Information systems for health care: a case study

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Information systems for health care

- Expected to be one of the areas where more effort will be applied in the next few years
- Has issues involving the all the disciplines of computer science and informatics
- Information systems have a huge impact in terms of
  1. economy
  2. social benefits
  3. work rationalization
  4. reliability

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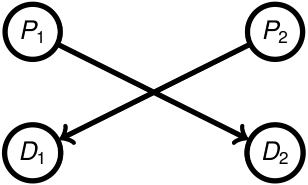
KEP: kidney exchange program

- in many countries, recent legislation allows patients needing a kidney transplant to receive it from a living donor
- what to do when the transplant from that donor is not possible?
  - blood type
  - other incompatibilities
- patient-donor pair may enter a kidney exchange program (KEP)

Kidney exchanges

- idea: allow two (or more) patients in incompatible pairs to exchange their donors
- each recipient receives a compatible kidney from the donor of another pair



Incompatible pairs $P_1 - D_1$ and $P_2 - D_2$ exchange donors

- P_1 receives a transplant from D_2 and vice versa

Graph representation:

- vertices are patient-donor pairs
- arcs link a patient to compatible donors

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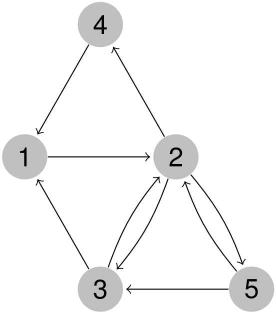
Kidney exchanges: example



- instance with five pairs
- the maximum number of transplants is four:
  cycle 1 – 2 – 5 – 3 – 1
- what if the allowed number of simultaneous transplants is three?
- what if it is two?

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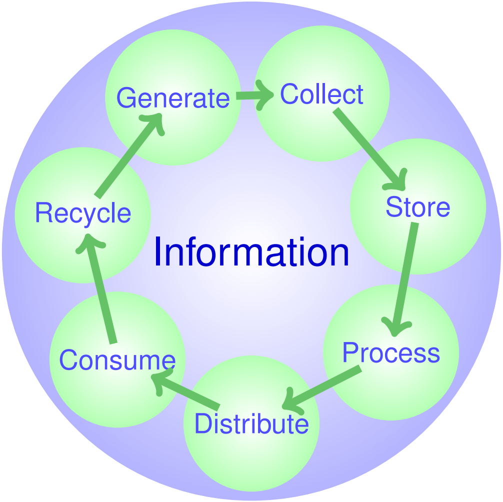
The information cycle in health care systems



Information cycle: generation

- Who enters the program?
  - an individual?
  - a doctor?
  - a hospital?
- How to assure reliability of the data?
  - who is responsible?
  - who checks its accuracy?
- Who stores the information?
- Dynamic system: environment continuously changing

Information cycle: transmission

- How can the information be shared? with whom?
- How to ensure privacy? what is privacy in this context?
- Can information be misused?
- How to ensure its quality?
- How/when should shared information be updated?

Information cycle: processing and management

- How to **optimize** the system for the current data $\longrightarrow$ efficiency
- Is the solution found in a **reasonable time**? $\longrightarrow$ effectiveness
- Will the solution stand with **changes** in data? $\longrightarrow$ robustness

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Information cycle: usage

- How to implement the solution found?
- Update information:
  - remove outdated information
  - insert new information
- Speed of implementation is crucial:
  - will the agents be still available?
  - will their condition be one considered?

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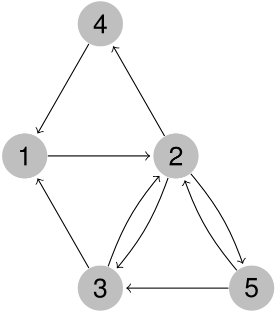
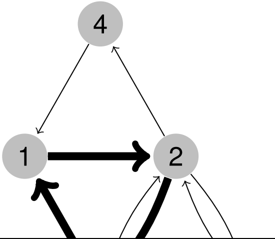
Information processing

- How to optimize the system for the current data?

