The Multi-league Scheduling Problem with Pairing Constraints

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Outline

- Motivation
- Scheduling rules
- Iterated Local Search
  - Generating initial solutions
  - Tabu Search
    - Neighborhood structures
    - Implementation highlights
  - Perturbation mechanism
- Preliminary computational results
- Future research steps

Why League Scheduling?

- Big Business!
  - US National TV pays $500 million / year for baseball
  - College basketball conferences get up to $30 million

- Wide variety of problem types
  - (double) Round Robin tournaments, Balanced tournament Design Problem (BTDP), Bipartite Tournament Problem (BTP), Traveling Tournament Problem (TTP)

- Even small instances are very difficult to solve

Why League Scheduling?

- Quite rich literature, however there is room for significant theoretical and methodological advances
  - Constraint Programming (CP)
    - CP models with [1..n] variables
  - Integer Programming (IP)
    - IP models with 0-1 variables
  - Metaheuristic Algorithms
    - Local Search
    - Evolutionary Approaches

Scheduling Rules

- What elements a professional league needs to consider?
  - Transportation (e.g. minimize travelling distances)
  - Police (e.g. number of games played in a city)
  - Stadium Availability (e.g. blocks due to other events)
  - Rivalries (e.g. spacing restrictions between derbies per team or per city)
  - Television requests (e.g. preferences on particular days, thanksgiving games etc)

Scheduling Rules

□ What elements a professional league needs to consider? (cont.)

- Fans (e.g. match-up preferences early or late in the season)

- Balance (e.g. playing against more-rested opponents)

- History (e.g. who played who last year)

- Other (e.g. top team and bottom team constraints, geographical constraints)

- Fairness and home-away patterns
  - Balance between number of home and away games
  - Prefer alternating home away pattern

Scheduling Rules

- Some definitions:
  - **Home game**: a team is playing home
  - **Away or road game**: a team in playing on the road
  - **Bye week:** a week when a team does not play (one week per team during the regular season)
  - **Block (availability of venues)**: a period of team when a stadium is not available. Blocks may be breakable or unbreakable.
  - **H/A pattern:** sequences of consecutive home and away games
    - HH|AA|Doubles|HHH|AAA|Triples|HHHH|AAAA|Quads

Scheduling Rules

- Some definitions:
  - **Schedule grid:** Mapping of matches into rounds such that each team plays at most once in each round.
  - **Hard constraint:** a constraint that if broken makes the schedule unplayable. If no other alternative is possible a high penalty cost will occur (e.g. 999)
  - **Soft constraint:** a constraint that may be broken if necessary. If no other alternative exists a penalty cost (typically from 25 to 350) will occur

Objective: Minimize violations / penalties

Scheduling Rules

- Intra- and Inter-League Pairing Constraints (simultaneous home ban)
  - Indicative examples from the English Premier League, League Championship, League 1 and League 2
    - Bristol City - Bristol Rovers
    - Southampton - AFC Bournemouth
    - Manchester City - Manchester United
- **Observation: The schedules and the feasible home-away patterns among different leagues are interconnected throughout the planning horizon!**

Iterated Local Search

- **Step 1: Generate an initial solution**

  - Greedy Randomized heuristic

- **Step 2: Tabu Search (until a time limit is reached)**

  - At each iteration select at random a neighborhood structure

  - Evaluate all neighbors and select the **best admissible** neighboring solution

  - Update short-term memory structures (**tabu lists**): moves and violations of constraints

  - Update best found schedule

- **Step 3: Perturbation**

Generating an initial solution

- Assign in the schedule grid **all a priori fixed matchups.**

- Next, for all unscheduled matches insert in the grid the match that **minimizes violations**

  - We schedule only the first half of the schedule (assuming mirroring)

  - Basic rules are always respected

    - Number of home and away games per team

    - Opponent assignment and matches per team

- [Same process is repeated for all leagues.]

Swap Teams

- Swaps the matches of 2 teams (T1, T2) for all rounds (expect matchups between T1 and T2)
  - The H/A pattern is maintained (except for T1 and T2).
  - Matchup requests might be violated.
  - The neighborhood size depends only on the number of teams.

