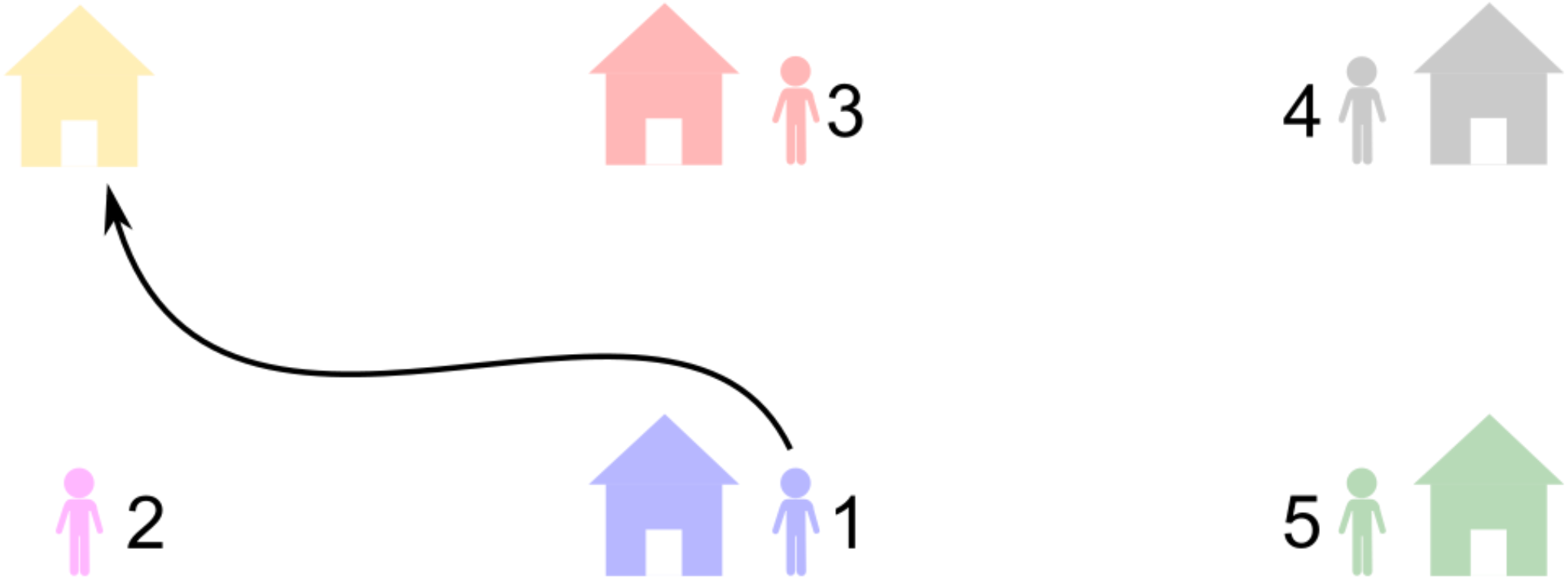

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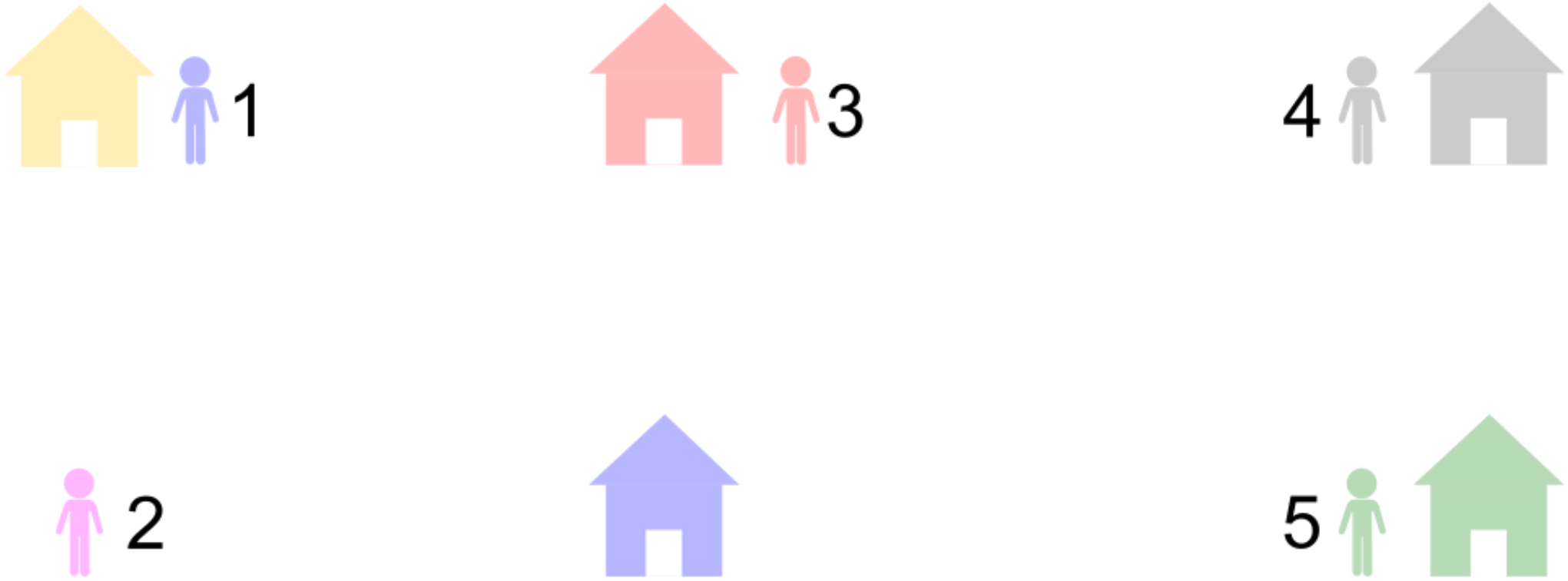

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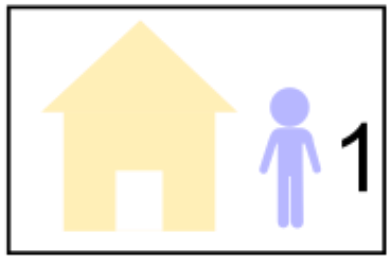

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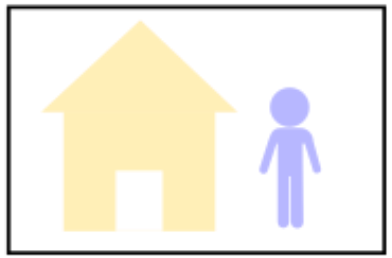

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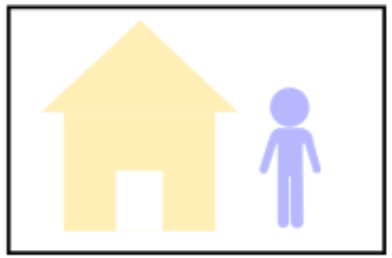

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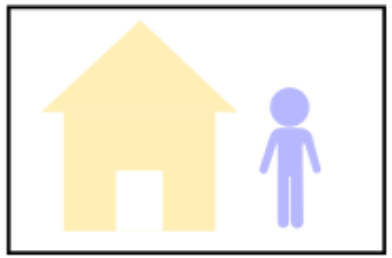

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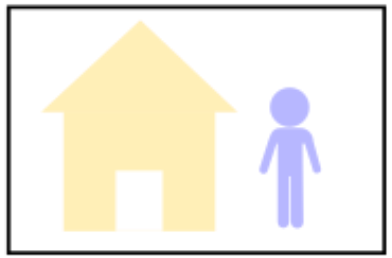

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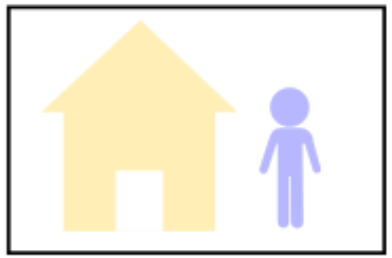

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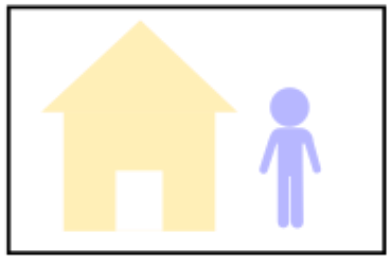

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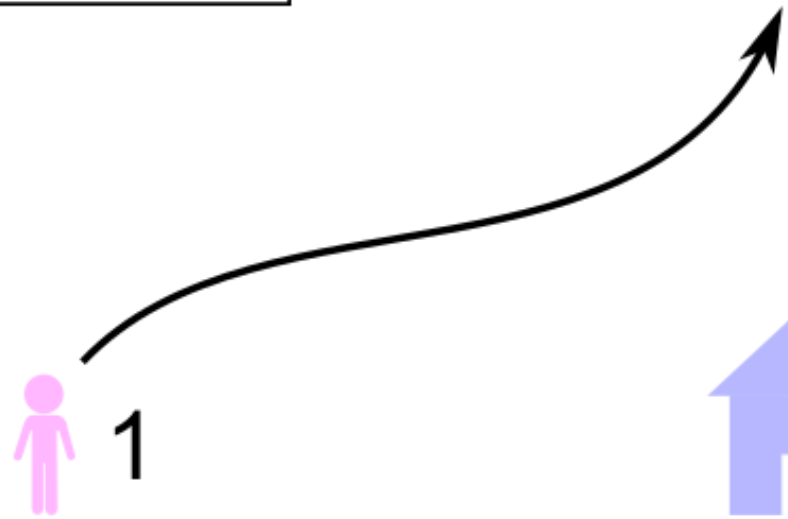

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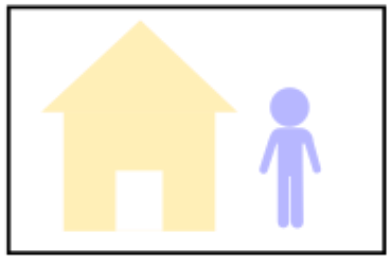

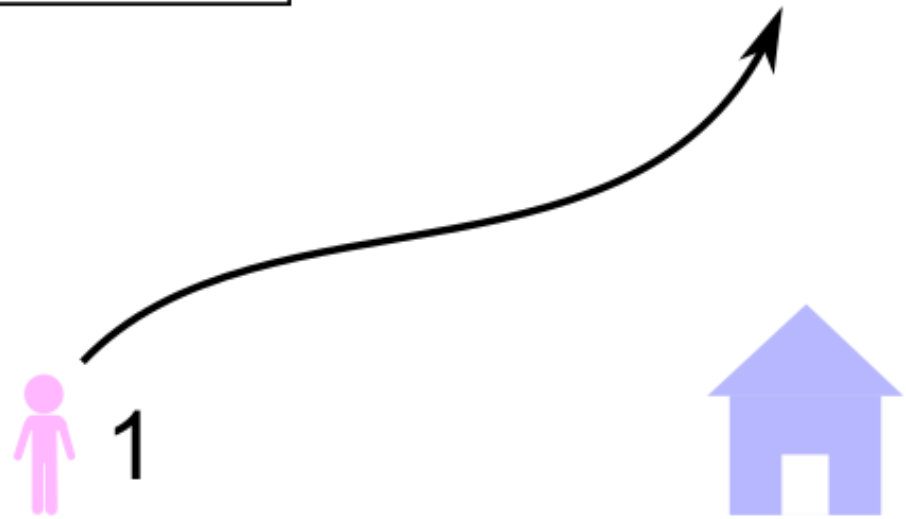

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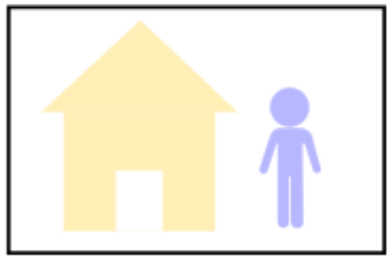

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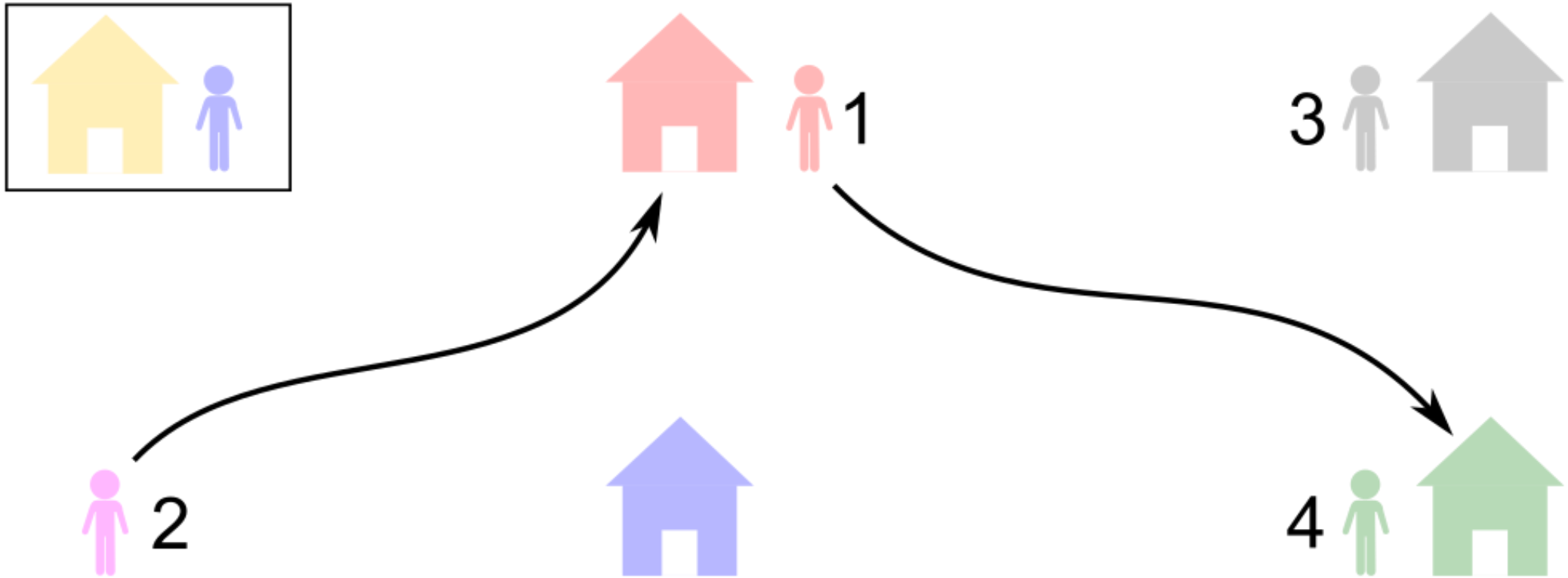

