Maastricht University *Department of Knowledge Engineering*

Thesis Topics Networks and Strategic Optimization

and some thesis topics related to businesses

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APG Group N.V. (Department of Innovation)

Two projects:

- Predicting future income of individual customers based on data w.r.t. education, age, gender, earlier income etc.

- Building a digital assistant for life planning

Both projects relate to datamining.

For more information: contact Frank

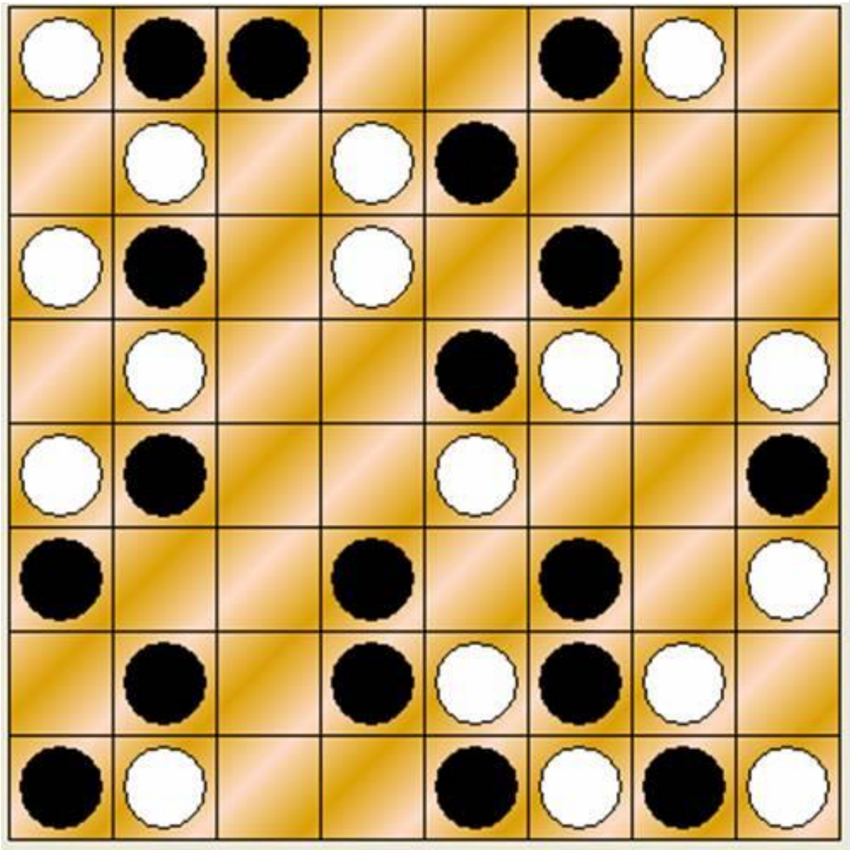
Networks and Strategic Optimization

Research Topics:

- game theoretical modeling (Gijs, Jean, Kateřina, Frank)
  - cooperative games / fair sharing
  - dynamic games / optimal strategies, equilibria, algorithms
  - evolutionary games and local dynamics / stability issues
  - network games / coalition formation, hide and seek
- game practical modeling / search methods (Mark, Jos)
  - solving board games / single-, 2-player and multi-player
  - developing AI-players for board games
  - algorithms and complexity
- applications in biology
  - algorithms for producing phylogenetic networks (Steven)
  - game theoretic applications in biology (Kateřina, Frank)
- Operations Research models (Steven, Matus, Jean, Frank)

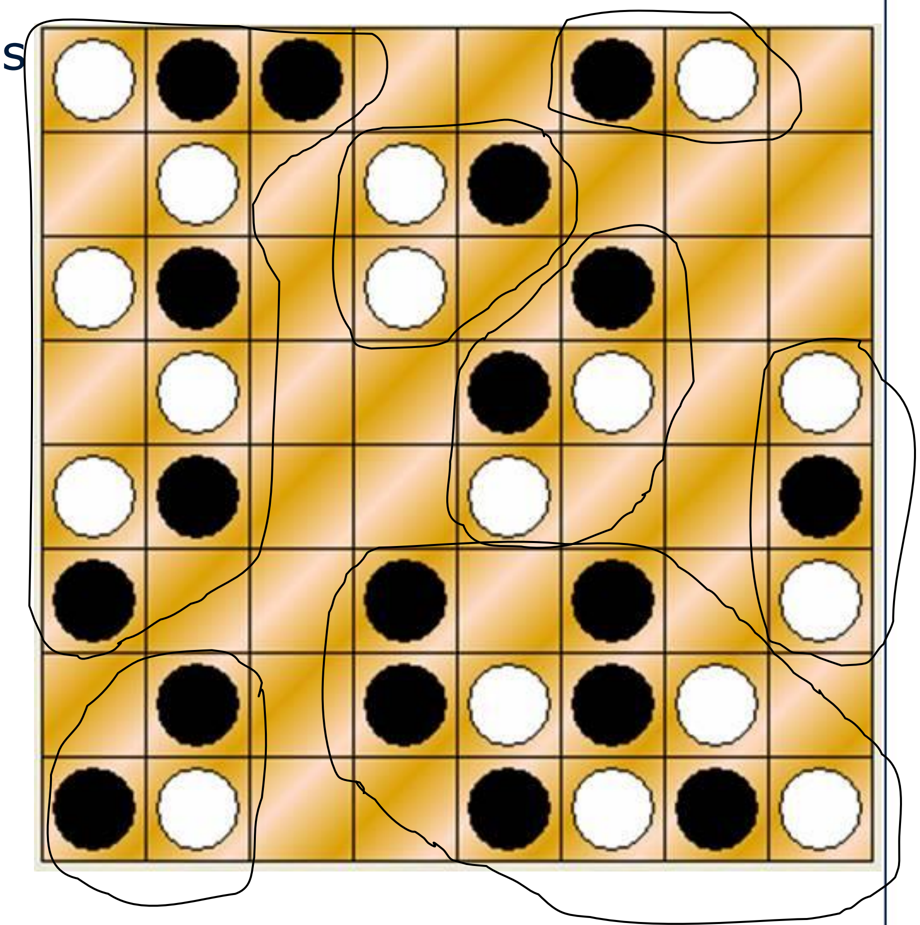
Clobber: Monte-Carlo Tree Search

- Combinatorial Game
- Player who cannot move loses
- MCTS Program MILA
- Task: Improve MILA’s play-out strategy
- Supervision: Mark Winands