Swap Teams (LDA,CSC) before

	LDA	BFC	ADC	CSC	CSH	ML	LFC	MPZ	SC	SG	DS	UCR
1	CSH	CSC	@LFC	@BFC	@LDA	@SC	ADC	@DS	ML	@UCR	MPZ	SG
2	LFC	@ADC	BFC	SC	DS	@UCR	@LDA	@SG	@CSC	MPZ	@CSH	ML
3	@ML	UCR	SC	@MPZ	@SG	LDA	@DS	CSC	@ADC	CSH	LFC	@BFC
4	UCR	@LFC	@CSH	SG	ADC	DS	BFC	@SC	MPZ	@CSC	@ML	@LDA
5	@SG	SC	@DS	@UCR	@MPZ	@LFC	ML	CSH	@BFC	LDA	ADC	CSC
6	BFC	@LDA	MPZ	DS	UCR	SG	@SC	@ADC	LFC	@ML	@CSC	@CSH
7	@DS	CSH	@SG	@LFC	@BFC	@MPZ	CSC	ML	@UCR	ADC	LDA	SC
8	MPZ	SG	UCR	@ML	@LFC	CSC	CSH	@LDA	DS	@BFC	@SC	@ADC
9	@CSC	@MPZ	ML	LDA	SC	@ADC	@UCR	BFC	@CSH	DS	@SG	LFC
10	ADC	@ML	@LDA	CSH	@CSC	BFC	MPZ	@LFC	SG	@SC	UCR	@DS
11	SC	DS	CSC	@ADC	ML	@CSH	@SG	@UCR	@LDA	LFC	@BFC	MPZ
12	@CSH	@CSC	LFC	BFC	LDA	SC	@ADC	DS	@ML	UCR	@MPZ	@SG
13	@LFC	ADC	@BFC	@SC	@DS	UCR	LDA	SG	CSC	@MPZ	CSH	@ML
14	ML	@UCR	@SC	MPZ	SG	@LDA	DS	@CSC	ADC	@CSH	@LFC	BFC
15	@UCR	LFC	CSH	@SG	@ADC	@DS	@BFC	SC	@MPZ	CSC	ML	LDA
16	SG	@SC	DS	UCR	MPZ	LFC	@ML	@CSH	BFC	@LDA	@ADC	@CSC
17	@BFC	LDA	@MPZ	@DS	@UCR	@SG	SC	ADC	@LFC	ML	CSC	CSH
18	DS	@CSH	SG	LFC	BFC	MPZ	@CSC	@ML	UCR	@ADC	@LDA	@SC
19	@MPZ	@SG	@UCR	ML	LFC	@CSC	@CSH	LDA	@DS	BFC	SC	ADC
20	CSC	MPZ	@ML	@LDA	@SC	ADC	UCR	@BFC	CSH	@DS	SG	@LFC
21	@ADC	ML	LDA	@CSH	CSC	@BFC	@MPZ	LFC	@SG	SC	@UCR	DS
22	@SC	@DS	@CSC	ADC	@ML	CSH	SG	UCR	LDA	@LFC	BFC	@MPZ

Swap Teams (LDA,CSC) after

	LDA	BFC	ADC	CSC	CSH	ML	LFC	MPZ	SC	SG	DS	UCR
1	@BFC	LDA	@LFC	CSH	@CSC	@SC	ADC	@DS	ML	@UCR	MPZ	SG
2	SC	@ADC	BFC	LFC	DS	@UCR	@CSC	@SG	@LDA	MPZ	@CSH	ML
3	@MPZ	UCR	SC	@ML	@SG	CSC	@DS	LDA	@ADC	CSH	LFC	@BFC
4	SG	@LFC	@CSH	UCR	ADC	DS	BFC	@SC	MPZ	@LDA	@ML	@CSC
5	@UCR	SC	@DS	@SG	@MPZ	@LFC	ML	CSH	@BFC	CSC	ADC	LDA
6	DS	@CSC	MPZ	BFC	UCR	SG	@SC	@ADC	LFC	@ML	@LDA	@CSH
7	@LFC	CSH	@SG	@DS	@BFC	@MPZ	LDA	ML	@UCR	ADC	CSC	SC
8	@ML	SG	UCR	MPZ	@LFC	LDA	CSH	@CSC	DS	@BFC	@SC	@ADC
9	CSC	@MPZ	ML	@LDA	SC	@ADC	@UCR	BFC	@CSH	DS	@SG	LFC
10	CSH	@ML	@CSC	ADC	@LDA	BFC	MPZ	@LFC	SG	@SC	UCR	@DS
11	@ADC	DS	LDA	SC	ML	@CSH	@SG	@UCR	@CSC	LFC	@BFC	MPZ
12	BFC	@LDA	LFC	@CSH	CSC	SC	@ADC	DS	@ML	UCR	@MPZ	@SG
13	@SC	ADC	@BFC	@LFC	@DS	UCR	CSC	SG	LDA	@MPZ	CSH	@ML
14	MPZ	@UCR	@SC	ML	SG	@CSC	DS	@LDA	ADC	@CSH	@LFC	BFC
15	@SG	LFC	CSH	@UCR	@ADC	@DS	@BFC	SC	@MPZ	LDA	ML	CSC
16	UCR	@SC	DS	SG	MPZ	LFC	@ML	@CSH	BFC	@CSC	@ADC	@LDA
17	@DS	CSC	@MPZ	@BFC	@UCR	@SG	SC	ADC	@LFC	ML	LDA	CSH
18	LFC	@CSH	SG	DS	BFC	MPZ	@LDA	@ML	UCR	@ADC	@CSC	@SC
19	ML	@SG	@UCR	@MPZ	LFC	@LDA	@CSH	CSC	@DS	BFC	SC	ADC
20	@CSC	MPZ	@ML	LDA	@SC	ADC	UCR	@BFC	CSH	@DS	SG	@LFC
21	@CSH	ML	CSC	@ADC	LDA	@BFC	@MPZ	LFC	@SG	SC	@UCR	DS
22	ADC	@DS	@LDA	@SC	@ML	CSH	SG	UCR	CSC	@LFC	BFC	@MPZ

Note that the swap must be propagated throughout the schedule to all teams!