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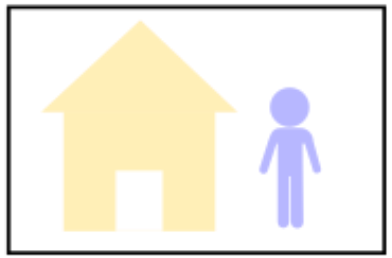

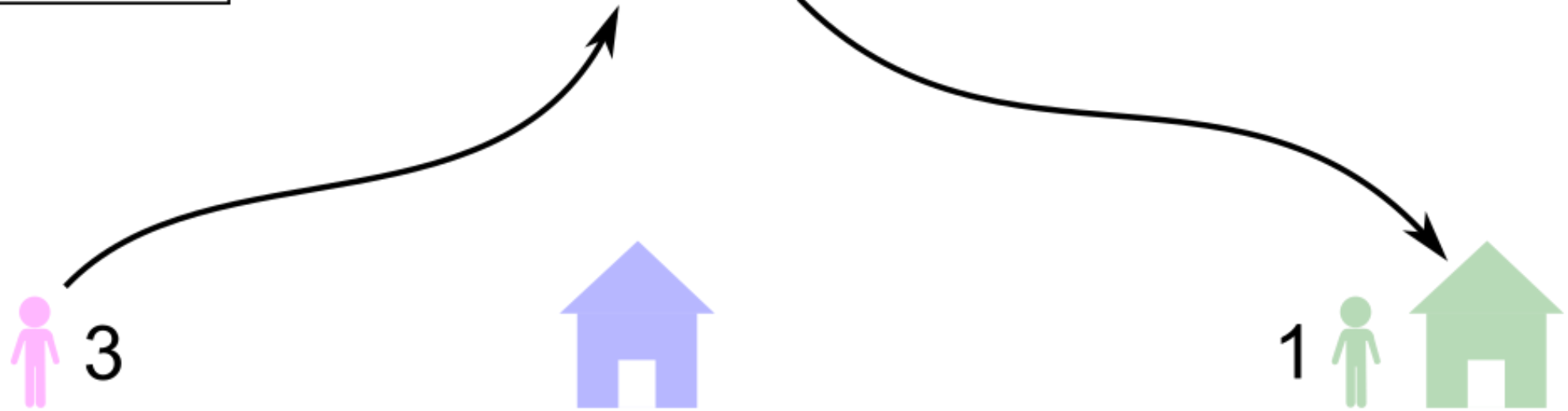

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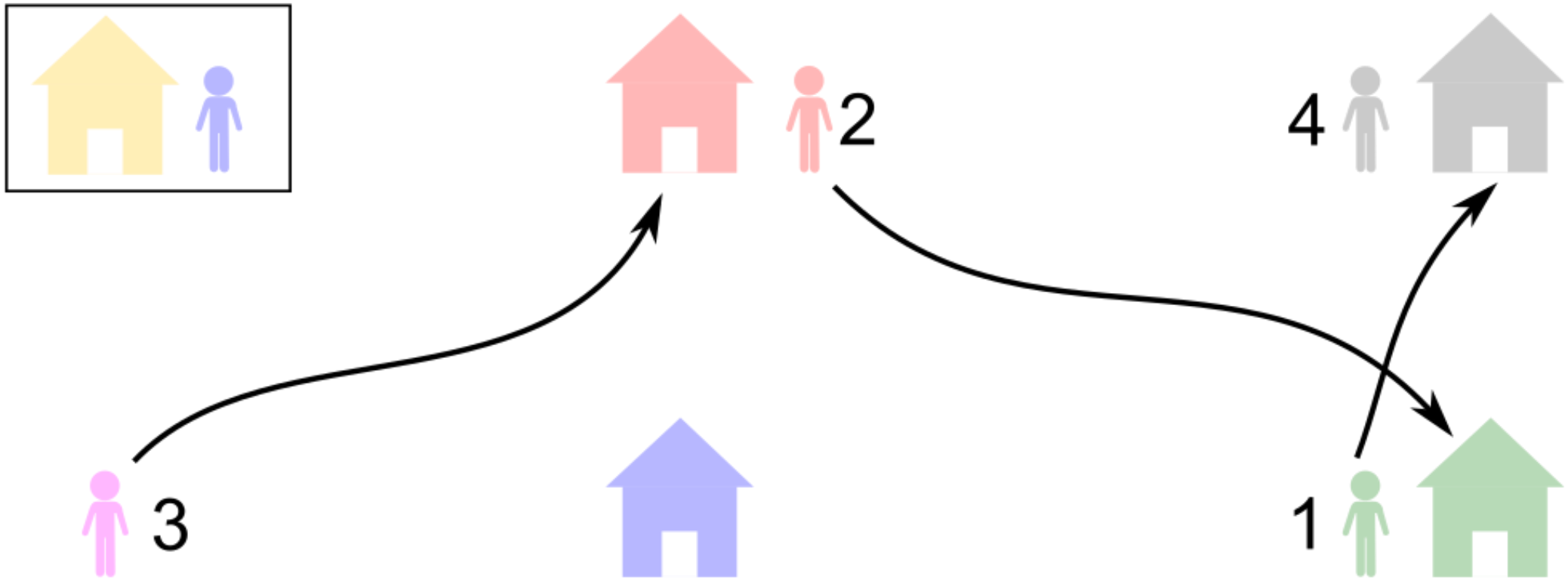

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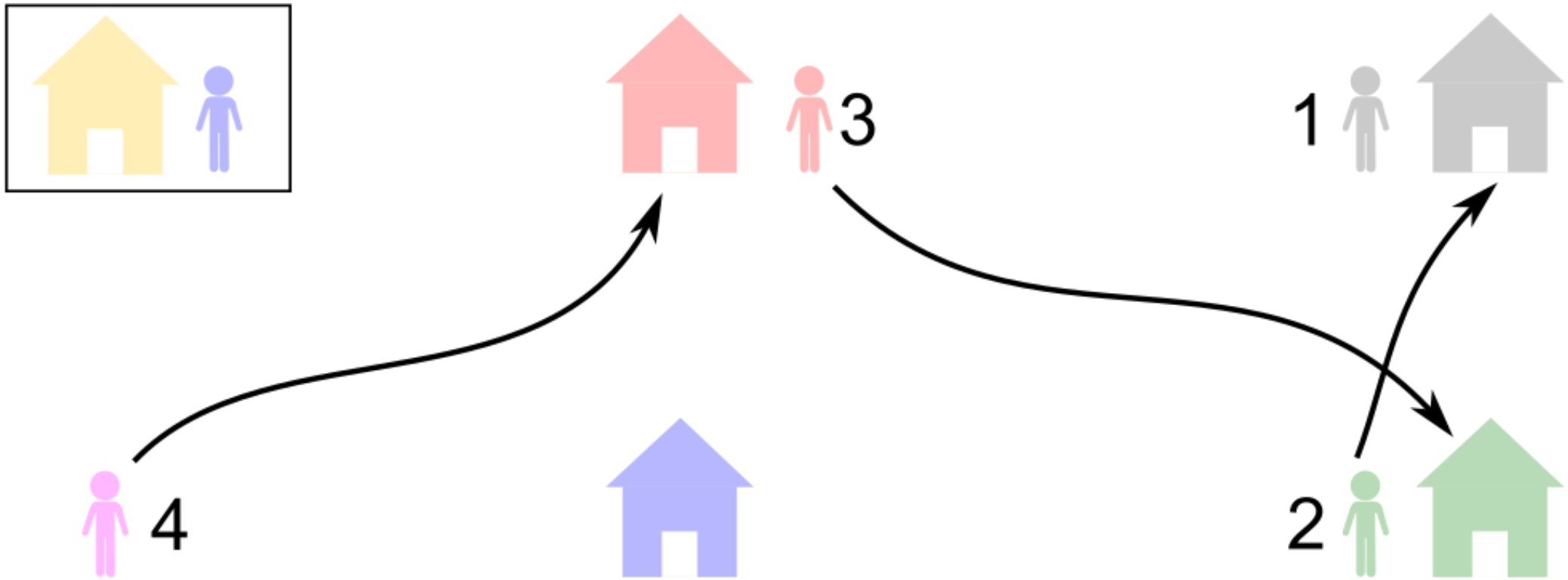

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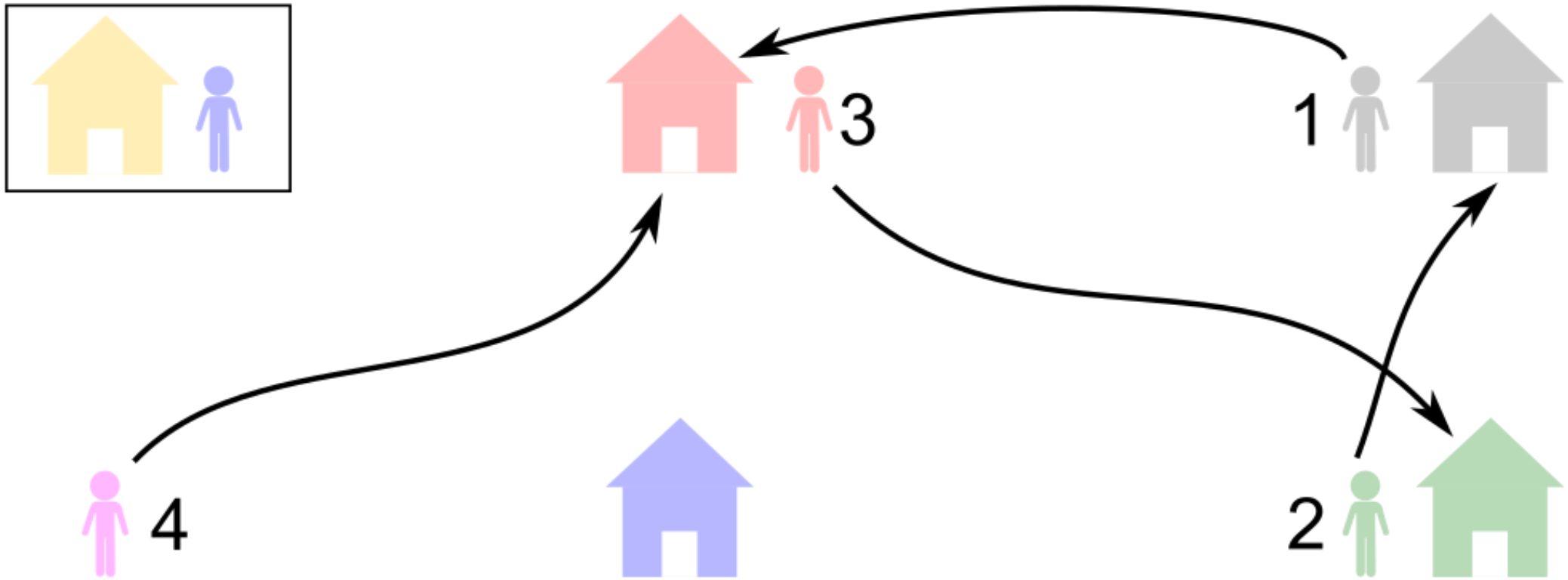

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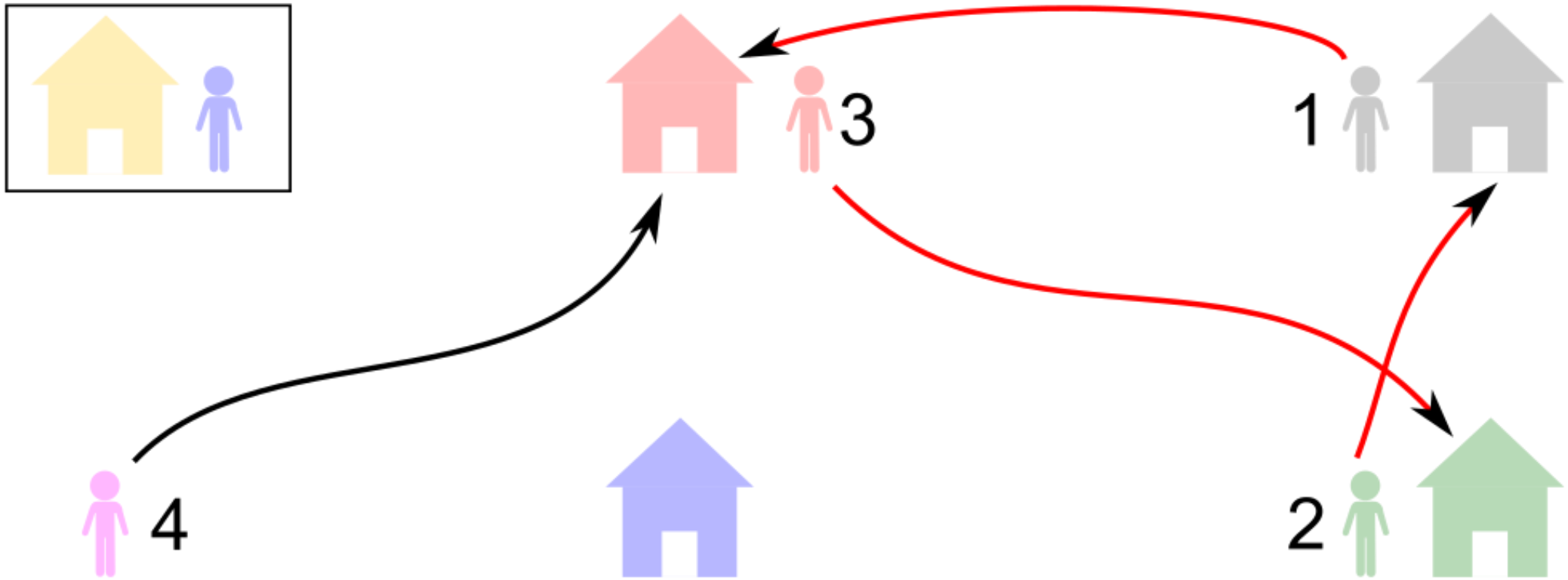

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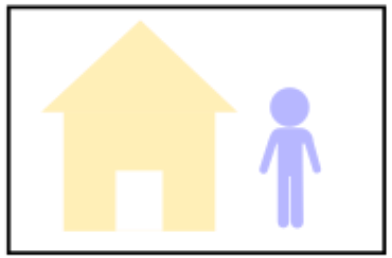