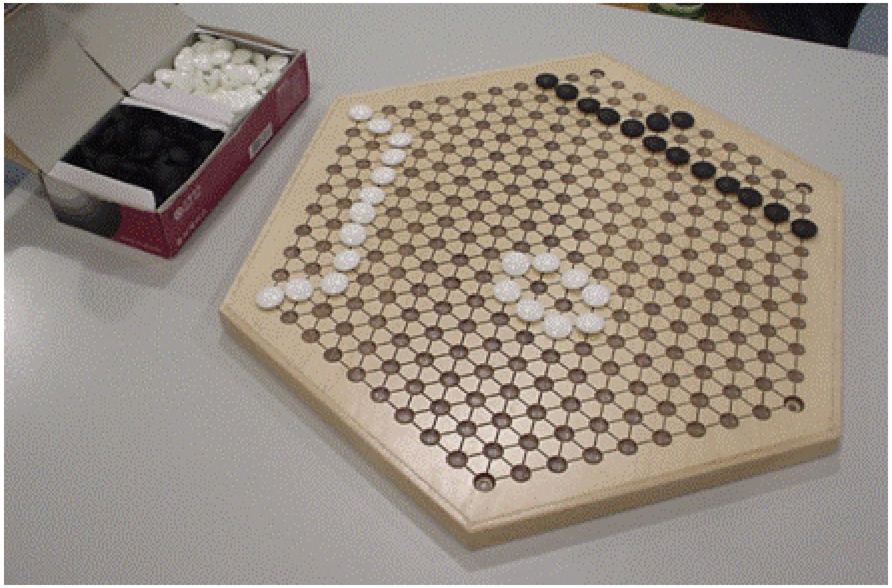


Clobber: Dual Search

- Partition game into sum of subgames
- Independence of subgames: moves have no effect on other subgames
- Task: Test Dual Search a new MCTS variant which takes advantage of subgames
- Supervision: Mark Winands



Havannah



- Connection Game
- Perfect Information
- Challenge:
  - Huge branching factor
  - Static board evaluator
- Task: Further development of existing MCTS engine
- Supervision: Mark Winands

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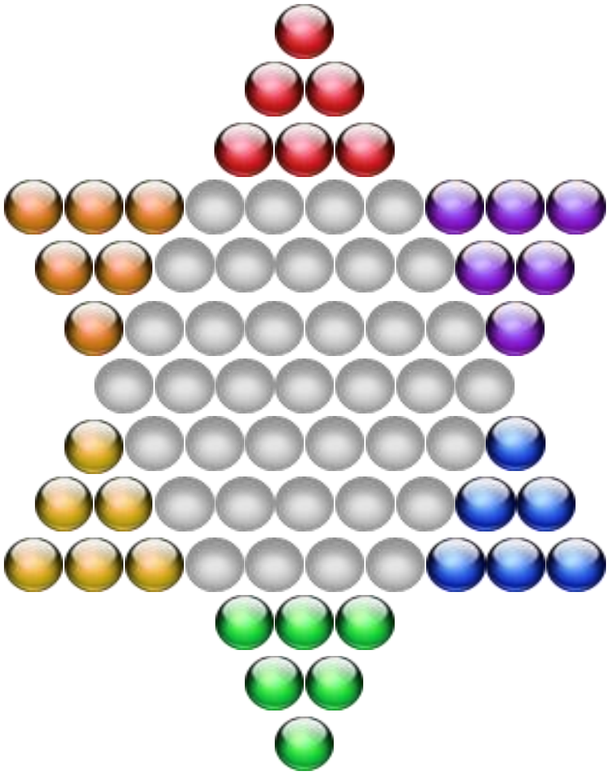
Multi-Player

- MP-Mixed Algorithm

  Chooses Search Method based on situation

- Top level decision
- Generalize to make decision in every node
- Chinese Checkers

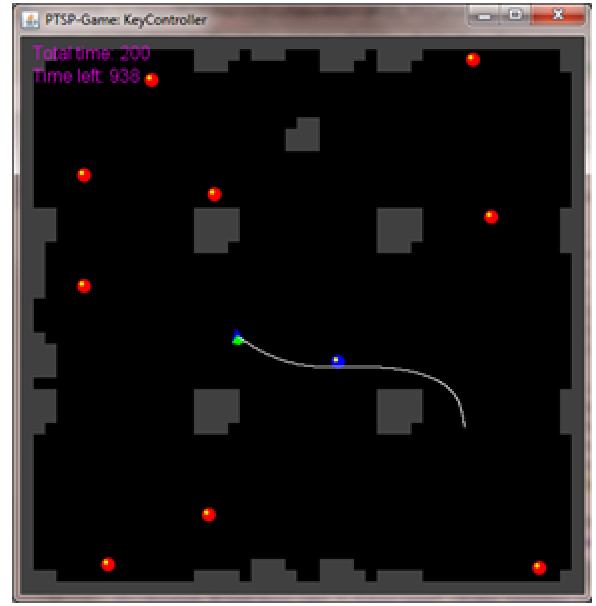


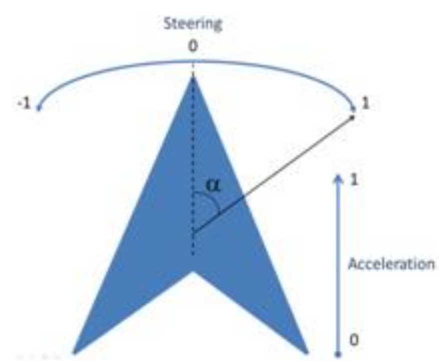
- Supervision: Mark Winands

Physical Travelling Salesman Problem

- Based on classic TSP
- Single player, real-time game
- Requires navigation of a single-point mass
- Task: create agent