Kidney exchanges: example





- feasible exchange: a set of vertex-disjoint cycles (*e.g.*, 1 – 2 – 3 – 1)
- size of an exchange: sum of the lengths of its cycles
- maximum exchange in this example: 4 (cycle 1 – 2 – 5 – 3 – 1)

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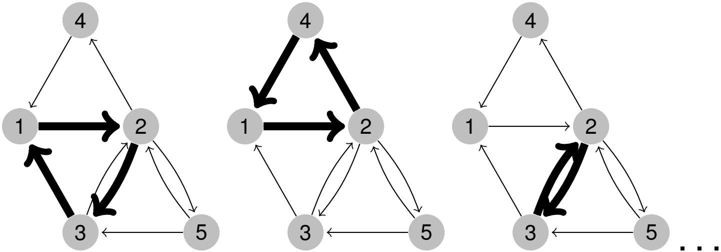
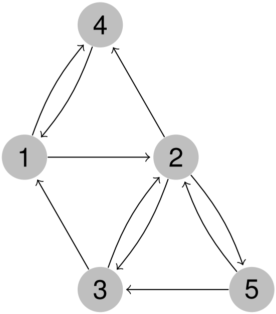
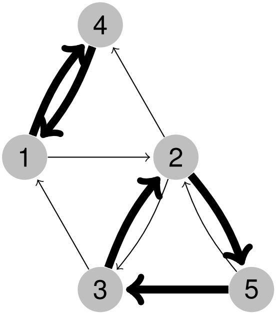
Kidney exchanges: maximum cycle size

- In many situations the length of each cycle is limited:
  - limitations in the number of operation rooms
  - number of surgeons available
- If maximum cycle size is $k = 3$, several solutions are possible.



Another example





Maximum cycle size and NP-hardness

- In many situations the length of each cycle is limited
- If length is not limited $\longrightarrow$ ***assignment problem*** (polynomial algorithms are known, *e.g.*, hungarian algorithm).
- If length is limited to 2 $\longrightarrow$ ***matching problem*** (polynomial algorithms are known: Edmonds algorithm).
- If length is limited to 3, 4, ... $\longrightarrow$ ***problem is NP-hard*** (no polynomial algorithms are known).

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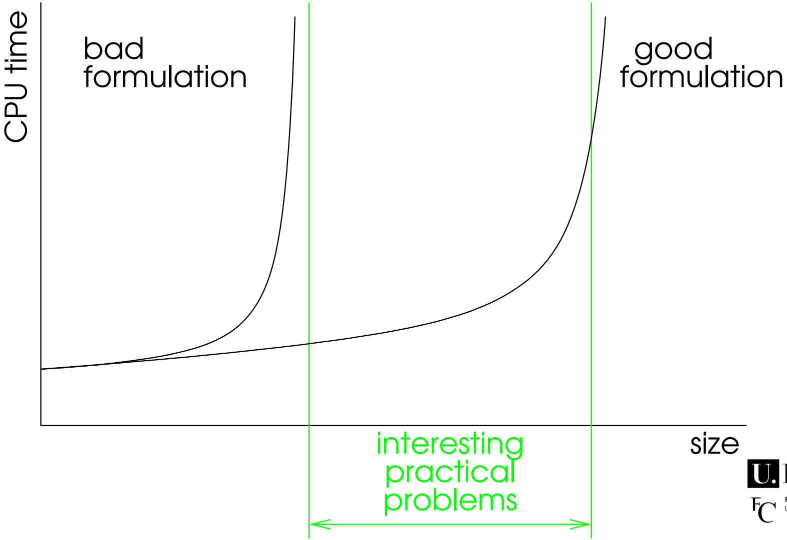
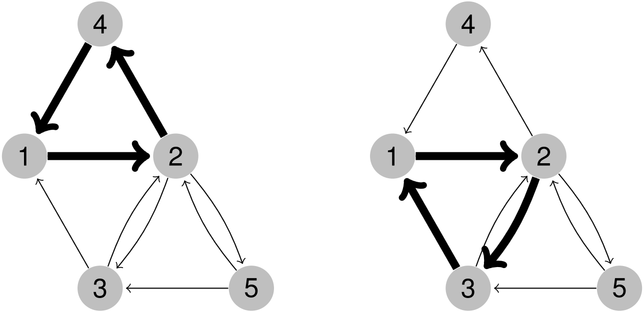
NP-hard problems