Swap Rounds

- Swap all matches between R1 and R2
    - This move changes the matchup spacing
    - Can destroy the H/A pattern
    - The size depends on the number of rounds
        - 18 rounds (double round robin with 10 teams) gives 153 combinations

Swap Round (R1,R2) before

	LDA	BFC	ADC	CSC	CSH	ML	LFC	MPZ	SC	SG	DS	UCR
1	@BFC	LDA	SG	ML	@SC	@CSC	UCR	@DS	CSH	@ADC	MPZ	@LFC
2	SC	@UCR	CSH	LFC	@ADC	DS	@CSC	@SG	@LDA	MPZ	@ML	BFC
3	@MPZ	ADC	@BFC	@CSH	CSC	@SG	@DS	LDA	@UCR	ML	LFC	SC
4	SG	@LFC	@CSC	ADC	DS	UCR	BFC	@SC	MPZ	@LDA	@CSH	@ML
5	@ADC	SC	LDA	@SG	@LFC	@MPZ	CSH	ML	@BFC	CSC	UCR	@DS
6	DS	@CSC	@ML	BFC	SG	ADC	@SC	@UCR	LFC	@CSH	@LDA	MPZ
7	@LFC	ML	SC	@DS	@MPZ	@BFC	LDA	CSH	@ADC	UCR	CSC	@SG
8	@CSH	SG	@UCR	MPZ	LDA	@LFC	ML	@CSC	DS	@BFC	@SC	ADC
9	CSC	@MPZ	LFC	@LDA	@UCR	SC	@ADC	BFC	@ML	DS	@SG	CSH
10	ML	@CSH	@DS	UCR	BFC	@LDA	MPZ	@LFC	SG	@SC	ADC	@CSC
11	@UCR	DS	MPZ	SC	@ML	CSH	@SG	@ADC	@CSC	LFC	@BFC	LDA
12	BFC	@LDA	@SG	@ML	SC	CSC	@UCR	DS	@CSH	ADC	@MPZ	LFC
13	@SC	UCR	@CSH	@LFC	ADC	@DS	CSC	SG	LDA	@MPZ	ML	@BFC
14	MPZ	@ADC	BFC	CSH	@CSC	SG	DS	@LDA	UCR	@ML	@LFC	@SC
15	@SG	LFC	CSC	@ADC	@DS	@UCR	@BFC	SC	@MPZ	LDA	CSH	ML
16	ADC	@SC	@LDA	SG	LFC	MPZ	@CSH	@ML	BFC	@CSC	@UCR	DS
17	@DS	CSC	ML	@BFC	@SG	@ADC	SC	UCR	@LFC	CSH	LDA	@MPZ
18	LFC	@ML	@SC	DS	MPZ	BFC	@LDA	@CSH	ADC	@UCR	@CSC	SG
19	CSH	@SG	UCR	@MPZ	@LDA	LFC	@ML	CSC	@DS	BFC	SC	@ADC
20	@CSC	MPZ	@LFC	LDA	UCR	@SC	ADC	@BFC	ML	@DS	SG	@CSH
21	@ML	CSH	DS	@UCR	@BFC	LDA	@MPZ	LFC	@SG	SC	@ADC	CSC
22	UCR	@DS	@MPZ	@SC	ML	@CSH	SG	ADC	CSC	@LFC	BFC	@LDA