- Supervision: Mark Winands

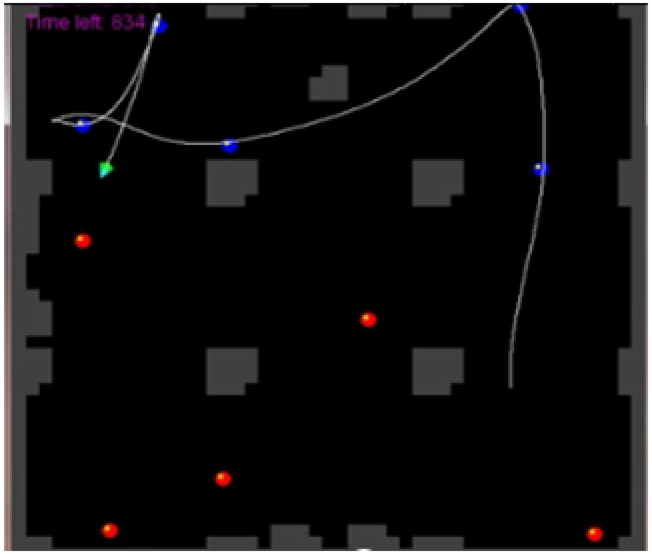




Action ID	Acceleration	Steering
0	No (0)	No (0)
1	No (0)	Left (-1)
2	No (0)	Right (1)
3	Yes (1)	No (0)
4	Yes (1)	Left (-1)
5	Yes (1)	Right (1)

Ms. Pacman / PTSP

- Ms. Pacman AI Player
- Real-time: must (re-)act quickly
- Task: improve existing MCTS agent by generalizing tree re-use
- Application to other real-time domain, such as PTSP



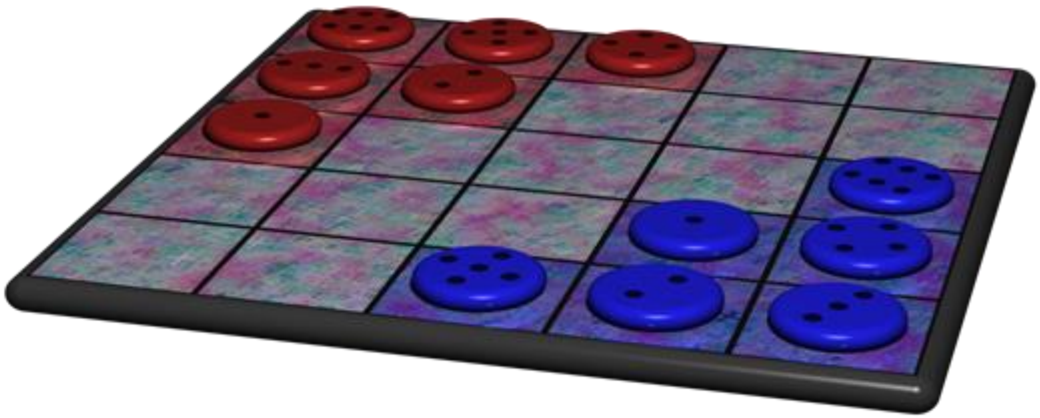
- Supervision:
  Marc Lanctot and Mark Winands

Carcassonne AI Player

- World-wide popular board game
- Challenge:
  stochastic domain (chance nodes)
- Task: Develop MCTS player for existing game
- Supervision: Marc Lanctot and Mark Winands

EinStein würfelt nicht!

- EWN: simple yet strategic
- Task: Develop search player (MCTS or alpha-beta)



- Challenge: obtain good evaluation function
- Possible follow-up: connect AI to **LittleGolem** online community to play humans/bots

- Supervision: Marc Lanctot and Mark Winands

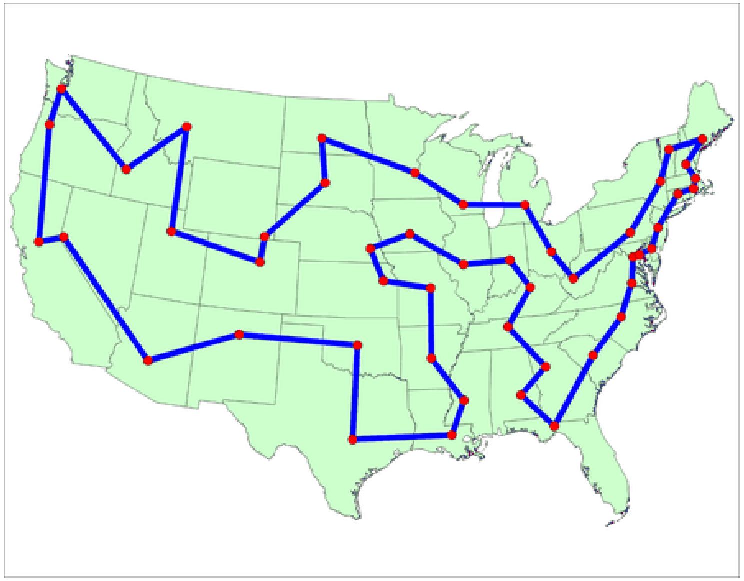
Bluff / Liar's Dice / Dudo / Perudo

- Popular dice bluffing game (as seen in movies!)
- Challenge: *imperfect information and stochasticity*

- Develop MCTS player, try to beat baseline player
- Supervision: Marc Lanctot and Mark Winands