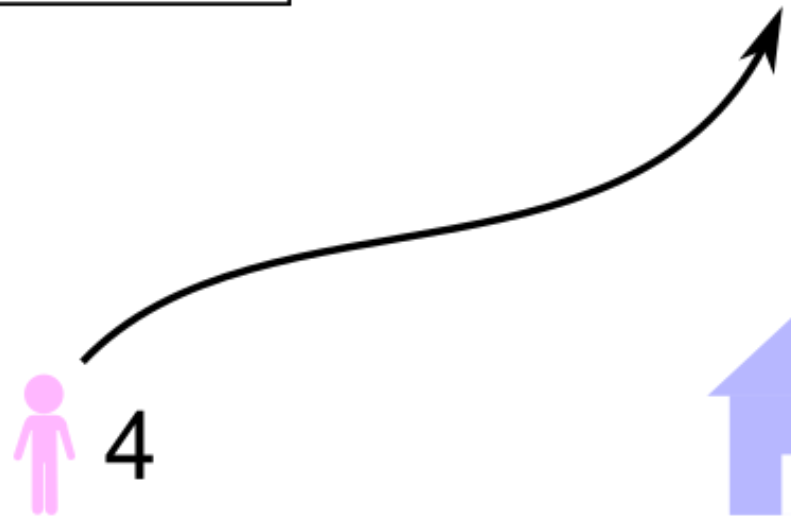

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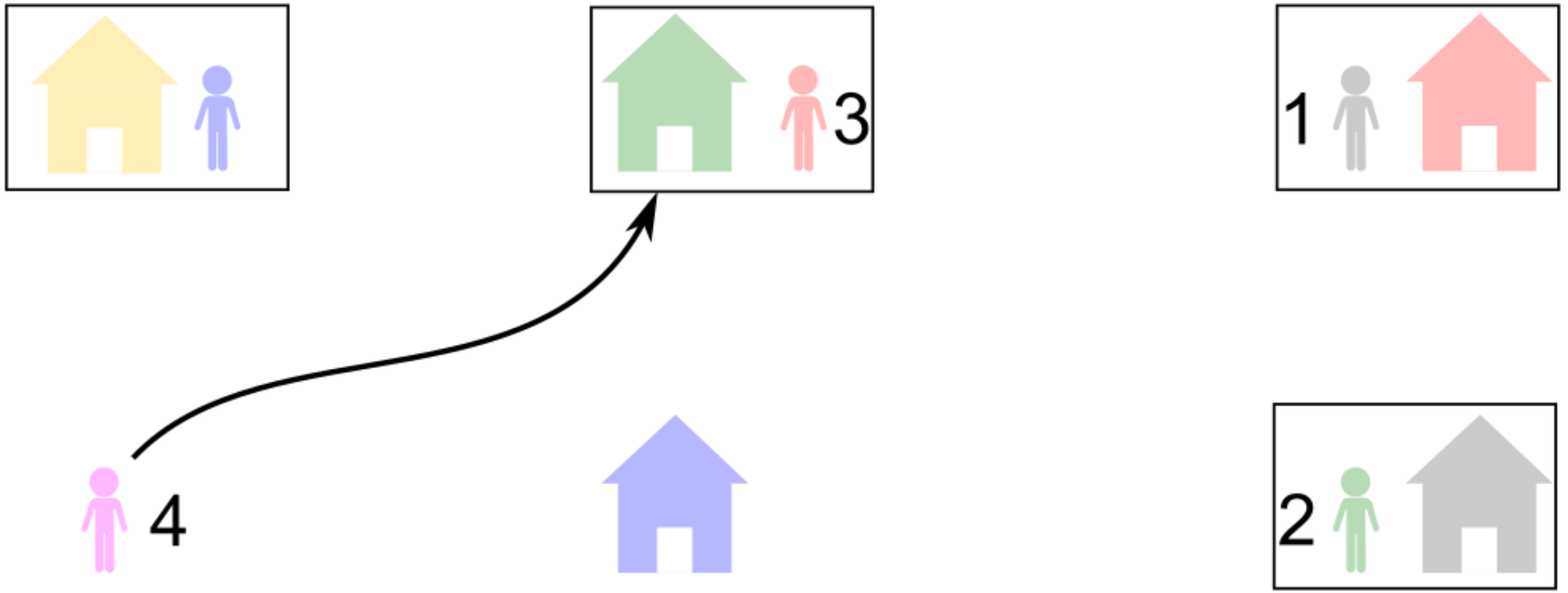

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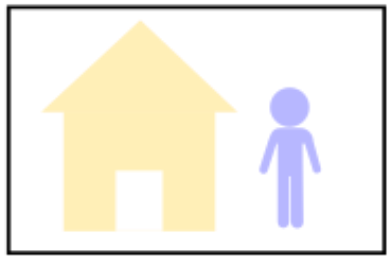

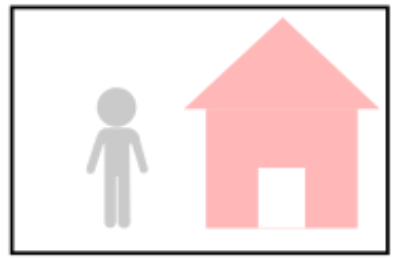

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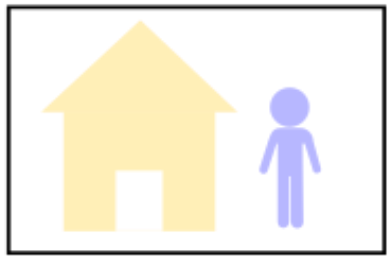

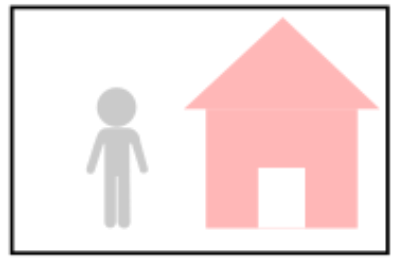

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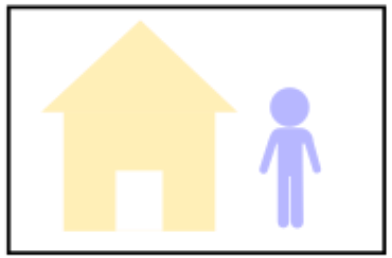

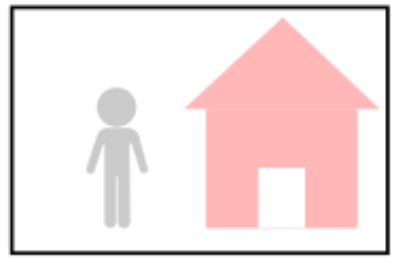

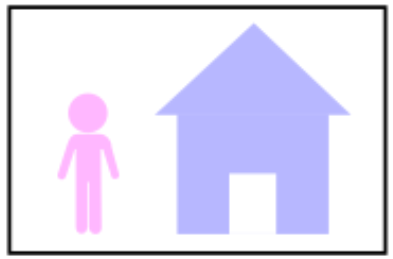

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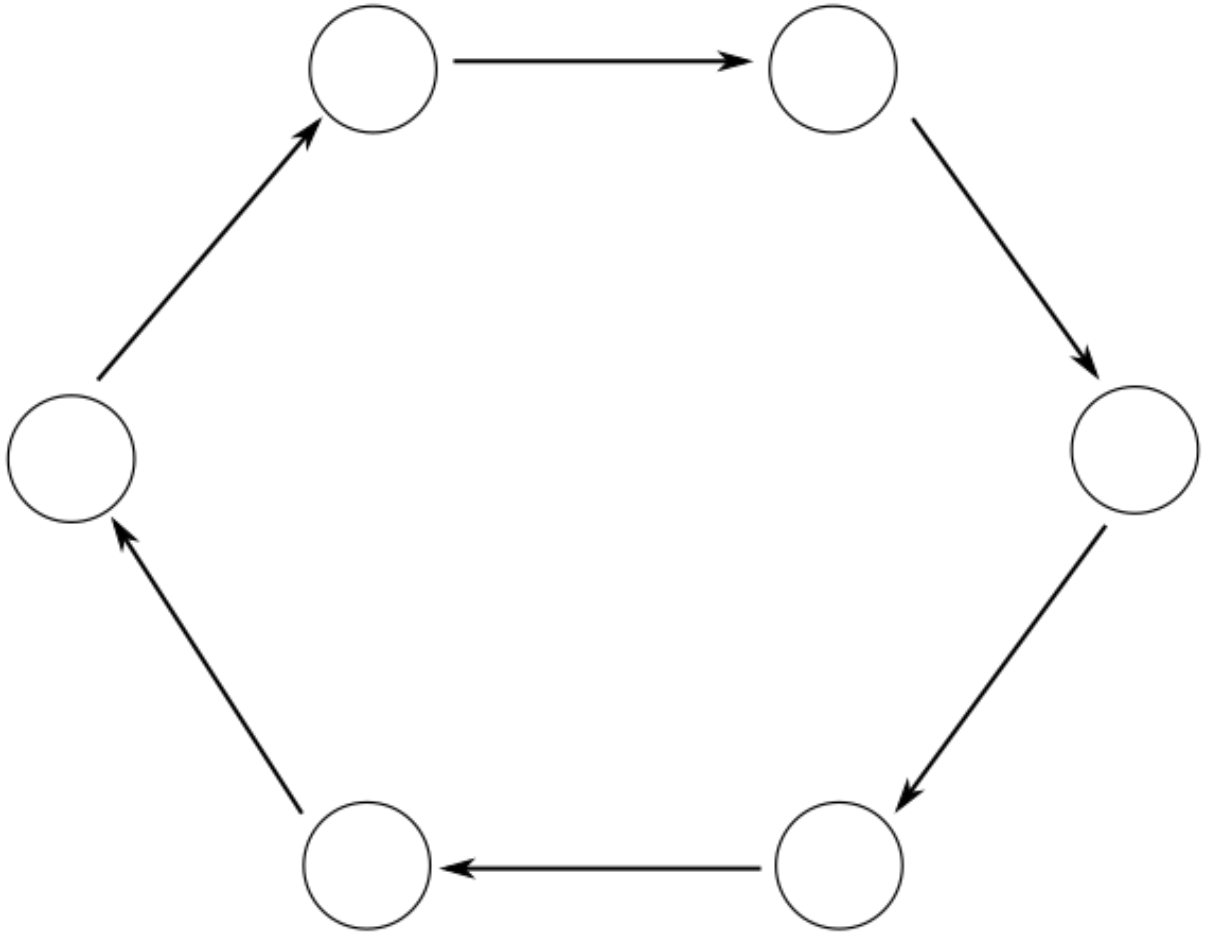

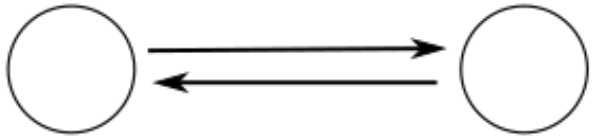

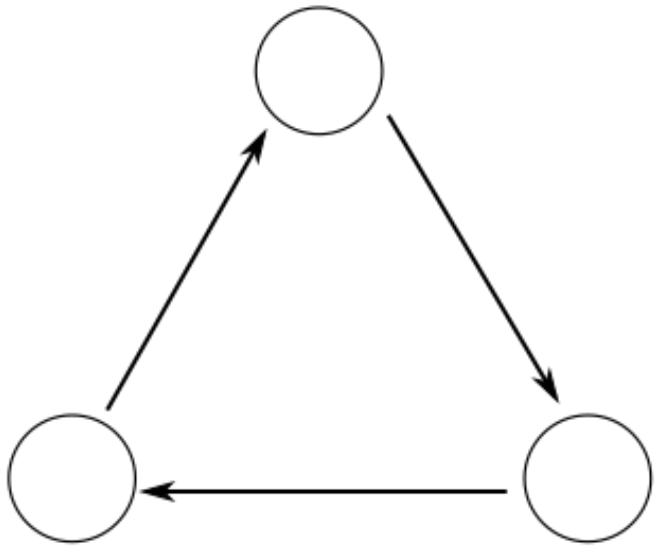

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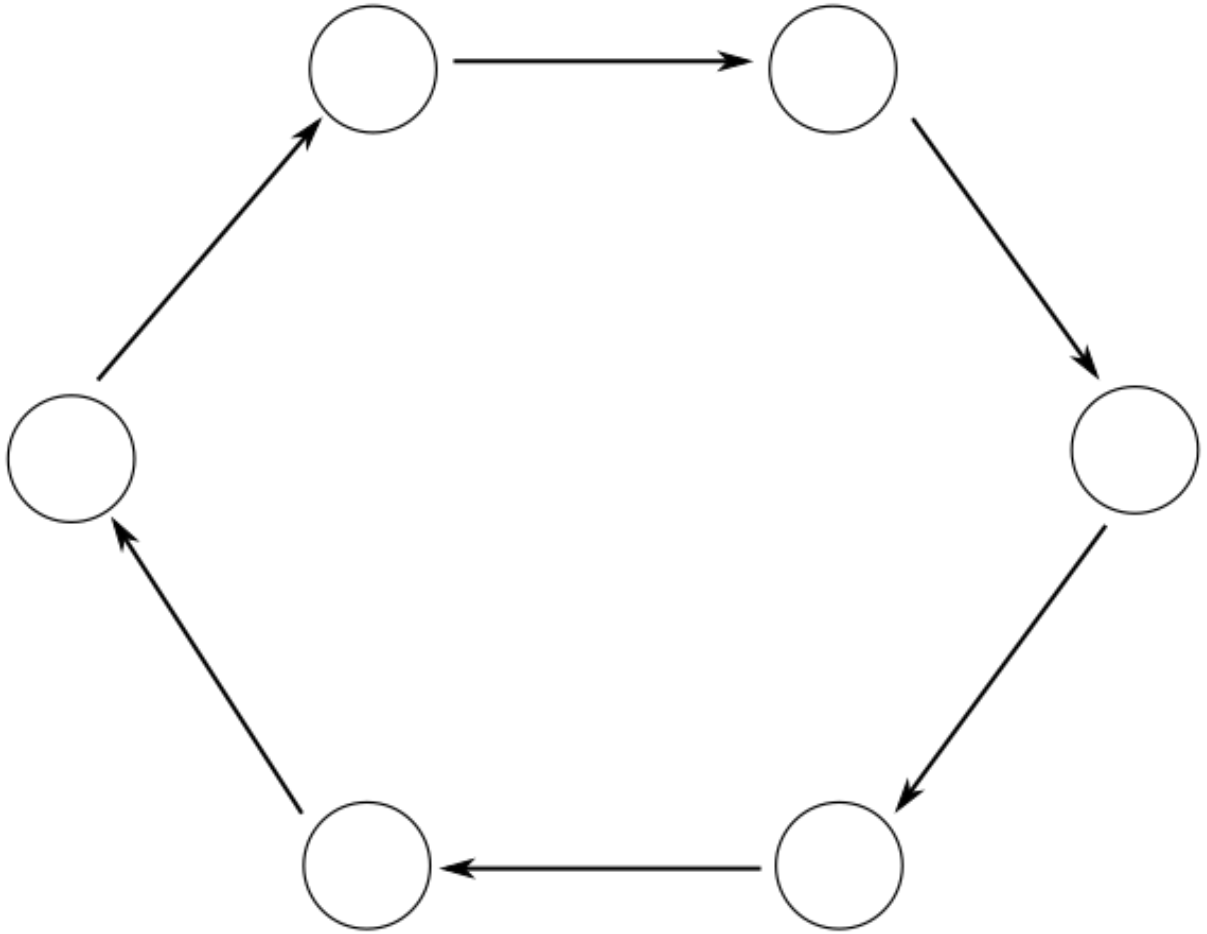