Swap Round (R1,R2) after

	LDA	BFC	ADC	CSC	CSH	ML	LFC	MPZ	SC	SG	DS	UCR
1	SC	@UCR	CSH	LFC	@ADC	DS	@CSC	@SG	@LDA	MPZ	@ML	BFC
2	@BFC	LDA	SG	ML	@SC	@CSC	UCR	@DS	CSH	@ADC	MPZ	@LFC
3	@MPZ	ADC	@BFC	@CSH	CSC	@SG	@DS	LDA	@UCR	ML	LFC	SC
4	SG	@LFC	@CSC	ADC	DS	UCR	BFC	@SC	MPZ	@LDA	@CSH	@ML
5	@ADC	SC	LDA	@SG	@LFC	@MPZ	CSH	ML	@BFC	CSC	UCR	@DS
6	DS	@CSC	@ML	BFC	SG	ADC	@SC	@UCR	LFC	@CSH	@LDA	MPZ
7	@LFC	ML	SC	@DS	@MPZ	@BFC	LDA	CSH	@ADC	UCR	CSC	@SG
8	@CSH	SG	@UCR	MPZ	LDA	@LFC	ML	@CSC	DS	@BFC	@SC	ADC
9	CSC	@MPZ	LFC	@LDA	@UCR	SC	@ADC	BFC	@ML	DS	@SG	CSH
10	ML	@CSH	@DS	UCR	BFC	@LDA	MPZ	@LFC	SG	@SC	ADC	@CSC
11	@UCR	DS	MPZ	SC	@ML	CSH	@SG	@ADC	@CSC	LFC	@BFC	LDA
12	BFC	@LDA	@SG	@ML	SC	CSC	@UCR	DS	@CSH	ADC	@MPZ	LFC
13	@SC	UCR	@CSH	@LFC	ADC	@DS	CSC	SG	LDA	@MPZ	ML	@BFC
14	MPZ	@ADC	BFC	CSH	@CSC	SG	DS	@LDA	UCR	@ML	@LFC	@SC
15	@SG	LFC	CSC	@ADC	@DS	@UCR	@BFC	SC	@MPZ	LDA	CSH	ML
16	ADC	@SC	@LDA	SG	LFC	MPZ	@CSH	@ML	BFC	@CSC	@UCR	DS
17	@DS	CSC	ML	@BFC	@SG	@ADC	SC	UCR	@LFC	CSH	LDA	@MPZ
18	LFC	@ML	@SC	DS	MPZ	BFC	@LDA	@CSH	ADC	@UCR	@CSC	SG
19	CSH	@SG	UCR	@MPZ	@LDA	LFC	@ML	CSC	@DS	BFC	SC	@ADC
20	@CSC	MPZ	@LFC	LDA	UCR	@SC	ADC	@BFC	ML	@DS	SG	@CSH
21	@ML	CSH	DS	@UCR	@BFC	LDA	@MPZ	LFC	@SG	SC	@ADC	CSC
22	UCR	@DS	@MPZ	@SC	ML	@CSH	SG	ADC	CSC	@LFC	BFC	@LDA

Partial Swap Rounds (T1,R1,R2)

- Instead of swapping all together 2 rounds, we only exchange 2 matches, which means swapping 2 rounds (R1 and R2) of a given team (T1)
  - Cyclical swap of a subset of matches between 2 rounds
  - Several teams might be affected (worst case scenario we swap all matches between 2 rounds)
  - The combinations are n^3 (n is the number of teams)

Partial Swap Rounds (T1,R1,R2) before

	LDA	BFC	ADC	CSC	CSH	ML	LFC	MPZ	SC	SG	DS	UCR
1	@SC	CSC	@LFC	@BFC	@ML	CSH	ADC	@DS	LDA	@UCR	MPZ	SG
2	@UCR	@ADC	BFC	SC	DS	LFC	@ML	@SG	@CSC	MPZ	@CSH	LDA
3	ML	UCR	SC	@MPZ	@SG	@LDA	@DS	CSC	@ADC	CSH	LFC	@BFC
4	DS	@LFC	@CSH	SG	ADC	UCR	BFC	@SC	MPZ	@CSC	@LDA	@ML
5	@LFC	SC	@DS	@UCR	@MPZ	@SG	LDA	CSH	@BFC	ML	ADC	CSC
6	SG	@ML	MPZ	DS	UCR	BFC	@SC	@ADC	LFC	@LDA	@CSC	@CSH
7	@MPZ	CSH	@SG	@LFC	@BFC	@DS	CSC	LDA	@UCR	ADC	ML	SC
8	CSC	SG	UCR	@LDA	@LFC	MPZ	CSH	@ML	DS	@BFC	@SC	@ADC
9	@ADC	@MPZ	LDA	ML	SC	@CSC	@UCR	BFC	@CSH	DS	@SG	LFC
10	BFC	@LDA	@ML	CSH	@CSC	ADC	MPZ	@LFC	SG	@SC	UCR	@DS
11	@CSH	DS	CSC	@ADC	LDA	SC	@SG	@UCR	@ML	LFC	@BFC	MPZ
12	SC	@CSC	LFC	BFC	ML	@CSH	@ADC	DS	@LDA	UCR	@MPZ	@SG
13	UCR	ADC	@BFC	@SC	@DS	@LFC	ML	SG	CSC	@MPZ	CSH	@LDA
14	@ML	@UCR	@SC	MPZ	SG	LDA	DS	@CSC	ADC	@CSH	@LFC	BFC
15	@DS	LFC	CSH	@SG	@ADC	@UCR	@BFC	SC	@MPZ	CSC	LDA	ML
16	LFC	@SC	DS	UCR	MPZ	SG	@LDA	@CSH	BFC	@ML	@ADC	@CSC
17	@SG	ML	@MPZ	@DS	@UCR	@BFC	SC	ADC	@LFC	LDA	CSC	CSH
18	MPZ	@CSH	SG	LFC	BFC	DS	@CSC	@LDA	UCR	@ADC	@ML	@SC
19	@CSC	@SG	@UCR	LDA	LFC	@MPZ	@CSH	ML	@DS	BFC	SC	ADC
20	ADC	MPZ	@LDA	@ML	@SC	CSC	UCR	@BFC	CSH	@DS	SG	@LFC
21	@BFC	LDA	ML	@CSH	CSC	@ADC	@MPZ	LFC	@SG	SC	@UCR	DS
22	CSH	@DS	@CSC	ADC	@LDA	@SC	SG	UCR	ML	@LFC	BFC	@MPZ

