CoRe Challenge 2022/2023: International Competition for Combinatorial Reconfiguration

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joint work with
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Background

- **Theoretical aspects** of Combinatorial Reconfiguration have been actively studied.
  - According to a survey by Dr. D. A. Hoang, researchers from over 470 individuals across 165 institutions in 34 countries have published papers related to combinatorial reconfiguration.
  - The annual publication count has increased approximately 15 times from 2008 to 2021.
- **Practical aspects** of Combinatorial Reconfiguration have just begun.
- In 2020, CoRe project was launched in Japan supported by "KAKENHI Grant-in-Aid for Transformative Research Areas (B)".

Background

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An issue on starting practical studies

- We do not have any baseline.
  - instances to be used for evaluation
  - solvers to be compared

Summary of this talk

- To make a baseline of the practical study of combinatorial reconfiguration, we hold international competitions called **CoRe Challenge 2022/2023**.

Achievements via the competition

- List of runnable solvers and results.
- Input file format.
- List of instances that distinguish the characteristics of solvers.
- Showing the current performance of the state-of-the-art solvers.

Effects after the competition

There are already five papers using the challenge resources:

- [Bousquet+, J. Combinatorics 2023], [Christen+, HSDIP 2023],
- [Ito+, CPAIOR 2023], [Yamada+, JELIA 2023], [Hirate+, JELIA 2023]

What is CoRe Challenge?

- **CoRe Challenge** is an international competition aiming to provide a baseline for practical studies.
- CoRe Challenge 2022/2023 targets **Independent Set Reconfiguration (ISR)** problems.

Why is ISR selected?

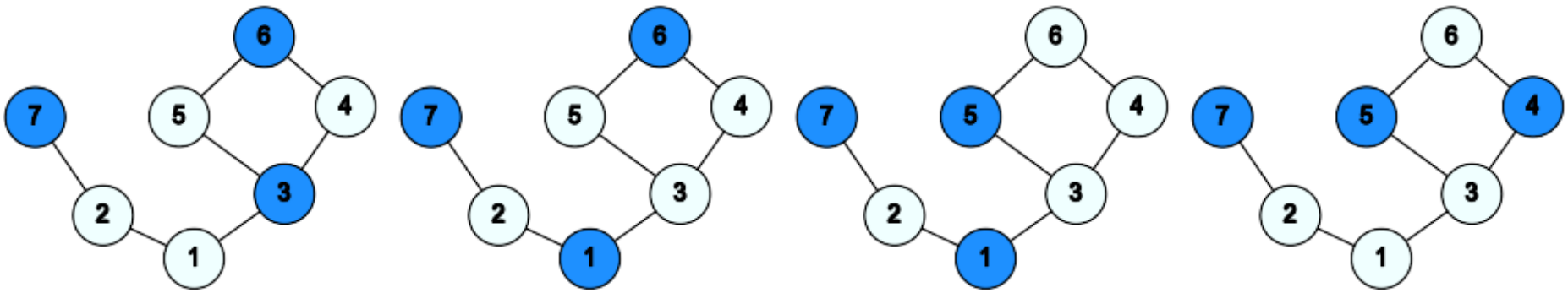
- It is one of the most theoretically well-studied reconfiguration problems.
- ISR is PSPACE-complete, which implies that there exist instances such that even a shortest reconfiguration sequence requires super polynomial steps.
- ISR is frequently used to prove the PSPACE-completeness of other problems.

What is ISR? By example

Input

- an undirected graph $G = (V, E)$ where $V = \{1, 2, 3, 4, 5, 6, 7\}$, $E = \{\{1, 2\}, \{1, 3\}, \{2, 7\}, \{3, 4\}, \{3, 5\}, \{4, 6\}, \{5, 6\}\}$
- the start state $I_s = \{3, 6, 7\}$
- the target state $I_t = \{4, 5, 7\}$
- reconfiguration rule (token jump, etc.)

For this instance, a reconfiguration sequence under the **token jump rule** (token can jump to any node) exists.



$I_0 = I_s$ I_1 I_2 $I_3 = I_t$

Questions

- Can we solve ISR instances efficiently by AI planners or BMC solvers?
- Which solver is better?
- How do they scale in terms of the number of nodes and the length?
- Which types of instances are difficult?
- How much does the reconfiguration length extend for a limited number of nodes?

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- Which solver is better?
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- How much does the reconfiguration length extend for a limited number of nodes?

CoRe Challenge will answer those questions (I hope).

Competition Tracks

- **Solver Track**
  - Contestants develop their own **ISR solvers**.
  - Metrics are:
    - ★ Existent
    - ★ Shortest
    - ★ Longest
  - We distinguish two types of solvers because Portfolio solvers are often easier to improve solver performance (and to encourage the development of new single algorithm).
    - ★ Single engine (single strategy)
    - ★ Portfolio (multiple strategy)
  - Used techniques in submission: IDA*, BMC, ZDD.
- **Graph Track**
  - Contestants create their own **ISR instances** with a given number of nodes.
  - The one with the longest-shortest step wins.