Mathematical programming formulations

- There are several possibilities for modeling the problem in mathematical programming
- One of the most successful is the *cycle formulation:*
  - enumerate all cycles in the graph with length at most k
  - for each cycle c, let variable x_c be 1 if c is chosen, 0 otherwise
  - every feasible solution corresponds to a set of vertex-disjoint cycles



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Cycle formulation

$$\text{maximize} \quad \sum_c w_c x_c \tag{1a}$$

$$\text{subject to} \quad \sum_{c:i \in c} x_c \leq 1 \quad \forall i \tag{1b}$$

$$x_c \in \{0, 1\} \quad \forall c$$

- case of $0 - 1$ weights: $w_c = |c|$, (length of cycle c)
- objective: maximize the weight of the exchange
- constraints: every vertex is at most in one cycle (*i.e.*, donate/receive at most one kidney)
- difficulty: number of variables

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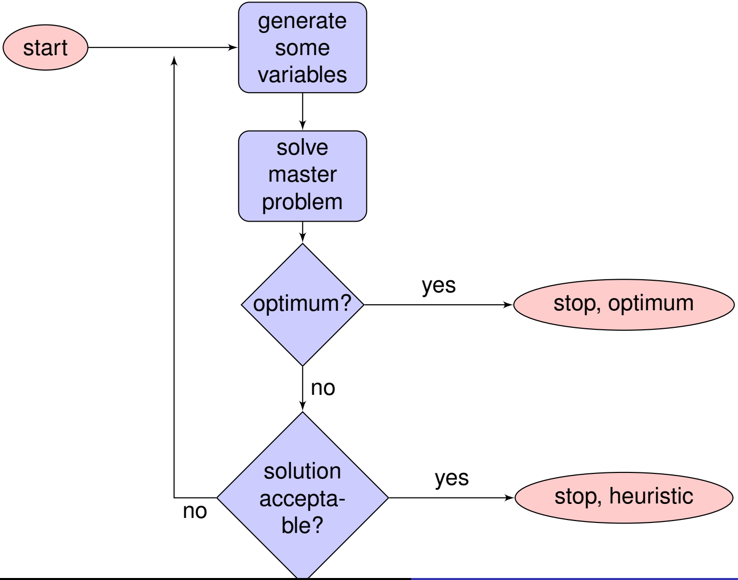
Cycle formulation

- Exponential number of variables
- Not all are needed for solving the problem
- Use only those necessary $\longrightarrow$ column generation

Column generation



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Current results

- Cycle formulation seems to be more than able to process foreseen number of patient-donor pairs in the KEP in Portugal
- Besides, it may allow to treat slightly different objectives:
  - produce robust solutions
  - maximize expectation of the number of transplants
- What if the "*market*" becomes the European Union?

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KEP benefits

- *“For someone to win, somebody else has to loose”* **???**
- No, this is **NOT** a zero-sum game!
- Value of the game: number of transplants done.
- This being said, care has to be taken: many ethical issues

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Final remarks

- Government/Regulation: from the ethical point of view, it is not acceptable that a KEP is left unimplemented
- But for implementing it, a number of questions have to be addressed:
  - Fairness: are agents being treated in an equitable way?
    - many operations for one hospital
    - no operations for another
  - What to do if in the optimum there is a clear looser?
  - Incentives $\longrightarrow$ market design.
  - How to deal with multiple possible donors?
  - All the issues raised in *information life cycle*
- I intentionally left questions of other ethical domains (*e.g.*, would it be acceptable to pay to someone for a kidney?)

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Conclusions

- There are many applications of information technologies in health care
- Applications involve many disciplines in computer science and informatics
- KEP: case where welfare of patients can be maximized
  - number of transplants
  - robustness of the solution
  - quality of the solution (maximize patient-donor compatibility)
- Careful implementation of operations research program leads to significant social benefits

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