Partial Swap Rounds (T1,R1,R2) after

	LDA	BFC	ADC	CSC	CSH	ML	LFC	MPZ	SC	SG	DS	UCR
1	@CSH	CSC	@LFC	@BFC	LDA	SC	ADC	@DS	@ML	@UCR	MPZ	SG
2	@UCR	@ADC	BFC	SC	DS	LFC	@ML	@SG	@CSC	MPZ	@CSH	LDA
3	ML	UCR	SC	@MPZ	@SG	@LDA	@DS	CSC	@ADC	CSH	LFC	@BFC
4	DS	@LFC	@CSH	SG	ADC	UCR	BFC	@SC	MPZ	@CSC	@LDA	@ML
5	@LFC	SC	@DS	@UCR	@MPZ	@SG	LDA	CSH	@BFC	ML	ADC	CSC
6	SG	@ML	MPZ	DS	UCR	BFC	@SC	@ADC	LFC	@LDA	@CSC	@CSH
7	@MPZ	CSH	@SG	@LFC	@BFC	@DS	CSC	LDA	@UCR	ADC	ML	SC
8	CSC	SG	UCR	@LDA	@LFC	MPZ	CSH	@ML	DS	@BFC	@SC	@ADC
9	@ADC	@MPZ	LDA	ML	SC	@CSC	@UCR	BFC	@CSH	DS	@SG	LFC
10	BFC	@LDA	@ML	CSH	@CSC	ADC	MPZ	@LFC	SG	@SC	UCR	@DS
11	@SC	DS	CSC	@ADC	@ML	CSH	@SG	@UCR	LDA	LFC	@BFC	MPZ
12	SC	@CSC	LFC	BFC	ML	@CSH	@ADC	DS	@LDA	UCR	@MPZ	@SG
13	UCR	ADC	@BFC	@SC	@DS	@LFC	ML	SG	CSC	@MPZ	CSH	@LDA
14	@ML	@UCR	@SC	MPZ	SG	LDA	DS	@CSC	ADC	@CSH	@LFC	BFC
15	@DS	LFC	CSH	@SG	@ADC	@UCR	@BFC	SC	@MPZ	CSC	LDA	ML
16	LFC	@SC	DS	UCR	MPZ	SG	@LDA	@CSH	BFC	@ML	@ADC	@CSC
17	@SG	ML	@MPZ	@DS	@UCR	@BFC	SC	ADC	@LFC	LDA	CSC	CSH
18	MPZ	@CSH	SG	LFC	BFC	DS	@CSC	@LDA	UCR	@ADC	@ML	@SC
19	@CSC	@SG	@UCR	LDA	LFC	@MPZ	@CSH	ML	@DS	BFC	SC	ADC
20	ADC	MPZ	@LDA	@ML	@SC	CSC	UCR	@BFC	CSH	@DS	SG	@LFC
21	@BFC	LDA	ML	@CSH	CSC	@ADC	@MPZ	LFC	@SG	SC	@UCR	DS
22	CSH	@DS	@CSC	ADC	@LDA	@SC	SG	UCR	ML	@LFC	BFC	@MPZ

Partial Team Swap (T1,T2,R1)

- Swap the matches of two teams (T1,T2) in a given round (R2).
  - Worst case scenario, we swap all matches between 2 teams.

Partial Team Swap (T1,T2,R1) before

	LDA	BFC	ADC	CSC	CSH	ML	LFC	MPZ	SC	SG	DS	UCR
1	@SC	CSC	@LFC	@BFC	@ML	CSH	ADC	@DS	LDA	@UCR	MPZ	SG
2	@UCR	@ADC	BFC	SC	DS	LFC	@ML	@SG	@CSC	MPZ	@CSH	LDA
3	ML	UCR	SC	@MPZ	@SG	@LDA	@DS	CSC	@ADC	CSH	LFC	@BFC
4	DS	@LFC	@CSH	SG	ADC	UCR	BFC	@SC	MPZ	@CSC	@LDA	@ML
5	@LFC	SC	@DS	@UCR	@MPZ	@SG	LDA	CSH	@BFC	ML	ADC	CSC
6	SG	@ML	MPZ	DS	UCR	BFC	@SC	@ADC	LFC	@LDA	@CSC	@CSH
7	@MPZ	CSH	@SG	@LFC	@BFC	@DS	CSC	LDA	@UCR	ADC	ML	SC
8	CSC	SG	UCR	@LDA	@LFC	MPZ	CSH	@ML	DS	@BFC	@SC	@ADC
9	@ADC	@MPZ	LDA	ML	SC	@CSC	@UCR	BFC	@CSH	DS	@SG	LFC
10	BFC	@LDA	@ML	CSH	@CSC	ADC	MPZ	@LFC	SG	@SC	UCR	@DS
11	@CSH	DS	CSC	@ADC	LDA	SC	@SG	@UCR	@ML	LFC	@BFC	MPZ
12	SC	@CSC	LFC	BFC	ML	@CSH	@ADC	DS	@LDA	UCR	@MPZ	@SG
13	UCR	ADC	@BFC	@SC	@DS	@LFC	ML	SG	CSC	@MPZ	CSH	@LDA
14	@ML	@UCR	@SC	MPZ	SG	LDA	DS	@CSC	ADC	@CSH	@LFC	BFC
15	@DS	LFC	CSH	@SG	@ADC	@UCR	@BFC	SC	@MPZ	CSC	LDA	ML
16	LFC	@SC	DS	UCR	MPZ	SG	@LDA	@CSH	BFC	@ML	@ADC	@CSC
17	@SG	ML	@MPZ	@DS	@UCR	@BFC	SC	ADC	@LFC	LDA	CSC	CSH
18	MPZ	@CSH	SG	LFC	BFC	DS	@CSC	@LDA	UCR	@ADC	@ML	@SC
19	@CSC	@SG	@UCR	LDA	LFC	@MPZ	@CSH	ML	@DS	BFC	SC	ADC
20	ADC	MPZ	@LDA	@ML	@SC	CSC	UCR	@BFC	CSH	@DS	SG	@LFC
21	@BFC	LDA	ML	@CSH	CSC	@ADC	@MPZ	LFC	@SG	SC	@UCR	DS
22	CSH	@DS	@CSC	ADC	@LDA	@SC	SG	UCR	ML	@LFC	BFC	@MPZ