Finally, there are submissions from 8 countries (12 universities and two companies).

CoRe Challenge 2022/2023 Setting (Solver Track)

CoRe Challenge 2022/2023

- solver tracks:
  - benchmark instances: 369 for 2022, 693 for 2023.
  - 11 solvers (AI Planner, BMC, ZDD) participated in a total

Submission/Evaluation in 2023

- Participants will do:
  - clone the template repository ▸ web, including a solver checker.
  - edit the repository and add a runnable Docker file.
  - submit the private GitHub repository.
- 16 machines are used for running docker-wrapped solvers.
  - CPU: Core i5 12400 (2.5GHz)
  - Mem: 64GB

Overview of Solvers Submitted

IDA*

- Use iteratively deepening A* (generalization of Dijkstra Algorithm).
- Implementation: Scorpion (state-of-the-art AI planner), original

BMC

- Construct a formula Ψ_k which is true iff there is a sequence of length k between I_s and I_t.
- Find Ψ_k from $k = 1$ and increment it until we obtain SAT.
- Implementation: NuSMV, SAT-based, ASP-based

ZDD

- Construct ZDD representing all independent sets of G.
- By maintaining ZDD, execute a breadth-first search from I_s to I_t.

Result: Solver Track (Existent) with 369 instances

- We evaluate the number of instances that contestants outputted “yes/no” and “reconfiguration sequence (if yes)”.

Single Engine

1st	IDA*	PARIS single (@haz-single)	299 (275/24)
2nd	BMC	recongo (@YuyaYamada-N)	244 (238/6)
3rd	BMC	@toda5603	207 (207/0)

Portfolio

1st	IDA*	PARIS (@haz)	334 (288/46)
2nd	IDA*	@telematik-tuhh	326 (280/46)
3rd	IDA*	PARIS single (@haz-single)	299 (276/24)

Result: Solver Track (Shortest) with 369 instances

- We evaluate the number of instances that contestants outputted reconfiguration sequences having the shortest length among all contestants.

Single Engine

1st	BMC	recongo (@YuyaYamada-N)	238
2nd	???	@tigrisg	232
3rd	IDA*	PARIS single (@haz-single)	213

Portfolio

1st	IDA*	@telematik-tuhh	280
2nd	IDA*	PARIS (@haz)	275
3rd	BMC	recongo (@YuyaYamada-N)	238

The longest stepper is @junkawahara (ZDD), which solves an instance having 90101 steps.

Result: Solver Track (Longest) with 369 instances

- We evaluate the number of instances that contestants outputted reconfiguration sequences having the longest length among all contestants.
- Note that a sequence cannot contain any loop, i.e., two identical independent sets.

Single Engine

1st	IDA*	PARIS single (@haz-single)	144
2nd	BMC	recongo (@YuyaYamada-N)	115
3rd	BMC	ReconfAIGERation (@Froleyks)	54

Portfolio

1st	IDA*	PARIS single (@haz-single)	143
2nd	BMC	recongo (@YuyaYamada-N)	115
3rd	IDA*	PARIS (@haz)	90

Results on Graph Track in 2022

10 nodes.

1st	@telematik-tuhh	10	
2nd	@tpierron	10	proven to be optimal
3rd	@akkyhowa	9	

50 nodes.

1st	@tpierron	3,410
2nd	PARIS (@haz)	3,069
3rd	@karakasaDcFd	3,069

100 nodes.

1st	@tpierron	3,495,250
2nd	PARIS (@haz)	3,145,725
3rd	@karakasaDcFd	3,145,725

Results on “Single Shortest” category in 2023

Note: this result is under review by participants.

Series	#Ins.	max. N.	max. L.	IDA*	BMC	ZDD
grid	49	40000	8	2	2	2
color04	202	10000	112	198	200	76
queen	48	10000	94	42	25	8
handcrafted	6	36	69	5	5	5
ph-isr	36	9205	31	1	0	1
random	200	520	115	139	193	35
exp. long	152	912	442175	28	7	113
Total	693			415	432	240

Conclusion

- **Theoretical aspects** of Combinatorial Reconfiguration have been actively studied.
- **Practical aspects** should be studied also, but it is an issue that we do not have any baseline.
- **CoRe Challenge** is an international competition aiming to provide the baseline for ISR and Combinatorial Reconfiguration.

Achievements

- List of runnable solvers.
- Input file format.
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There are already five papers using the resources of the challenge.

Resources

- CoRe Challenge 2022 ▸ web
- CoRe Challenge 2023 ▸ web
- SATracer ▸ web