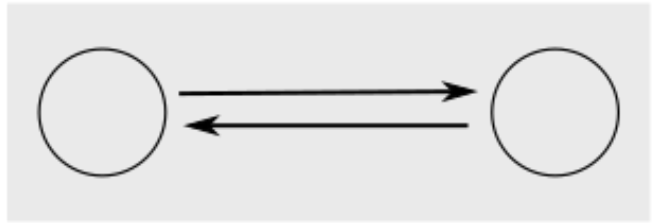

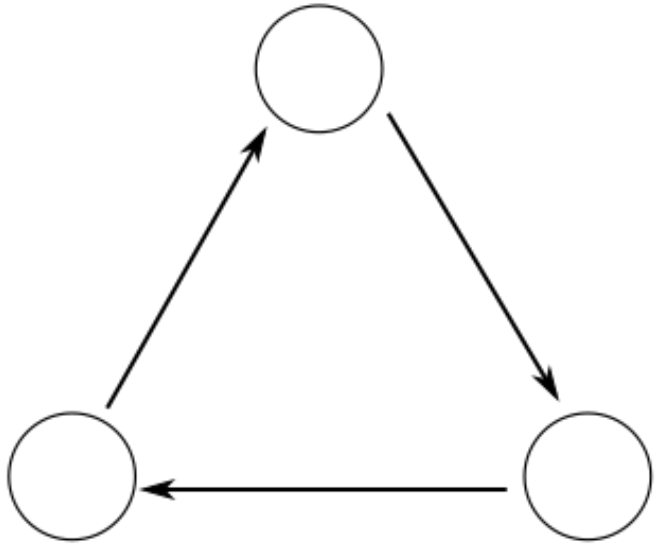

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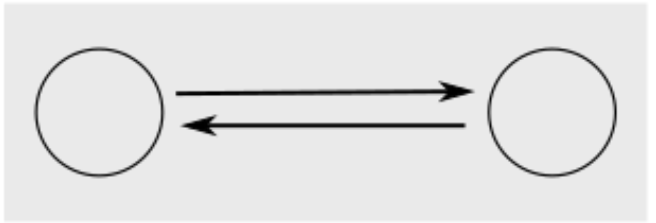

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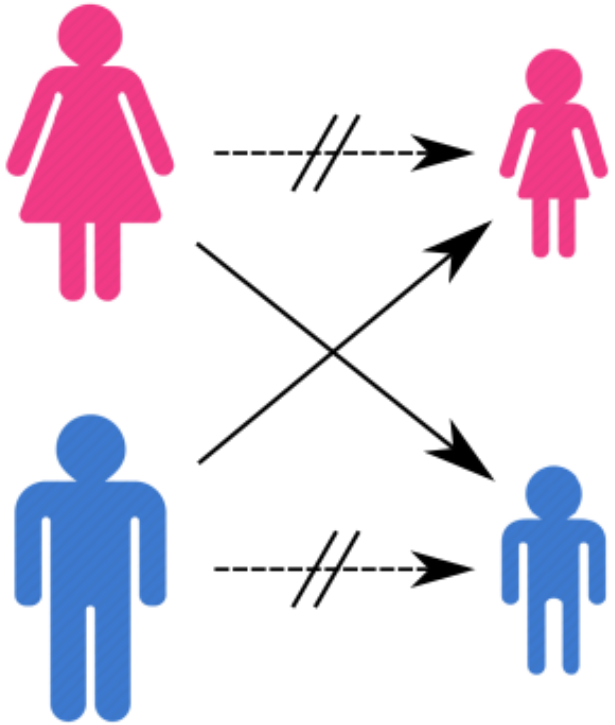

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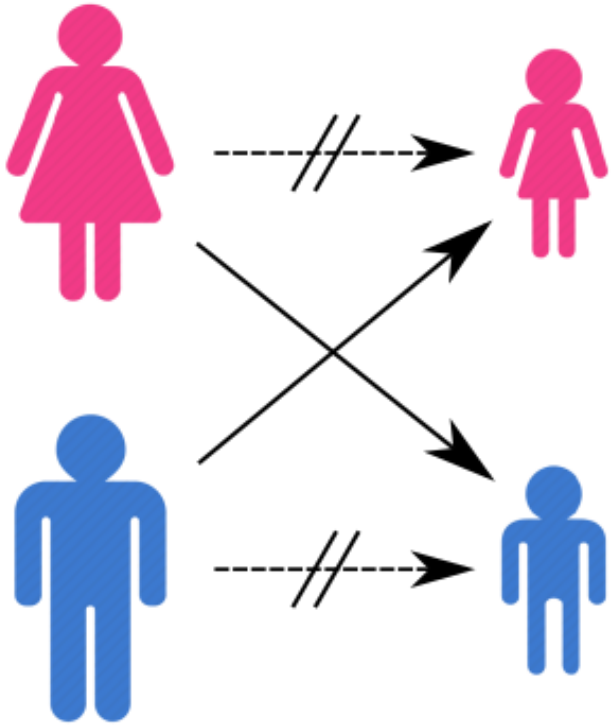

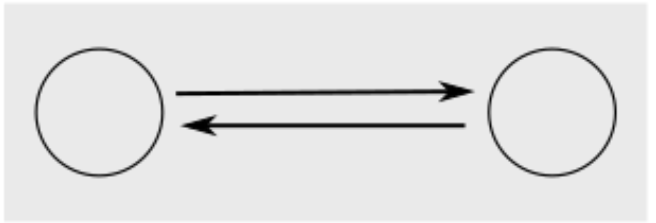

Four surgeries

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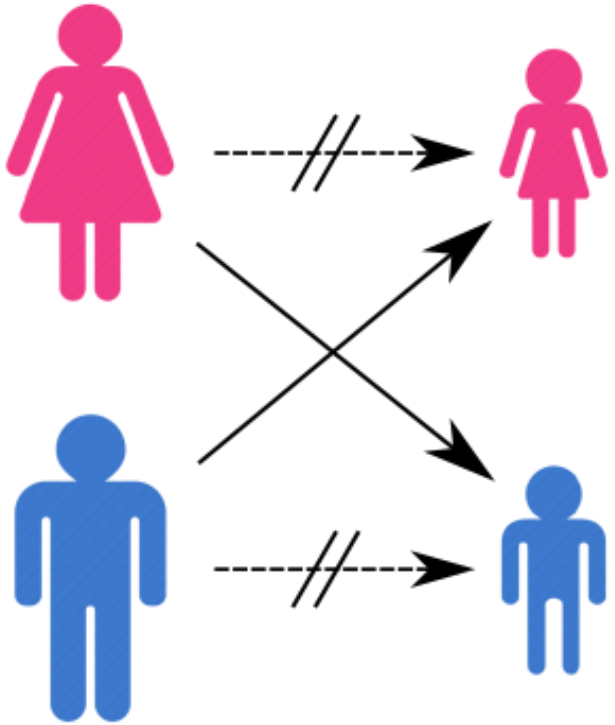

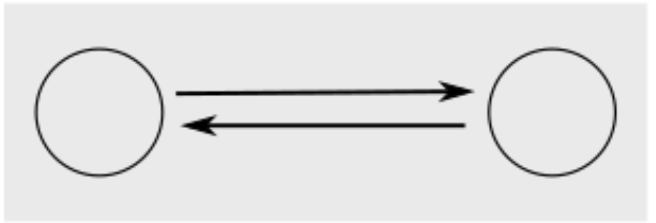

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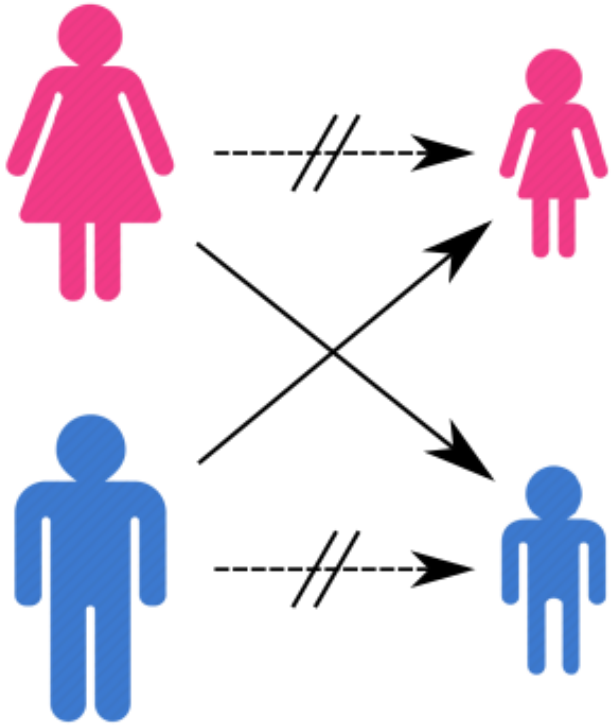

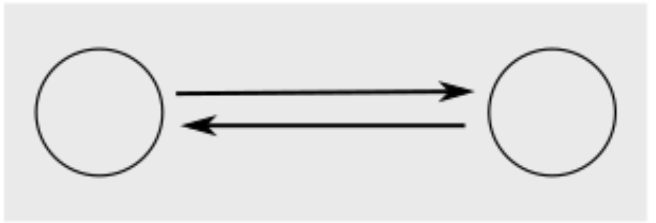

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Cannot risk doing

today

tomorrow

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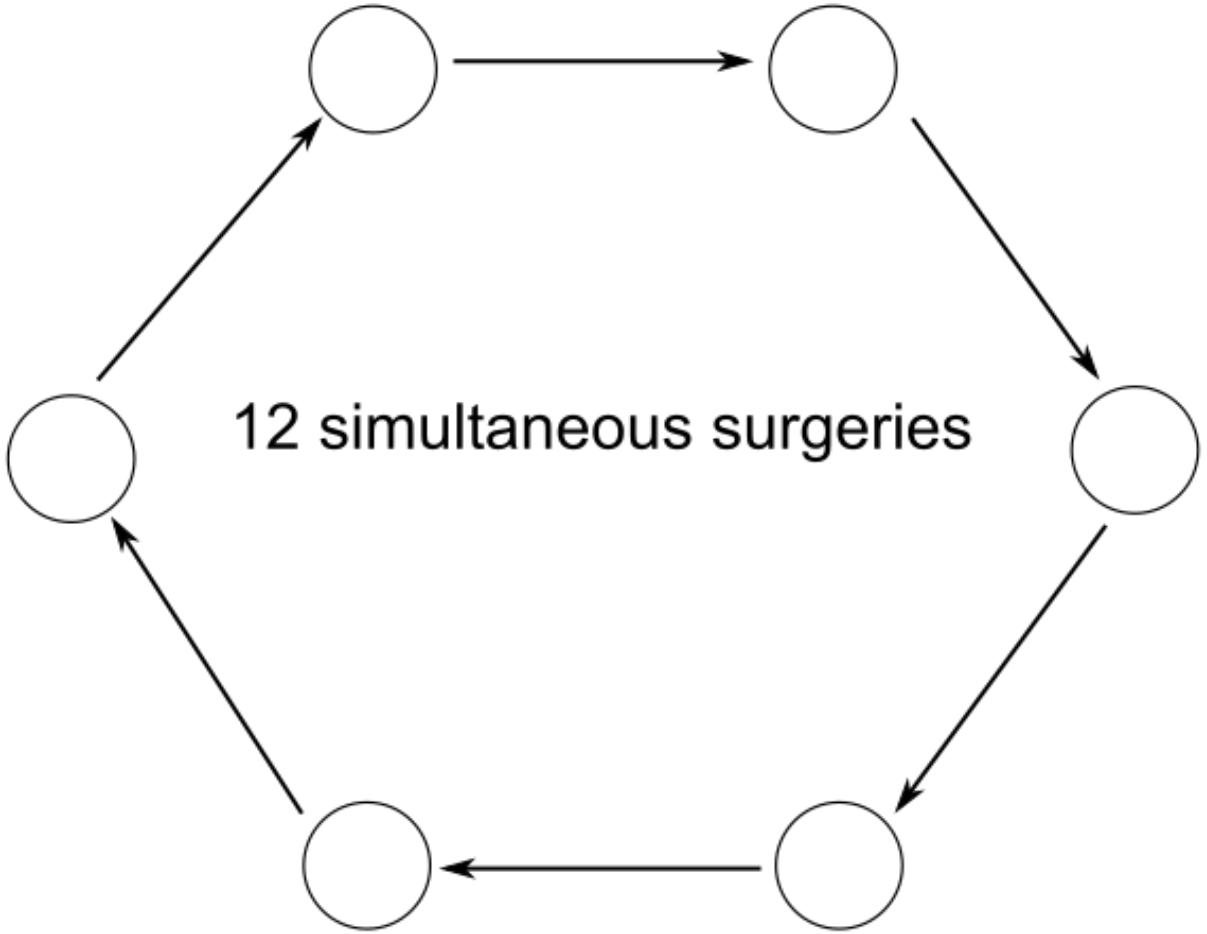
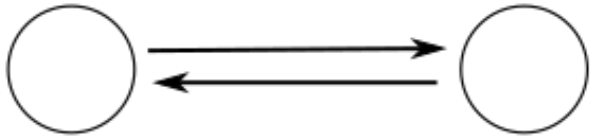
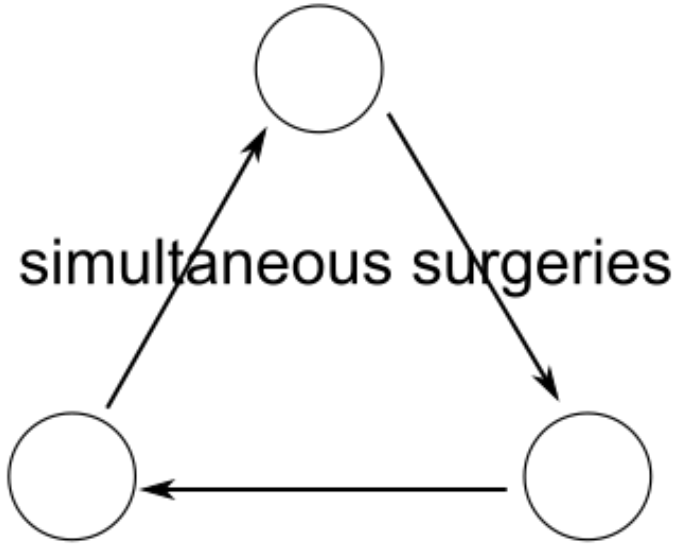