Partial Team Swap (T1,T2,R1) after

	LDA	BFC	ADC	CSC	CSH	ML	LFC	MPZ	SC	SG	DS	UCR
1	@SC	CSC	@LFC	@BFC	@ML	CSH	ADC	@DS	LDA	@UCR	MPZ	SG
2	@UCR	@MPZ	@SG	SC	DS	LFC	@ML	BFC	@CSC	ADC	@CSH	LDA
3	ML	UCR	SC	@MPZ	@SG	@LDA	@DS	CSC	@ADC	CSH	LFC	@BFC
4	DS	@LFC	@CSH	SG	ADC	UCR	BFC	@SC	MPZ	@CSC	@LDA	@ML
5	@LFC	SC	@DS	@UCR	@MPZ	@SG	LDA	CSH	@BFC	ML	ADC	CSC
6	SG	@ML	MPZ	DS	UCR	BFC	@SC	@ADC	LFC	@LDA	@CSC	@CSH
7	@ADC	CSH	LDA	@LFC	@BFC	@DS	CSC	@SG	@UCR	MPZ	ML	SC
8	CSC	SG	UCR	@LDA	@LFC	MPZ	CSH	@ML	DS	@BFC	@SC	@ADC
9	@MPZ	@ADC	BFC	ML	SC	@CSC	@UCR	LDA	@CSH	DS	@SG	LFC
10	BFC	@LDA	@ML	CSH	@CSC	ADC	MPZ	@LFC	SG	@SC	UCR	@DS
11	@CSH	DS	CSC	@ADC	LDA	SC	@SG	@UCR	@ML	LFC	@BFC	MPZ
12	SC	@CSC	LFC	BFC	ML	@CSH	@ADC	DS	@LDA	UCR	@MPZ	@SG
13	UCR	ADC	@BFC	@SC	@DS	@LFC	ML	SG	CSC	@MPZ	CSH	@LDA
14	@ML	@UCR	@SC	MPZ	SG	LDA	DS	@CSC	ADC	@CSH	@LFC	BFC
15	@DS	LFC	CSH	@SG	@ADC	@UCR	@BFC	SC	@MPZ	CSC	LDA	ML
16	LFC	@SC	DS	UCR	MPZ	SG	@LDA	@CSH	BFC	@ML	@ADC	@CSC
17	@SG	ML	@MPZ	@DS	@UCR	@BFC	SC	ADC	@LFC	LDA	CSC	CSH
18	MPZ	@CSH	SG	LFC	BFC	DS	@CSC	@LDA	UCR	@ADC	@ML	@SC
19	@CSC	@SG	@UCR	LDA	LFC	@MPZ	@CSH	ML	@DS	BFC	SC	ADC
20	ADC	MPZ	@LDA	@ML	@SC	CSC	UCR	@BFC	CSH	@DS	SG	@LFC
21	@BFC	LDA	ML	@CSH	CSC	@ADC	@MPZ	LFC	@SG	SC	@UCR	DS
22	CSH	@DS	@CSC	ADC	@LDA	@SC	SG	UCR	ML	@LFC	BFC	@MPZ

Two-exchange

□ Exchange matches (same opponents) between 2 rounds. The H/A pattern changes!

Week / Teams	LDA	BFC
12	ACD	CSC
…		
15	@CSC	@ACD

Week / Teams	LDA	BFC
12	@CSC	@ACD
…		
15	ACD	CSC

Home-exchange (T1,T2)

- Exchange home venue between two teams (T1,T2)
  - For n teams there are (n-1)n/2 neighboring solutions
  - H/A patterns changes!