Combinatorial Optimization

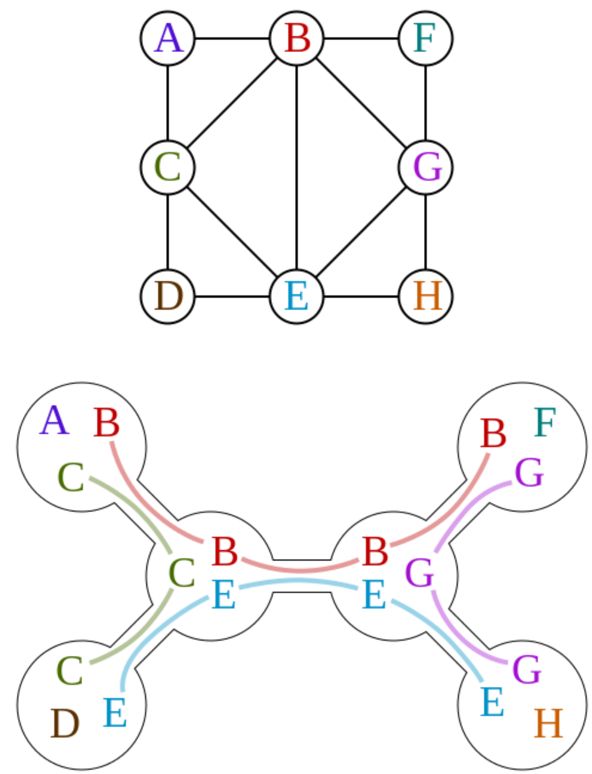
- Developing efficient algorithms to find an optimal object when exhaustive search is infeasible e.g. the *Travelling Salesman Problem*: given a set of cities with pairwise distances between them, what is the shortest tour that visits every city exactly once, and then returns to the starting point?
- Supervision: Steven Kelk



Optimal Traveling Salesman Tour through US Capital Cities

Algorithmic Graph Theory

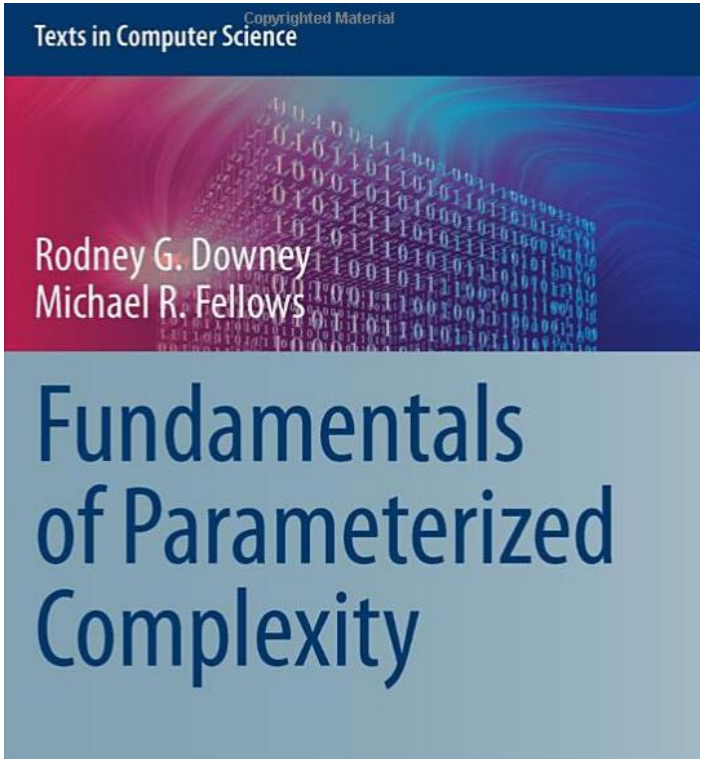
- Many NP-hard problems on graphs can be solved efficiently (even in linear time!) if the *treewidth* of the graph is comparatively small. Such width parameters are a topic of intense research interest and are a central part of the field known as algorithmic graph theory.
- Under which circumstances do the graphs that emerge from real-world applications, have bounded width?
- Supervision: Steven Kelk



The graph shown at the top has treewidth 2. (Wikipedia)

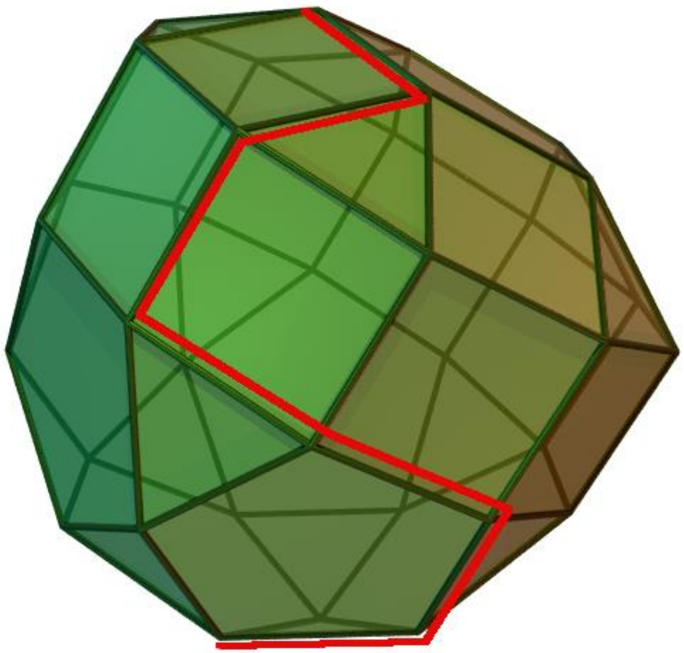
Fixed parameter tractability

- Fixed-parameter (FPT) algorithms have running times of the form f(k).poly(n) where n is the size of the input, f(.) is a function that does not depend on n and k is some parameter of the input (e.g. the treewidth of a graph, as discussed on the previous slide).
- FPT algorithms can be useful for solving NP-hard problems in practice.
- Which NP-hard problems arising in practice permit (efficient) FPT algorithms?
- Supervision: Steven Kelk



(Integer) Linear Programming

- (Integer) Linear Programming allows many allocation problems to be solved optimally by modelling them as the optimization of a linear objective function subject to a set of linear constraints. (I)LP revolutionised operations research in the twentieth century.
- Supervision: Steven Kelk