4 simultaneous surgeries





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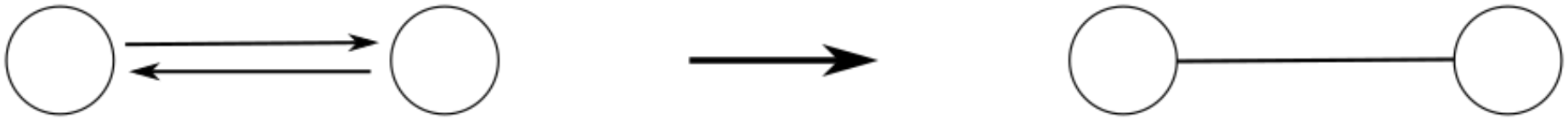

Early Proposals for Kidney Exchange

Proposal 1

Using TTCA

Proposal 2

?

Early Proposals for Kidney Exchange

Proposal 1

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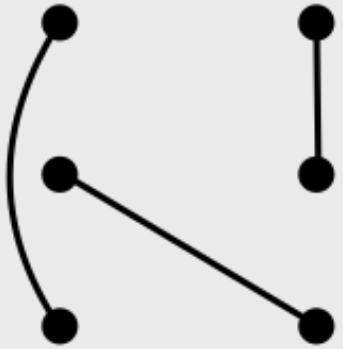
Proposal 2

Using Matchings



Proposal 2: Kidney Exchange using Matchings

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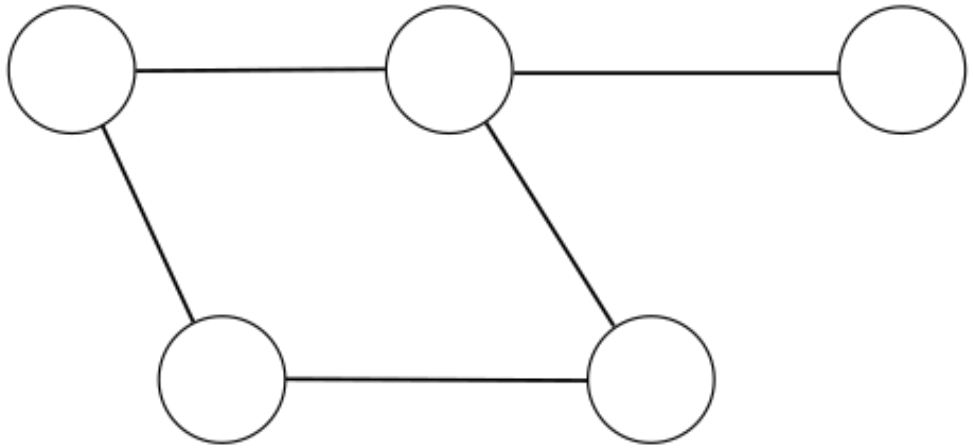

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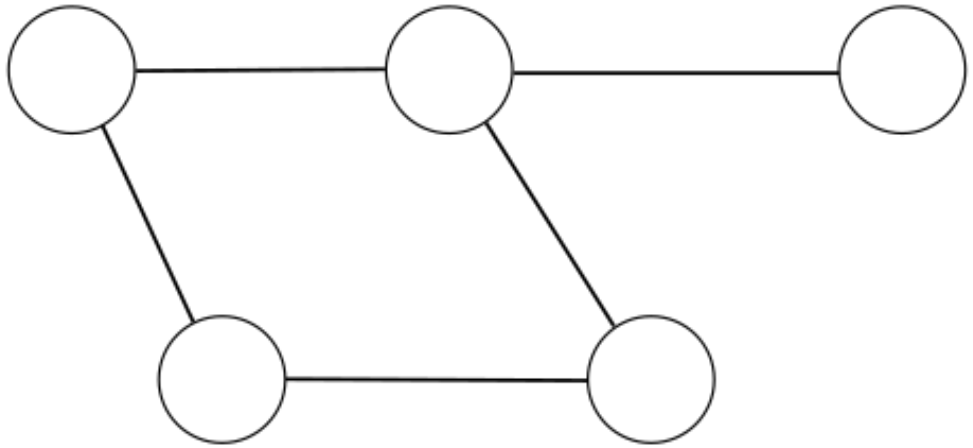

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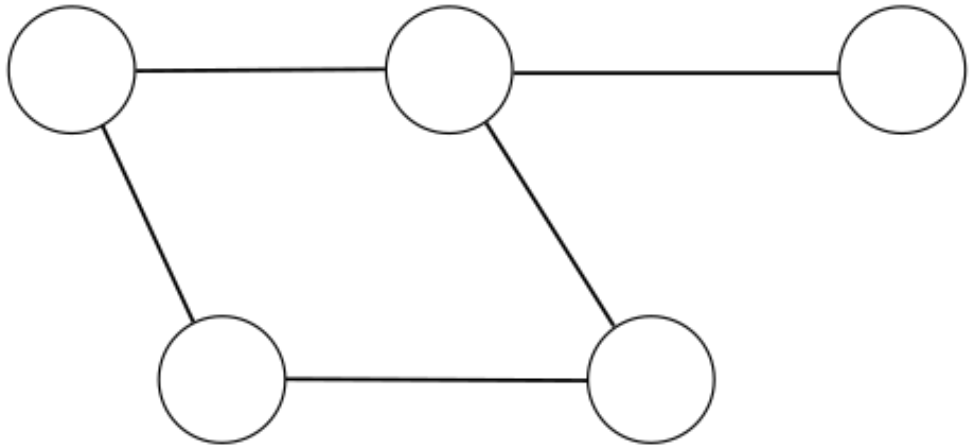

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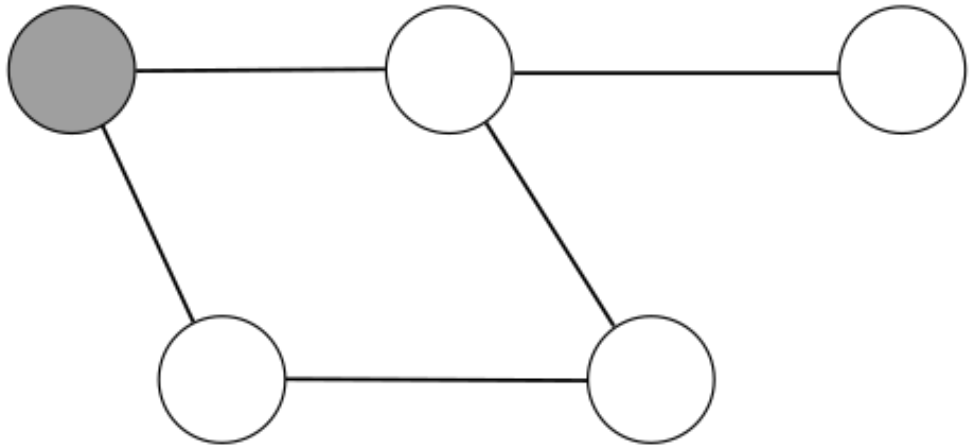

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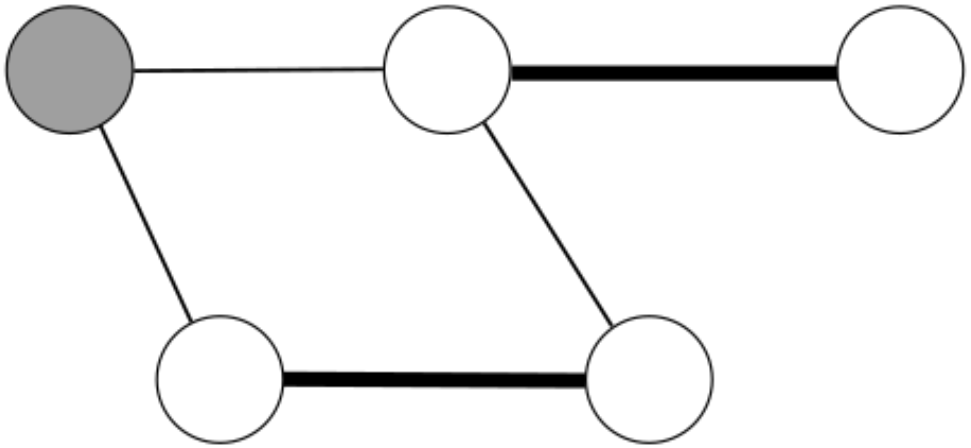

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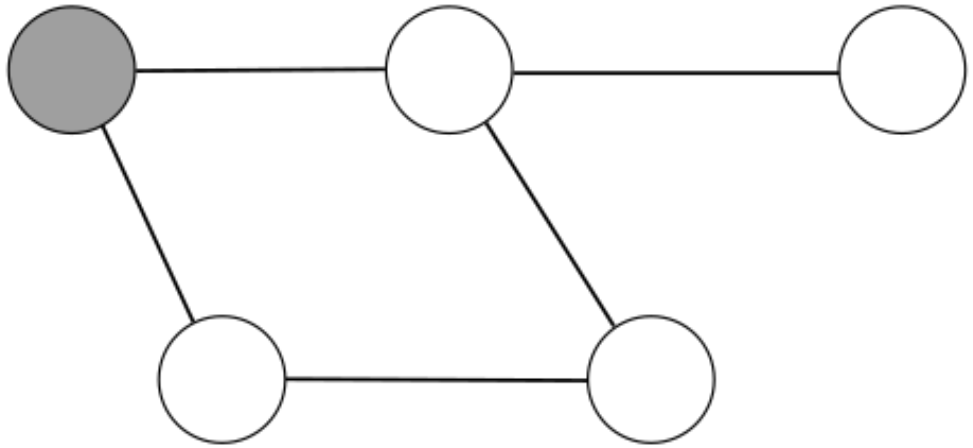

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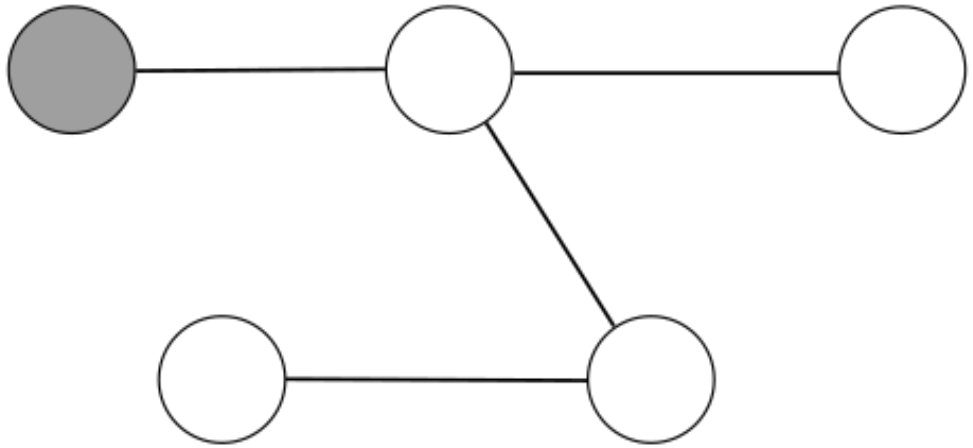

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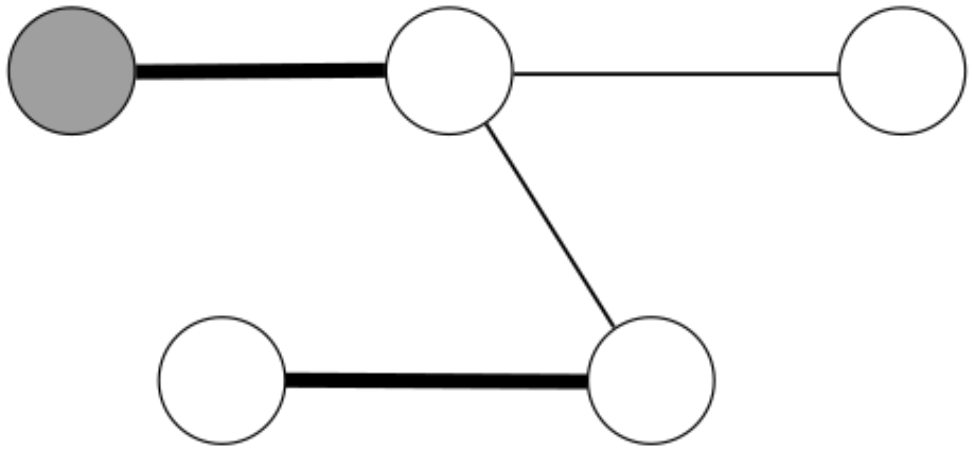