Home-exchange (T1,T2) before

LDA	BFC	ADC	CSC	CSH	ML	LFC	MPZ	SC	SG	DS	UCR
@BFC	LDA	SG	ML	@SC	@CSC	UCR	@DS	CSH	@ADC	MPZ	@LFC
SC	@UCR	CSH	LFC	@ADC	DS	@CSC	@SG	@LDA	MPZ	@ML	BFC
@MPZ	ADC	@BFC	@CSH	CSC	@SG	@DS	LDA	@UCR	ML	LFC	SC
SG	@LFC	@CSC	ADC	DS	UCR	BFC	@SC	MPZ	@LDA	@CSH	@ML
@ADC	SC	LDA	@SG	@LFC	@MPZ	CSH	ML	@BFC	CSC	UCR	@DS
DS	@CSC	@ML	BFC	SG	ADC	@SC	@UCR	LFC	@CSH	@LDA	MPZ
@LFC	ML	SC	@DS	@MPZ	@BFC	LDA	CSH	@ADC	UCR	CSC	@SG
@CSH	SG	@UCR	MPZ	LDA	LFC	@ML	@CSC	DS	@BFC	@SC	ADC
CSC	@MPZ	LFC	@LDA	@UCR	SC	@ADC	BFC	@ML	DS	@SG	CSH
ML	@CSH	@DS	UCR	BFC	@LDA	MPZ	@LFC	SG	@SC	ADC	@CSC
@UCR	DS	MPZ	SC	@ML	CSH	@SG	@ADC	@CSC	LFC	@BFC	LDA
BFC	@LDA	@SG	@ML	CSC	CSC	@UCR	DS	@CSH	ADC	@MPZ	LFC
@SC	UCR	@CSH	@LFC	ADC	@DS	CSC	SG	LDA	@MPZ	ML	@BFC
MPZ	@ADC	BFC	CSH	@CSC	SG	DS	@LDA	UCR	@ML	@LFC	@SC
@SG	LFC	CSC	@ADC	@DS	@UCR	@BFC	SC	@MPZ	LDA	CSH	ML
ADC	@SC	@LDA	SG	LFC	MPZ	@CSH	@ML	BFC	@CSC	@UCR	DS
@DS	CSC	ML	@BFC	@SG	@ADC	SC	UCR	@LFC	CSH	LDA	@MPZ
LFC	@ML	@SC	DS	MPZ	BFC	@LDA	@CSH	ADC	@UCR	@CSC	SG
CSH	@SG	UCR	@MPZ	@LDA	@LFC	ML	CSC	@DS	BFC	SC	@ADC
@CSC	MPZ	@LFC	LDA	UCR	@SC	ADC	@BFC	ML	@DS	SG	@CSH
@ML	CSH	DS	@UCR	@BFC	LDA	@MPZ	LFC	@SG	SC	@ADC	CSC
UCR	@DS	@MPZ	@SC	ML	@CSH	SG	ADC	CSC	@LFC	BFC	@LDA

Home-exchange (T1,T2) after

LDA	BFC	ADC	CSC	CSH	ML	LFC	MPZ	SC	SG	DS	UCR
@BFC	LDA	SG	ML	@SC	@CSC	UCR	@DS	CSH	@ADC	MPZ	@LFC
SC	@UCR	CSH	LFC	@ADC	DS	@CSC	@SG	@LDA	MPZ	@ML	BFC
@MPZ	ADC	@BFC	@CSH	CSC	@SG	@DS	LDA	@UCR	ML	LFC	SC
SG	@LFC	@CSC	ADC	DS	UCR	BFC	@SC	MPZ	@LDA	@CSH	@ML
@ADC	SC	LDA	@SG	@LFC	@MPZ	CSH	ML	@BFC	CSC	UCR	@DS
DS	@CSC	@ML	BFC	SG	ADC	@SC	@UCR	LFC	@CSH	@LDA	MPZ
@LFC	ML	SC	@DS	@MPZ	@BFC	LDA	CSH	@ADC	UCR	CSC	@SG
@CSH	SG	@UCR	MPZ	LDA	@LFC	ML	@CSC	DS	@BFC	@SC	ADC
CSC	@MPZ	LFC	@LDA	@UCR	SC	@ADC	BFC	@ML	DS	@SG	CSH
ML	@CSH	@DS	UCR	BFC	@LDA	MPZ	@LFC	SG	@SC	ADC	@CSC
@UCR	DS	MPZ	SC	@ML	CSH	@SG	@ADC	@CSC	LFC	@BFC	LDA
BFC	@LDA	@SG	@ML	SC	CSC	@UCR	DS	@CSH	ADC	@MPZ	LFC
@SC	UCR	@CSH	@LFC	ADC	@DS	CSC	SG	LDA	@MPZ	ML	@BFC
MPZ	@ADC	BFC	CSH	@CSC	SG	DS	@LDA	UCR	@ML	@LFC	@SC
@SG	LFC	CSC	@ADC	@DS	@UCR	@BFC	SC	@MPZ	LDA	CSH	ML
ADC	@SC	@LDA	SG	LFC	MPZ	@CSH	@ML	BFC	@CSC	@UCR	DS
@DS	CSC	ML	@BFC	@SG	@ADC	SC	UCR	@LFC	CSH	LDA	@MPZ
LFC	@ML	@SC	DS	MPZ	BFC	@LDA	@CSH	ADC	@UCR	@CSC	SG
CSH	@SG	UCR	@MPZ	@LDA	LFC	@ML	CSC	@DS	BFC	SC	@ADC
@CSC	MPZ	@LFC	LDA	UCR	@SC	ADC	@BFC	ML	@DS	SG	@CSH
@ML	CSH	DS	@UCR	@BFC	LDA	@MPZ	LFC	@SG	SC	@ADC	CSC
UCR	@DS	@MPZ	@SC	ML	@CSH	SG	ADC	CSC	@LFC	BFC	@LDA