The Simplex Method solves LPs by moving from cornerpoint to cornerpoint

Constraint Programming (CP)

- Constraint Programming (CP) concerns (like ILP) solving problems by specifying constraints that desired solutions must satisfy, but unlike ILP the constraints are higher-level and much more expressive, which makes modelling real-life problems much easier.
- There is a growing literature on combining the expressive power of CP with the raw optimizing power of ILP.
- Supervision: Steven Kelk

MiniZinc is a medium-level constraint programming language. Source: http://www.minizinc.org/

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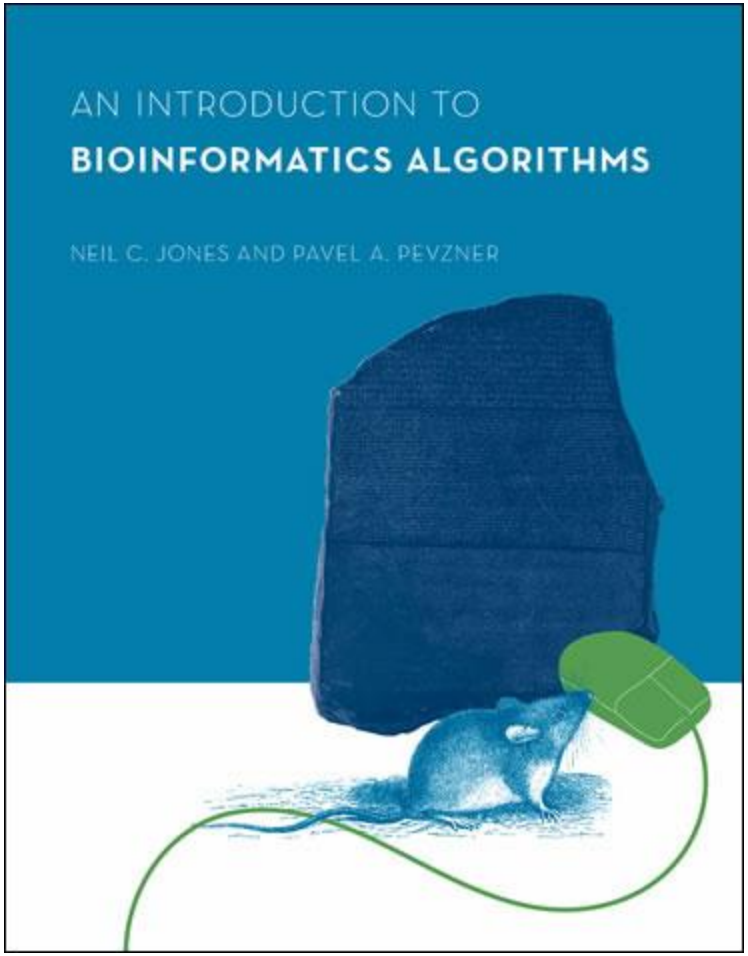
(Algorithmic) Bioinformatics

- Developing efficient algorithms to solve discrete optimization problems arising in bioinformatics.
- See books such as *An Introduction to Bioinformatics Algorithms* (Jones and Pevzner) for more background.
- Supervision: Steven Kelk

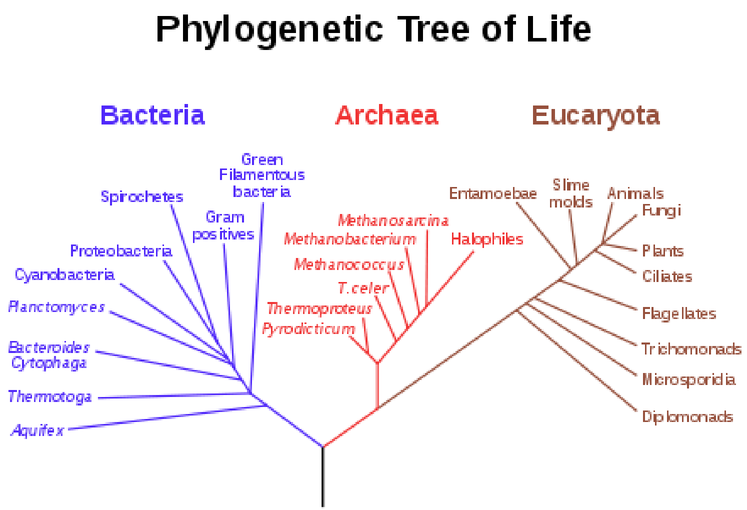


Phylogenetics, Phylogenetic networks

- Given the DNA sequences of a set of modern-day species, can we infer how they evolved from a single common ancestor millions of years ago?

- The problem is already hard enough for evolutionary trees, but what about difficult-to-model events such as hybridization?