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Polynomial time
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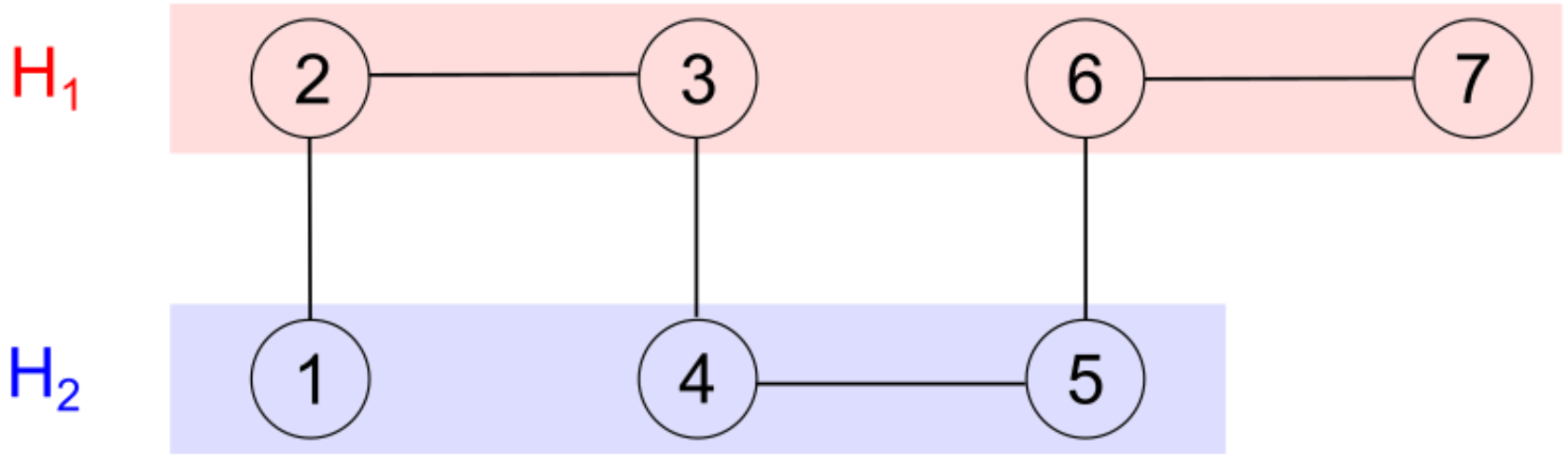

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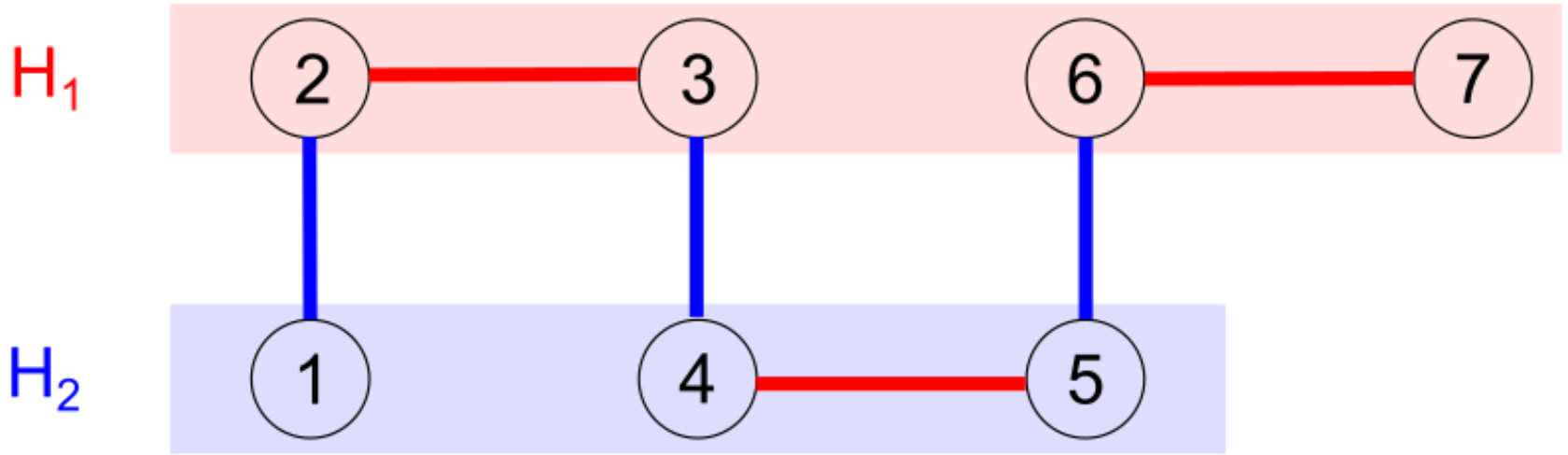

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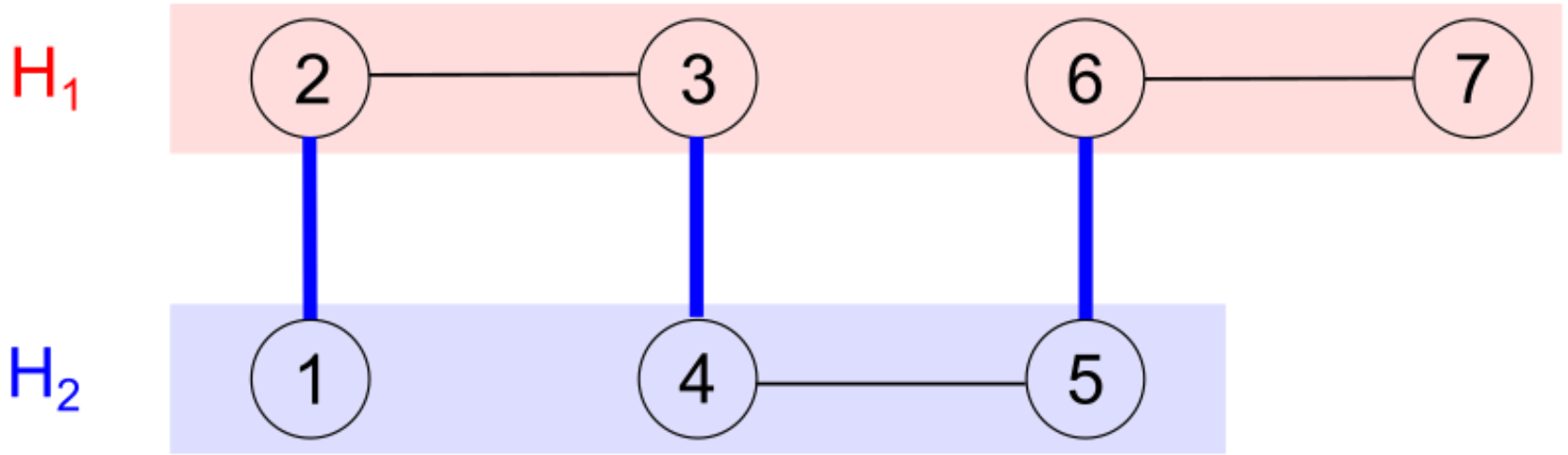

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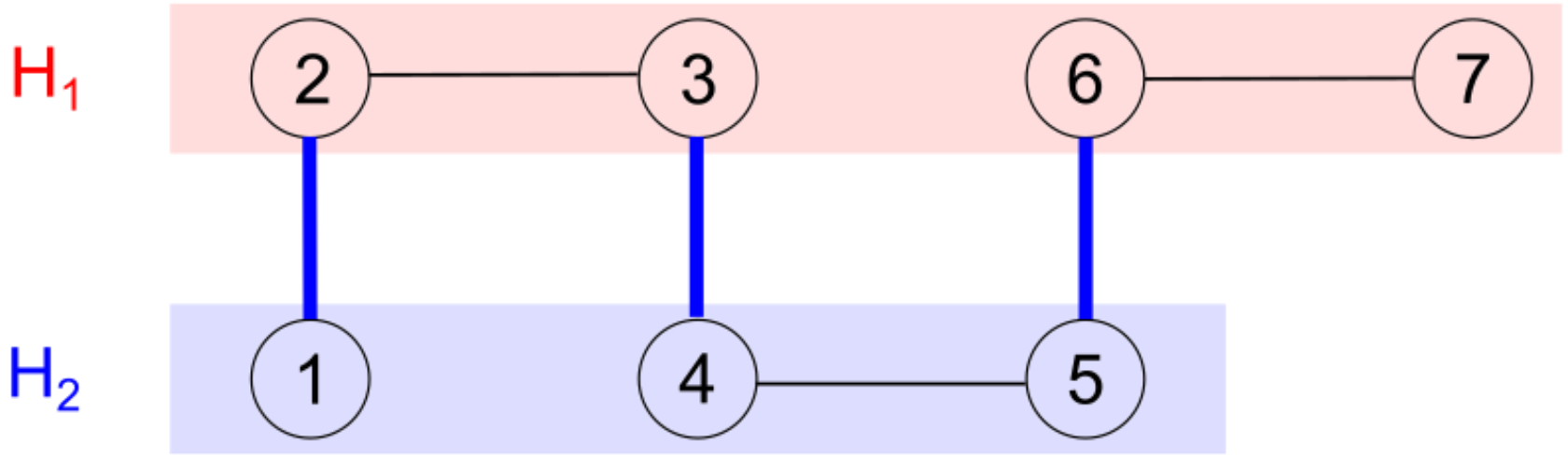

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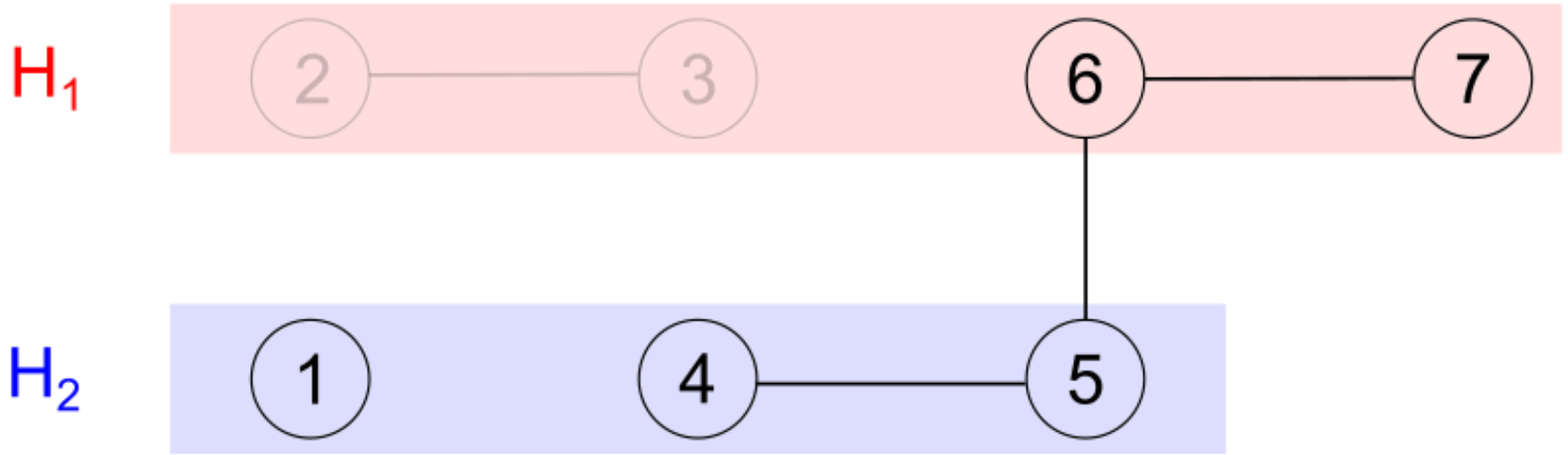

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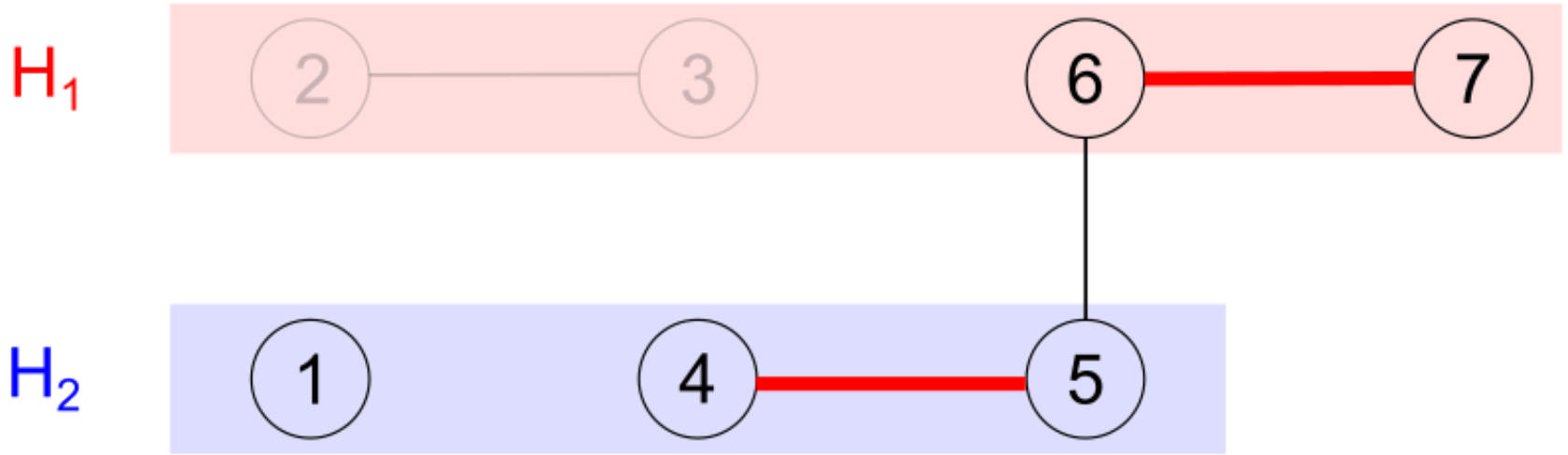

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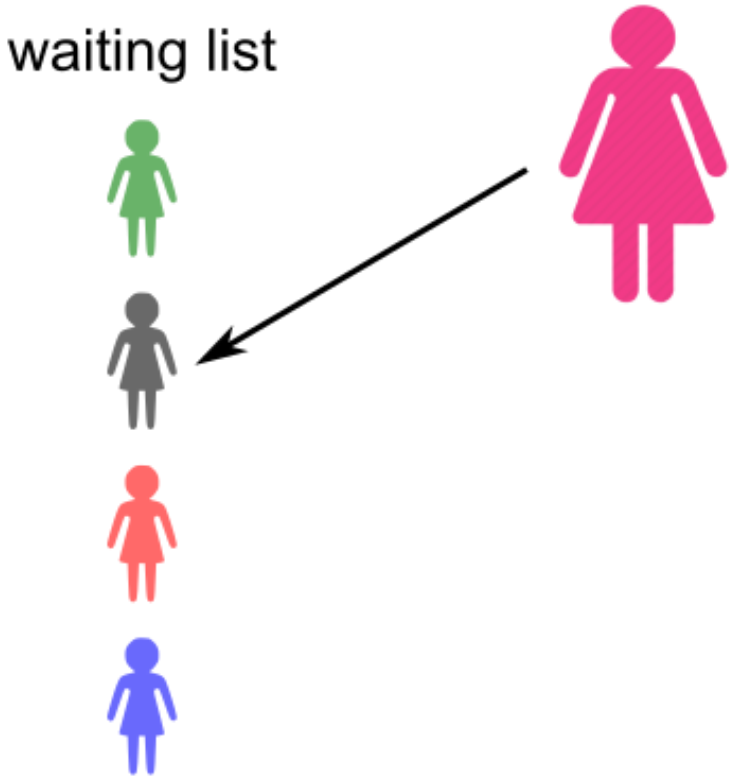