3-Match Exchange (T1,T2,R1,R2,R3)

☐ 3-match swap between T1 and T2 across 3 rounds

Round / Teams	CHI	DET
12	NYJ	SF
13	GB	@NYJ
15	@SF	@GB

1st combination

Round / Teams	CHI	DET
12	@SF	@NYJ
13	NYJ	@GB
15	GB	SF

3-Match Exchange (T1,T2,R1,R2,R3)

- 3-match swap between T1 and T2 across 3 rounds

Round / Teams	CHI	DET
12	NYJ	SF
13	GB	@NYJ
15	@SF	@GB

2nd combination

Round / Teams	CHI	DET
12	GB	@NYJ
13	@SF	@GB
15	NYJ	SF

3-Match Exchange (T1,T2,R1,R2,R3)

- 3-match swap between T1 and T2 across 3 rounds

Round / Teams	CHI	DET
12	NYJ	SF
13	GB	@NYJ
15	@SF	@GB

3rd combination

Round / Teams	CHI	DET
12	@SF	@GB
13	NYJ	SF
15	GB	@NYJ

Implementation highlights

- *Tabu Lists (maintained for a number of iterations):*
  - Previously changed matchups cannot re-appear at the same round
  - Previously violated Pairing, Spacing and Venue availability hard constraints (999 penalty) cannot re-appear

- *Aspiration condition:*
  - Neighboring solution is better than the best found solution

Implementation highlights (cont.)

- *Neighborhood selection:*
  - First accept strategy considering all leagues.
  - Only improving moves are accepted considering Home-exchange and Two-exchange structures.
  - Fixed matchups cannot be moved.
  - Constraint violations are valued the same among all leagues. At each local search iteration we keep track of all violations from all leagues (due to pairing constraints).
- Randomly ruin and re-create part of the schedule of the league with more constraint violations

Preliminary computational results

Data

- 12 instances (6 mirrored) with up to 4 leagues, 18 teams and 38 round

- Different types of constraints randomly selected

Experiments

- Treat each league as independent assuming no intra-league pairings (baseline)

- Introduce inter-league pairings and compare between loose and tight parings scenarios

  - In all cases we guaranteed that a feasible with no violations exists (via a MIP approach)

Preliminary computational results

Single-league scheduling runs

☐ High quality solutions with low scores can be generated in relatively short computational times (less than 2 to 4 hours)

#Pr	Score per league				Multi-league total
1	0	0			0
2	999	6519			7518
3	25	375	0		400
4	0	0	2997		2997
5	1374	0	0	0	1374
6	325	4995	2273	0	7593
7	0	0			0
8	999	2373			3372
9	0	0	0		0
10	0	425	999		1424
11	1374	0	0	0	1374
12	1224	0	0	999	2223

Preliminary computational results

Multi-league scheduling runs

☐ The effect of pairing constraint is very high and makes the problem significantly harder to solve

#Pr	Score per league				Multi-league total	Loose Paring	Tight Pairing
1	0	0			0	0	21736
2	999	6519			7518	12034	34876
3	25	375	0		400	400	5124
4	0	0	2997		2997	17362	53945
5	1374	0	0	0	1374	19876	66421
6	325	4995	2273	0	7593	31946	93452
7	0	0			0	0	5310
8	999	2373			3372	8352	52098
9	0	0	0		0	10010	7992
10	0	425	999		1424	12813	35962
11	1374	0	0	0	1374	23025	43023
12	1224	0	0	999	2223	15892	51098

Future Research Steps

- **Rigorous tuning of hyperparameters**
  - Tabu lists size, number of inner local search iterations, depth of perturbation etc

- Consider compound neighborhood structures
  - Multiple moves in a single iteration

- Neighborhood restricted based on the available H-A patterns
  - H-A patterns per team will be found in a pre-processing stage using exact approaches
  - HAHAAHHAAH …, AAHHAHHA …, etc.

Future Steps

- Explore different constraint prioritization schemes and/or hierarchies among the leagues

- Explore additional Key Performance Indicators (and alternative tie breakers) in the objective function
  - Distance travelling
  - Competitive Imbalance and Fairness

- Create a more consistent benchmark data set

Wrap-up

- Optimization can make a big impact on sports
  - Reduce costs
  - Maximize utilization of resources
  - Create more exciting, fair and competitive schedules
  - Potential to increase revenue to the clubs and leagues
- (Professional) sports is a great application area for OR and analytics.

Thank you for your attention!