- Supervision: Steven Kelk

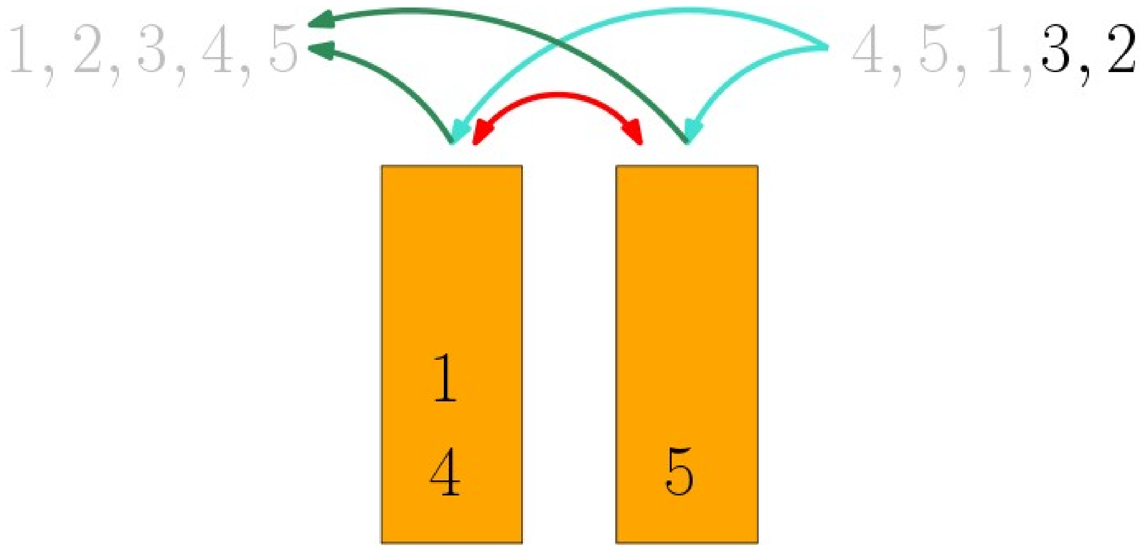


(a) Phylogenetic tree (b) Phylogenetic network

Sorting with two stacks

Given:
- Two stacks (Last In, First Out data structure)
- An input sequence of numbers (on the right)

Task:
- Sort the numbers using movements within the two stacks
- Minimize the number of moves



Contact/Supervision: Matúš Mihalák (`matus.mihalak@maastrichtuniversity.nl`)

Price of Selfishness

General setting:

- A strategic game with rational, self-interested players 1,2,…,n
- Players play strategies $s=(s_1,s_2,\ldots,s_n)$ and reach Nash equilibrium
- Every player i plays to minimize her cost $_i(s_1,\ldots,s_n)$
- Define $\text{socialcost}(s) := \sum_i cost_i(s_1, s_2, \ldots, s_n)$

Task:

- Let s^{opt} be a strategy vector minimizing $\text{socialcost}(s)$
- Quantify (from above and below) the ratio

$$\frac{socialcost(worst\ Nash\ Equilibrium\ s)}{socialcost(s^{opt})}$$

Contact/Supervision: Matúš Mihalák (matus.mihalak@maastrichtuniversity.nl)

Game-Theoretical & Optimal Control Models in Systems Biology

- Development of game-theoretical and optimal control models for predator-prey systems, describing the intra-seasonal (continuous) & inter-seasonal (discrete) dynamics
- Solving underlying hybrid Nash and/or Stackelberg games to find optimal strategies for involved populations
- Investigating under which conditions these strategies are ubeatable, i.e., evolutionarily stable

- Supervision:
  Kateřina Staňková

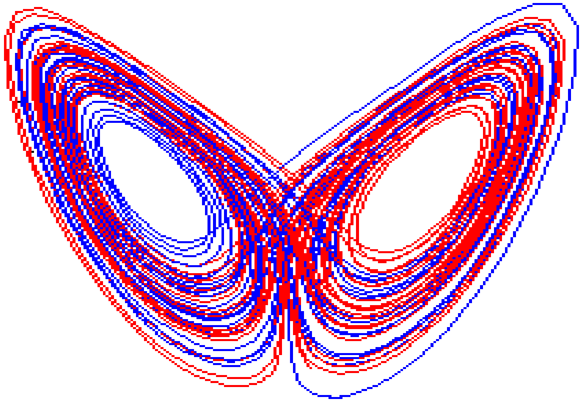
Optimal Toll Design Problem

- Modeling traffic networks that can be tolled as a dynamic system
- Studying properties of such a system
- Modeling interactions between the drivers that make their dynamic travel choices and the road authority that tolls some roads in the network in order to minimize traffic jams

- Finding optimal behavior for both drivers and road authority in such a game
- Supervision: Kateřina Staňková

Chaos in real-world dynamic systems

- Challenge: To study chaotic behavior of real-world systems such as traffic systems, models describing weather, energy market systems and to understand how these systems can be stabilized
- Step 1: Modeling a real-world system of interest
- Step 2: Studying its properties including chaotic behavior
- Step 3: Using controls to stabilize the system
- Supervision: Kateřina Staňková

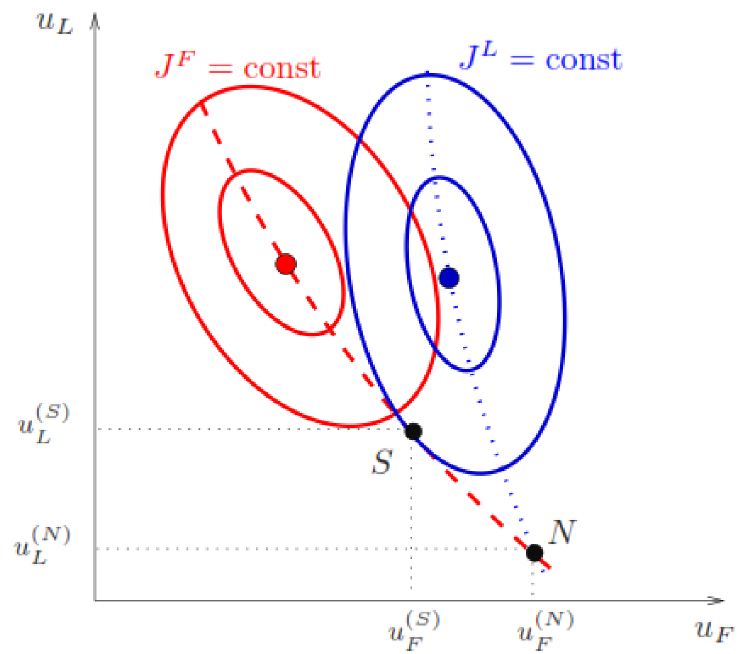


Game Theory in Swarm Robotics

- Goal: Investigation of possible game-theoretical concepts which are applicable for heterogeneous swarm robotics in different application scenarios (e.g. Flocking, Dispersion, Coverage).
- Supervision: Kateřina Staňková & Bijan Ranjbar-Sehraei

Subgame Perfection in Stackelberg Games

- This project focuses on finding subgame perfect equilibria (SPE) in Stackelberg games (SG).
- SG: A game that has a hierarchical structure among the players: leader vs. follower
- SPE: Refinement of Nash equilibrium
- Supervision: Gijs Schoenmakers and Kateřina Staňková