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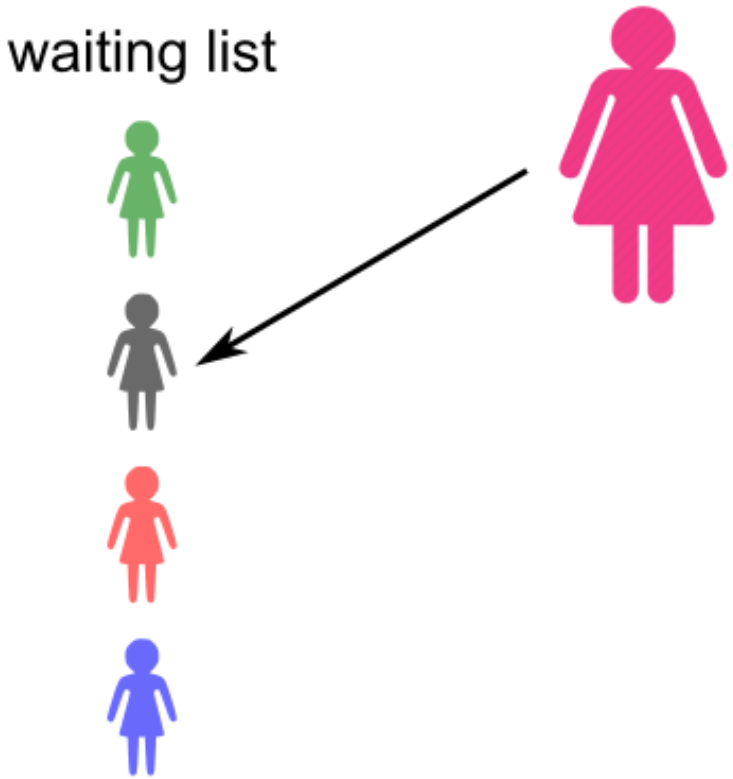

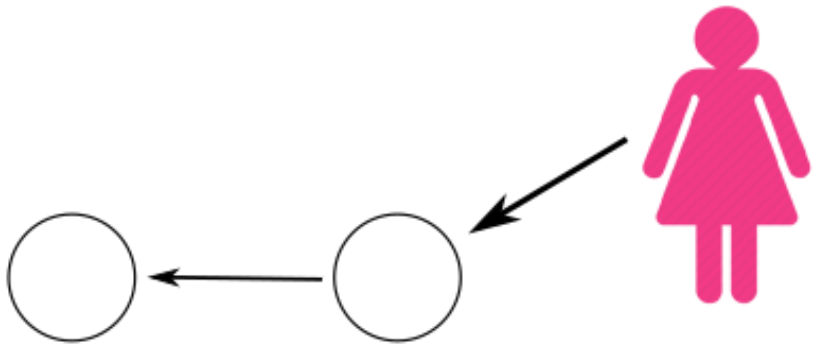

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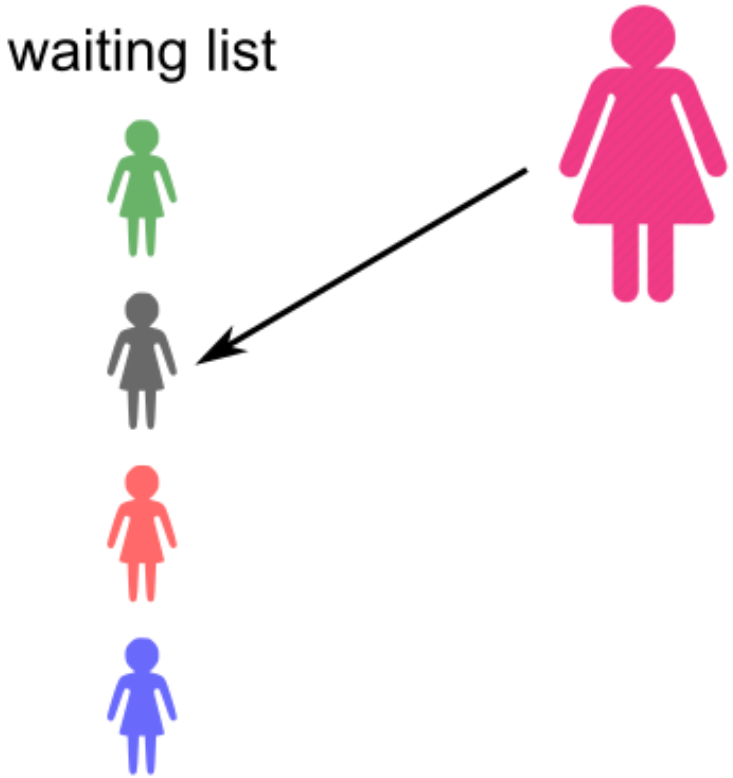

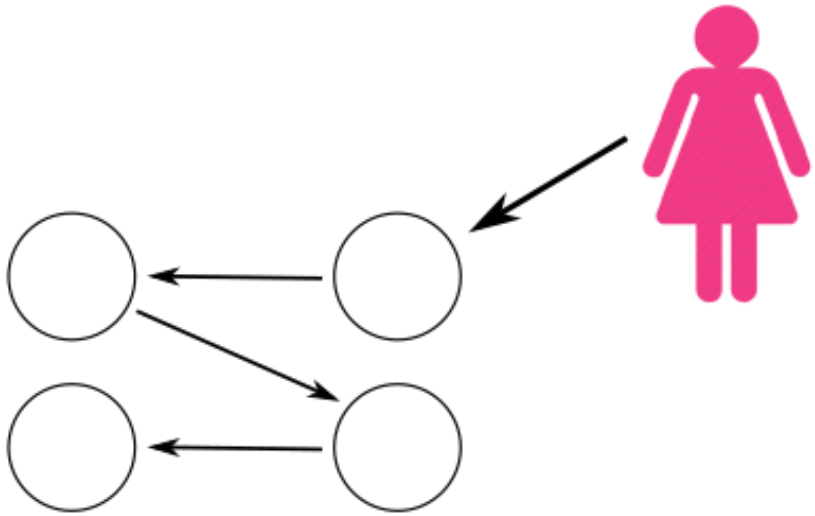

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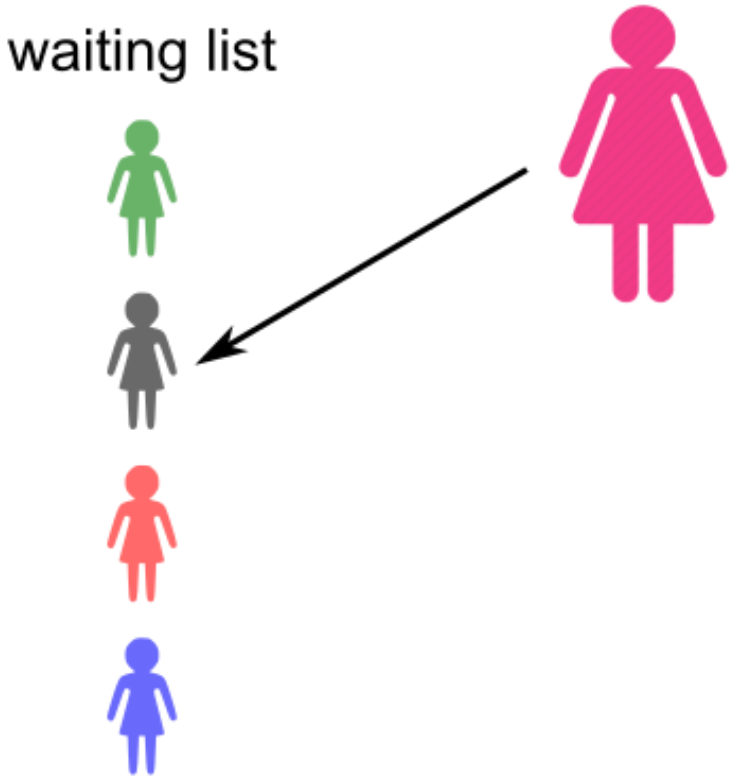

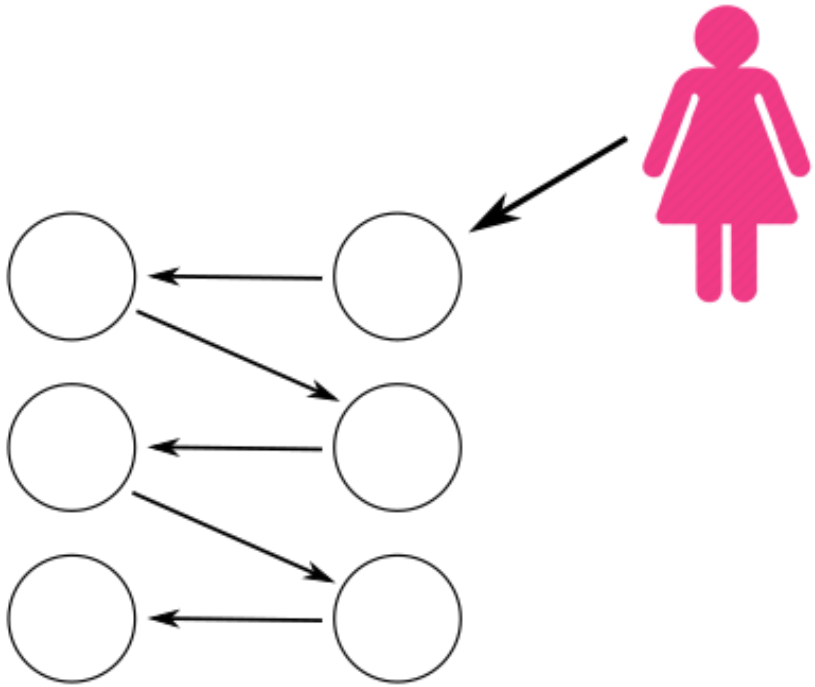

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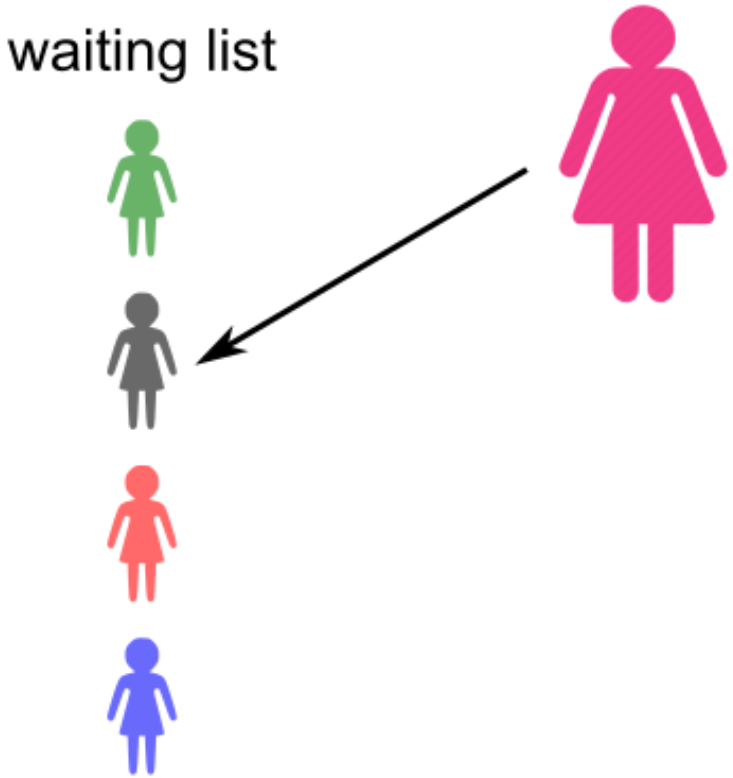

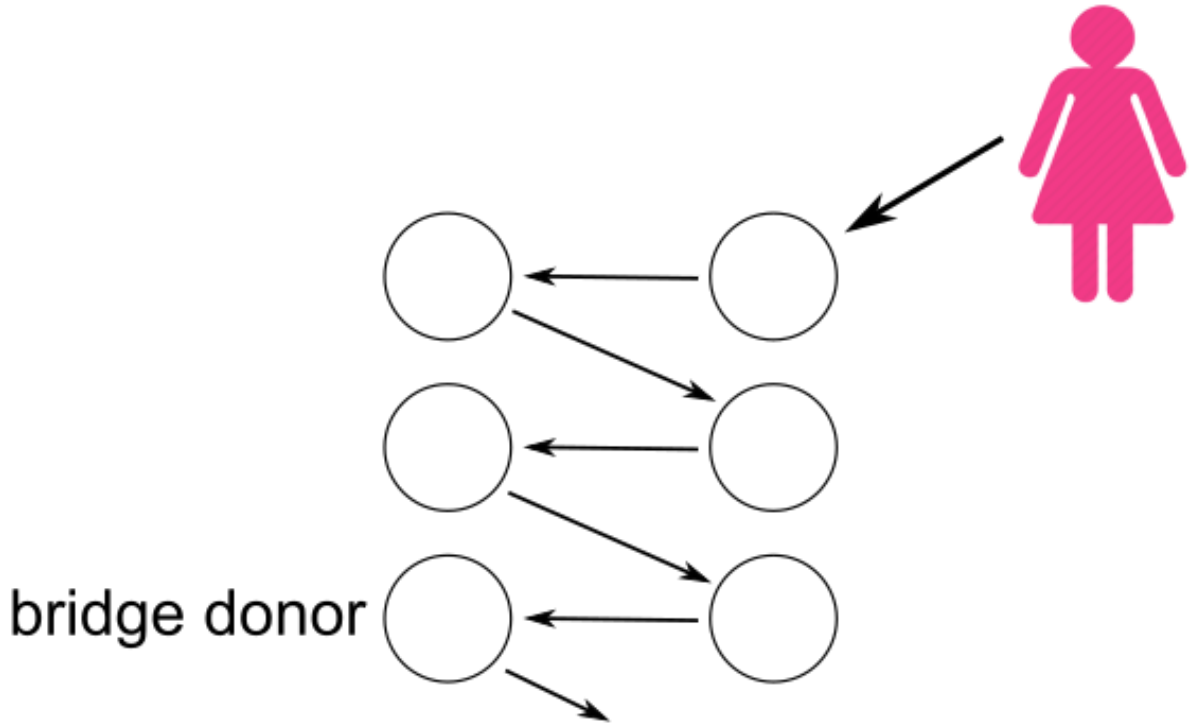

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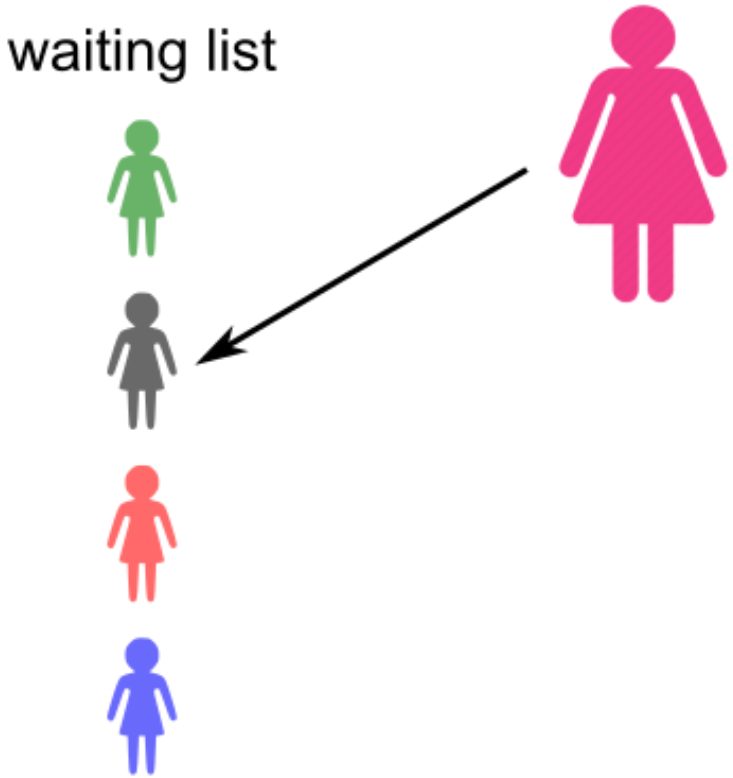
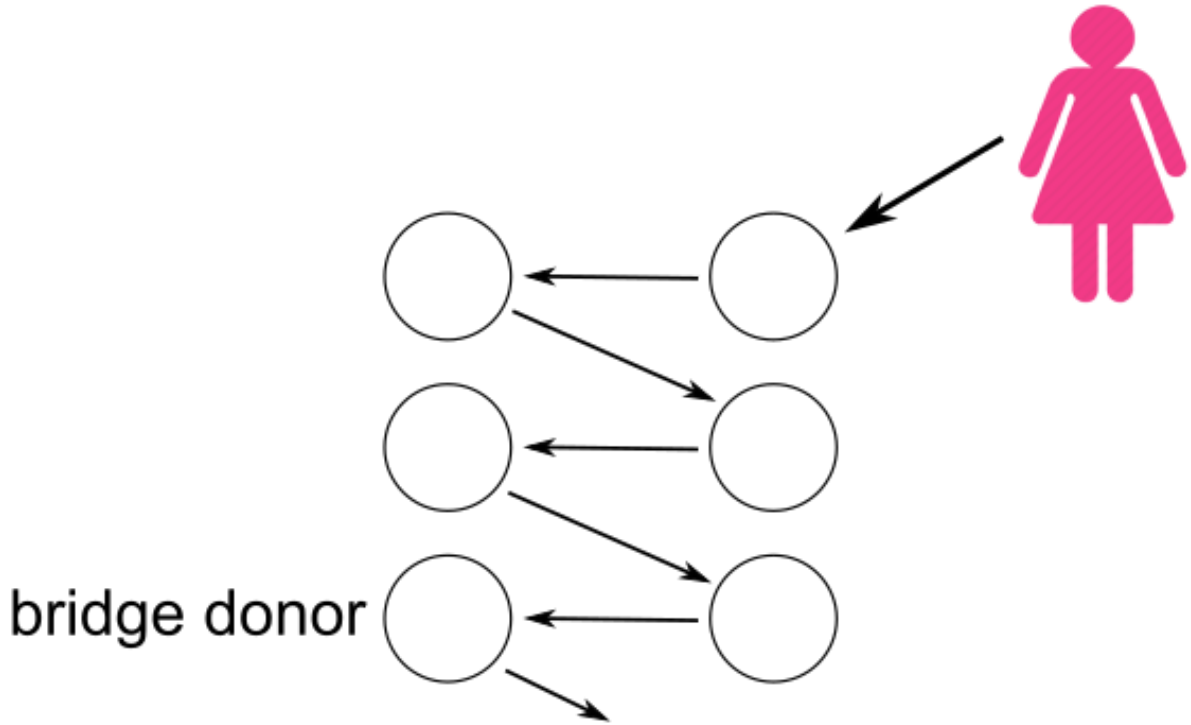




Transplants in an altruistic donor chain can be done non-simultaneously.

THE KIDNEY CHAIN

How a single organ donation changed 20 lives and created the longest-running transplant chain

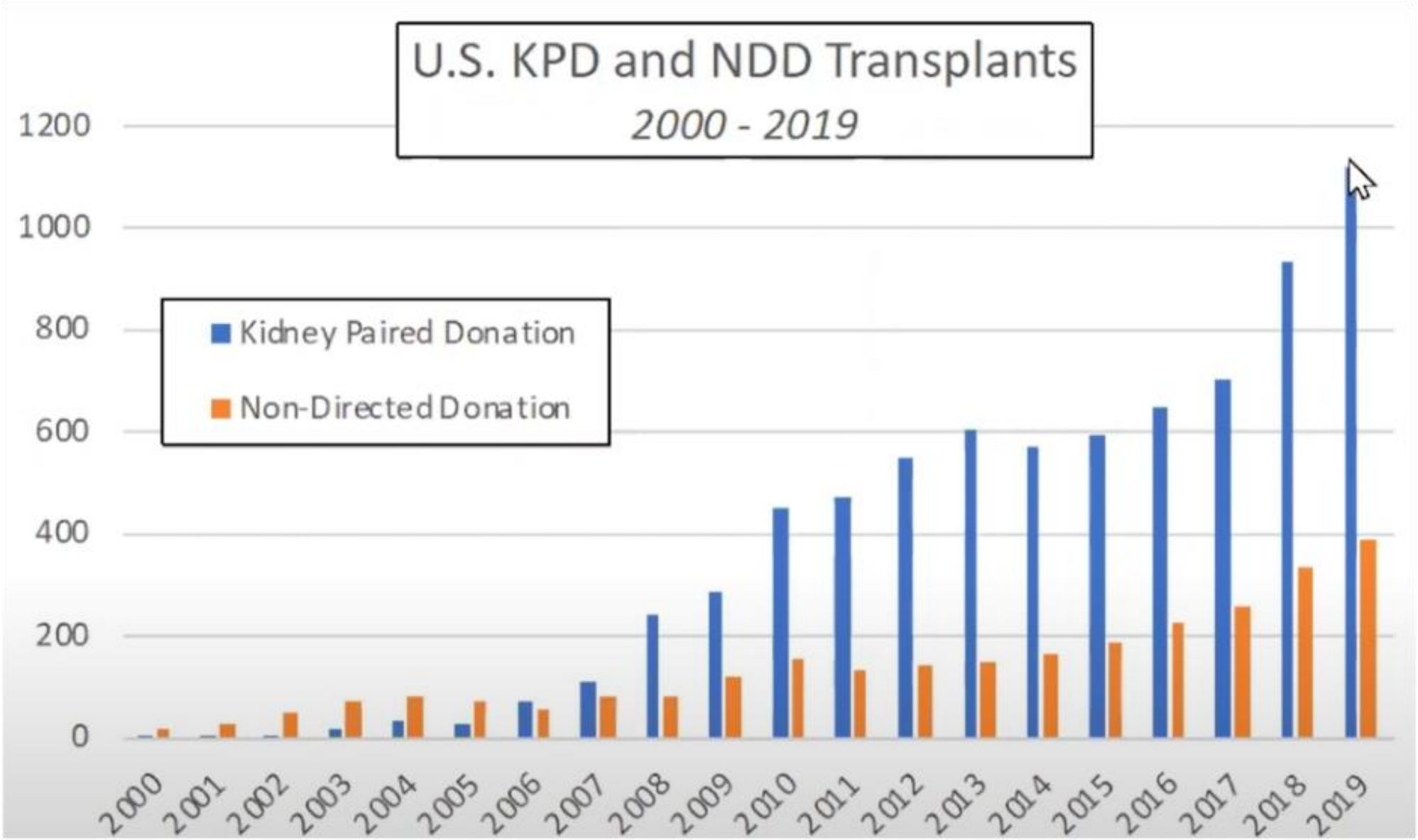


Figure source: Talk by Alvin Roth on "*Kidney Exchange: An Operations Perspective*" hosted by INFORMS Health Applications Society; June 2021

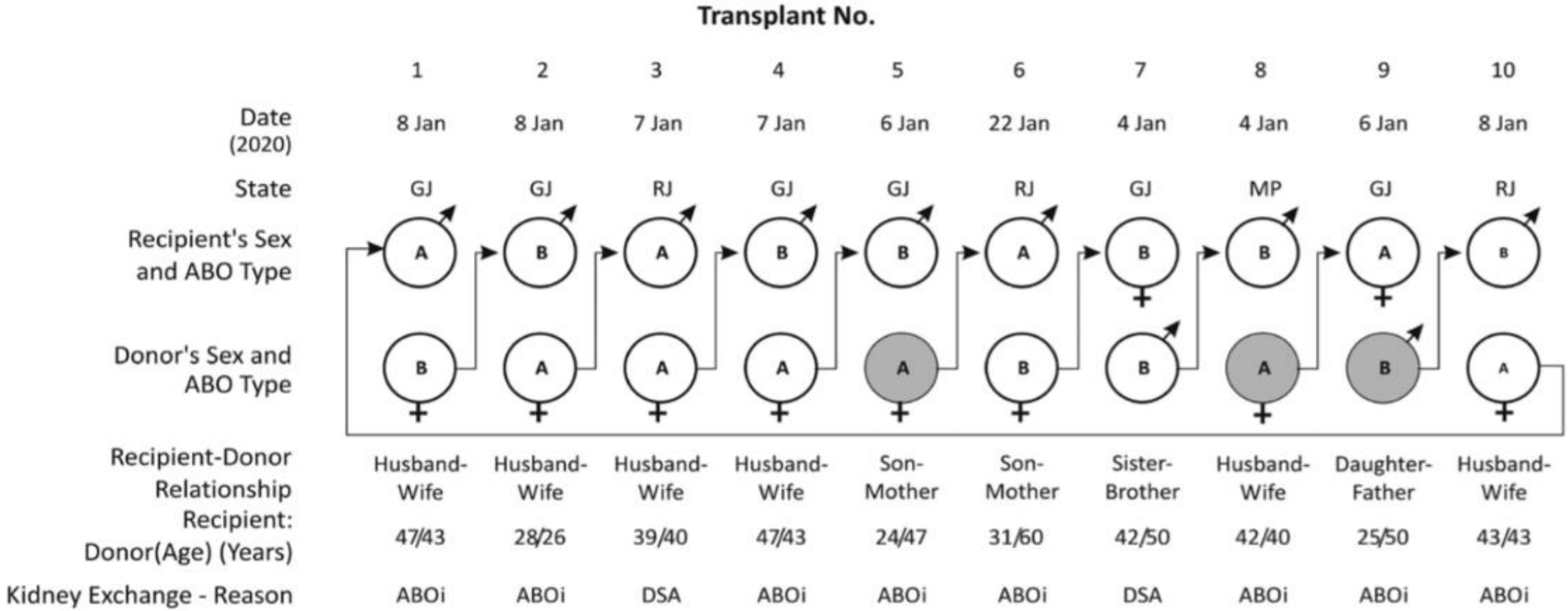
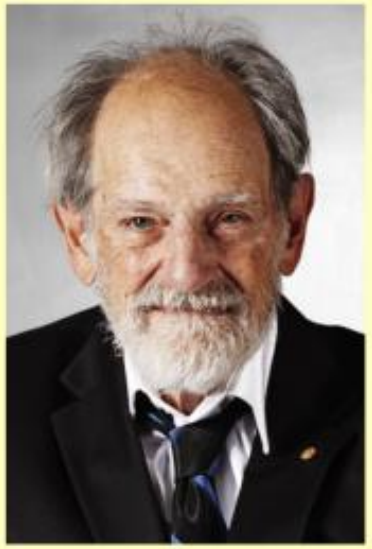


FIGURE 1. A nonsimultaneous 10-way kidney exchange cycle. GJ, Gujarat; MP, Madhya Pradesh; RJ, Rajasthan.

Kute et al. *"Paired Kidney Exchange in India: Future Potential and Challenges Based on the Experience at a Single Center"*, Transplantation, May 2021, 105(5), pp 929-932

Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel 2012

Alvin E. Roth



Lloyd S. Shapley

"*for the theory of stable allocations and the practice of market design*."

Challenges in Kidney Exchange

Economic: Incentives of hospitals vs maximizing overall welfare.

Computational: Finding a maximum matching using 3-cycles is NP-hard.

Informational: Patients and donors arrive sequentially.

Logistical: Long cycles require many simultaneous surgeries.

Legal: Many countries do not permit altruistic donation.

Ethical: Is it OK to buy and sell kidneys?

Next Time

Cake cutting

References

- Housing markets and TTCA

  Lloyd Shapley and Herbert Scarf
  "*On Cores and Indivisibility*"
  Journal of Mathematical Economics,1(1), 1974 pg 23-37
  https://www.sciencedirect.com/science/article/pii/0304406874900330

- Truthfulness under TTCA

  Alvin E. Roth
  "*Incentive Compatibility in a Market with Indivisible Goods*"
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