Stackelberg versus Nash

Matrix Games with Alternating Moves

- Goal: Finding an easy way to calculate the optimal strategies in repeated games with alternating moves
- Task: examine optimal strategies found using backward induction to discover a structural relationship between strategic cycle and matrix properties
- Supervision:
  Kateřina Staňková & Frank Thuijsman

7	5	0
1	8	2
6	3	9

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Hide and Seek on Graphs

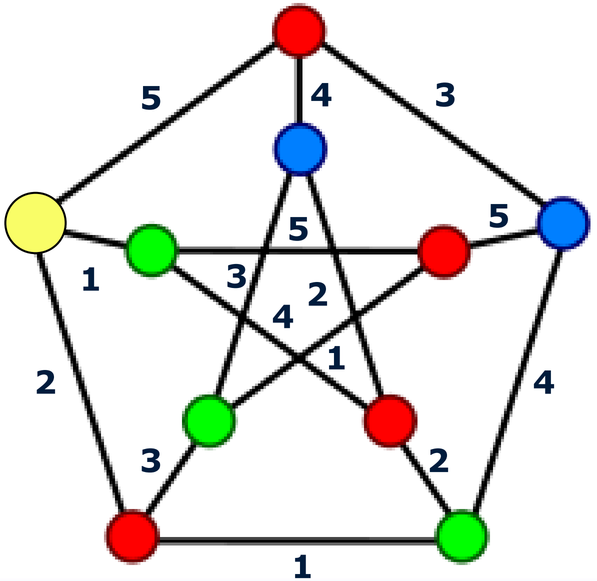
- Goal: To develop an algorithm to find an object hidden in a graph as fast as possible

  Alternatives: object static, in node or edge, or dynamic

- Task: Explore literature, explore heuristics, explore structured graphs

- Supervision: Jean Derks, Steven Kelk

  & Frank Thuijsman



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Network Formation in One-Way Flow Networks

- Players can create, delete or replace a link, or pass
- Links have a cost, profits flow through links
- Goal: to develop an efficient procedure to find a stable network

- Supervision:

  Jean Derks & Frank Thuijsman

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Bird Broods and Cooperative Game Theory

- Goal: to explore possible relationships between food distribution among chicks in bird broods and well-known solution concepts from cooperative game theory (e.g. Shapley-value, nucleolus)
- Task: using bird brood data to define appropriate and meaningful cooperative games (with coalition structures) for further analysis
- Supervision:

  Jean Derks & Frank Thuijsman

Replicator Dynamics and Seasonal Fitness

- Goal: Classifying possible patterns for stable orbits in 3x3 games with periodic fitness matrix A^t
- $x'_i(t) = x_i(t) \cdot (e_i A^t x(t) - x(t) A^t x(t))$
- Supervision:

  Frank Thuijsman

$$\begin{pmatrix} 0 & 1 & \cos(\rho\, t) \\ \cos\left(\rho\, \left(\frac{4\,\pi}{3} + \frac{2\,t}{3}\right)\right) & 0 & 1 \\ 1 & \cos\left(\rho\, \left(\pi + \frac{2\,t}{3}\right)\right) & 0 \end{pmatrix}$$

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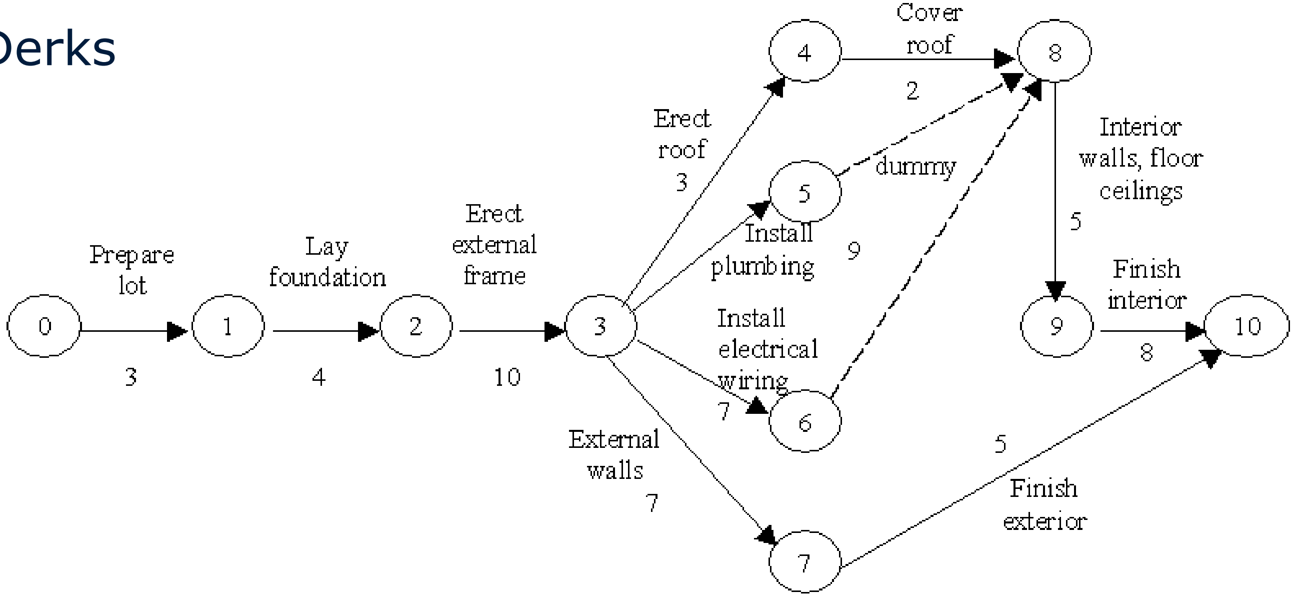
Project Support Games

Task: Cost and profit allocation among the participants in a project

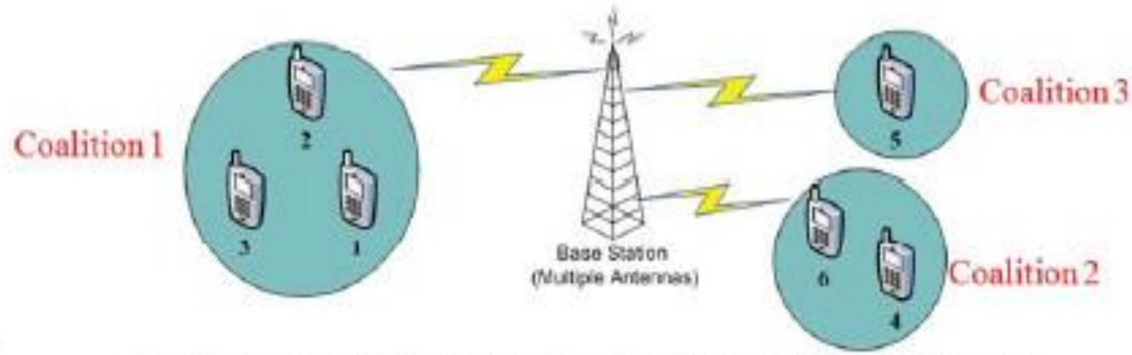
Supervision: Jean Derks



Cooperative game techniques for mobile communication networks

Task 1: design of coalition formation procedures.

Task 2: cost allocation



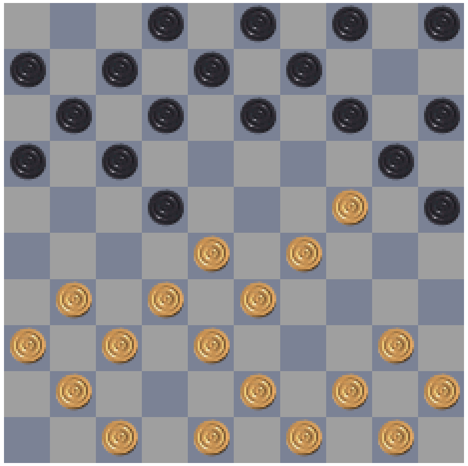
Time slot 1	Time slot 2	Time slot 3	Time slot 4	Time slot 5	Time slot 6
User 1	User 2	User 3	User 4	User 5	User 6

Time slot 1	Time slot 2	Time slot 3	Time slot 4	Time slot 5	Time slot 6
Coal. 1	Coal. 1	Coal. 1	Coal. 2	Coal. 3	Coal. 2

Supervision:
Jean Derks

Stochastic Games: Algorithmic Search For Equilibria

- Classes of Stochastic Games: Irreducible games, ARAT games, perfect information games, zero-sum games etc.
- This project: Construction and implemention of algorithms to find e.g. stationary or subgame perfect equilibria in these and other classes of stochastic games.
- Supervision: Gijs Schoenmakers



An example of a recursive zero-sum stochastic game with perfect information

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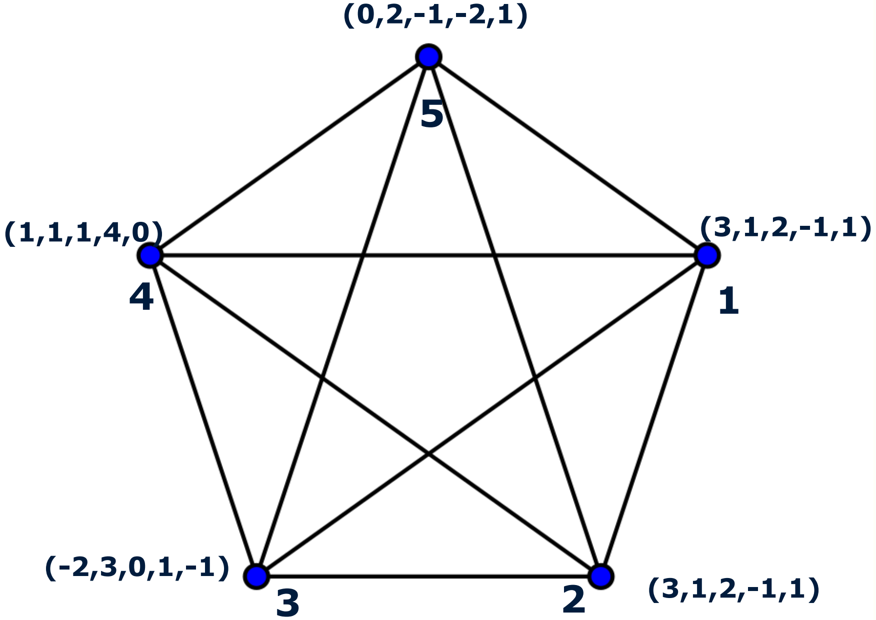
Refinements of Nash Equilibrium in Games on Graphs

- In games on graphs Nash equilibria are often abundant, whereas subgame perfect equilibria may fail to exist.
- This project: To find and investigate other types of equilibrium refinements in these games.
- Supervision: Gijs Schoenmakers



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Incorporating Combinatorial Game Theory into alpha-beta search

- For combinatorial games independent subgames develop during game play. Now the (correct) value of the game becomes the sum of the values of all the subgames
- Additionally: classic way of playing a computer game is using alpha-beta search with a decent (knowledge-based) evaluation function
- This project: how can we combine the two, i.e., incorporate values of known subgames in an alpha-beta search?
- Possible games: Domineering, Clobber, Amazons, …
- Supervision: Jos Uiterwijk

Developing evaluation functions based on Combinatorial Game Theory

- Again: classic way of playing a computer game is using alpha-beta search with a decent (knowledge-based) evaluation function
- This project: can evaluation functions be built based on the values of known subgames in an alpha-beta search? In particular, can this also be done when (some) subgames have no known values (yet), e.g., approximate evaluation functions?
- Possible games: Domineering, Clobber, Amazons, …
- Supervision: Jos Uiterwijk