TOWARDS THE USAGE OF WINDOW COUNTING CONSTRAINTS IN THE SYNTHESIS OF REACTIVE SYSTEMS TO REDUCE STATE SPACE EXPLOSION

Linda Feeken, Martin Fränzle

GandALF 2024, 20.06.2024

DLR

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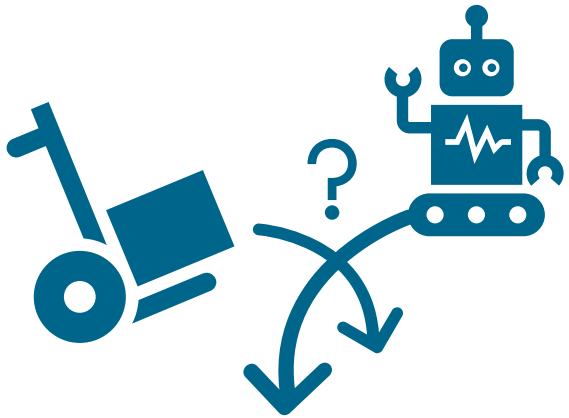
Linda Feeken, German Aerospace Center (DLR), 20.06.2024

Synthesis of Reactive Systems

Short Introduction

System interacts with environment



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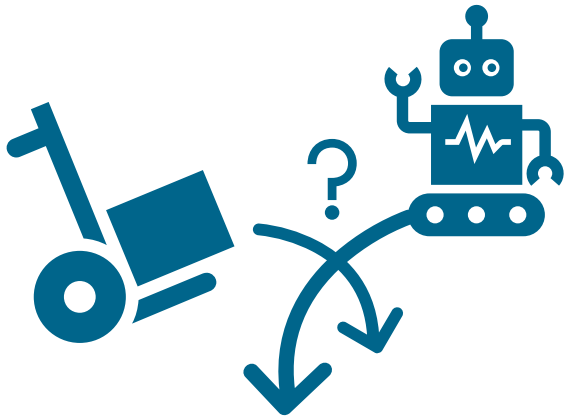
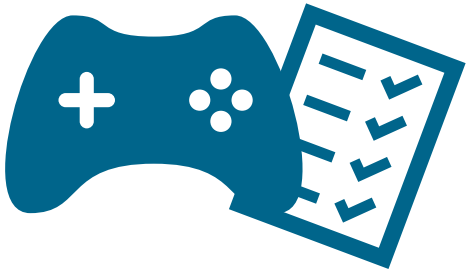


Strategies compliant with system specification



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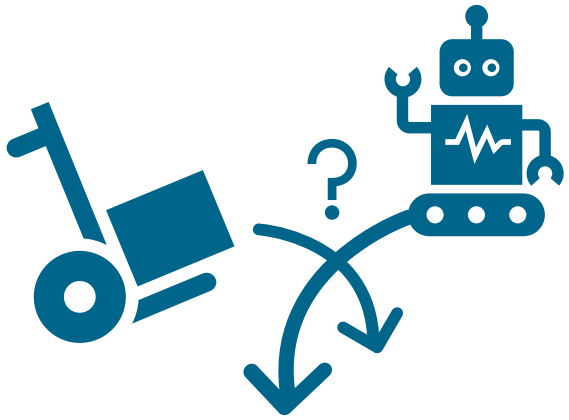

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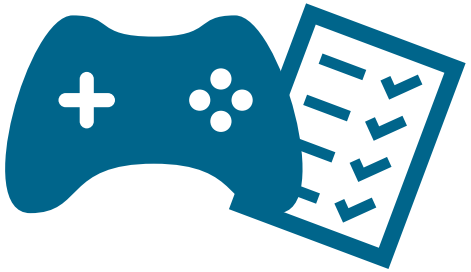
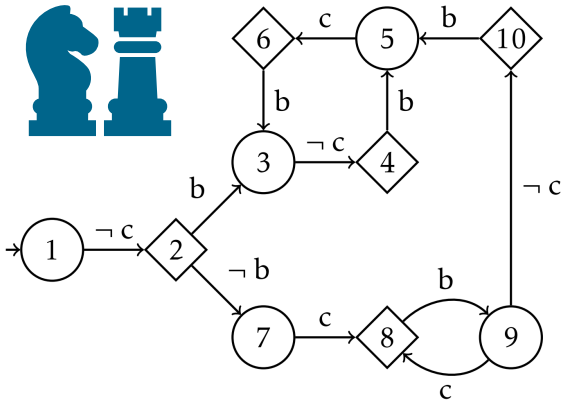


Game-theoretic approach



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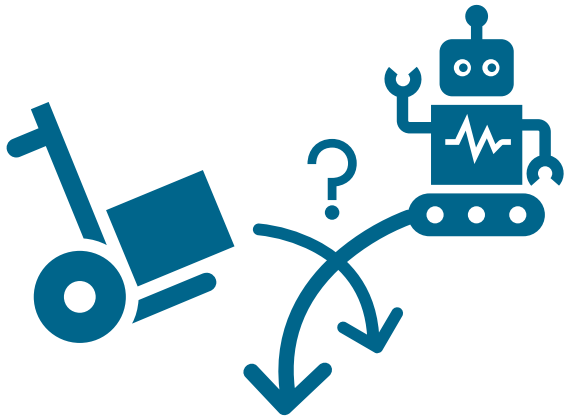

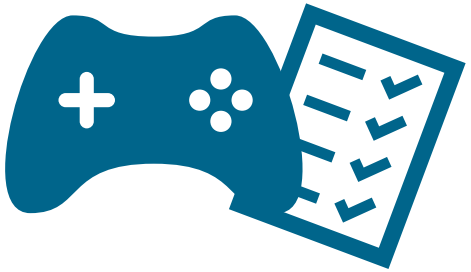

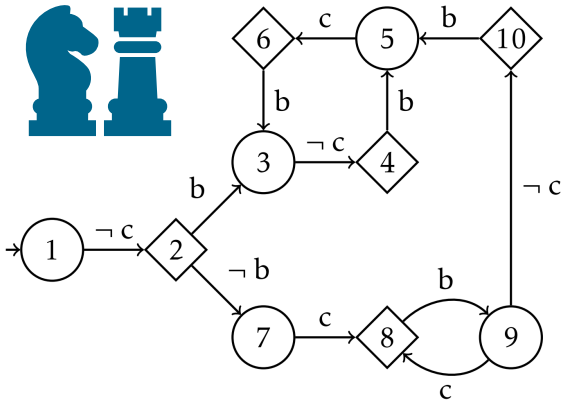

Here:

- Two-player finite-state game with infinite plays
- Specification given as combination of window counting constraints and explicit game graph

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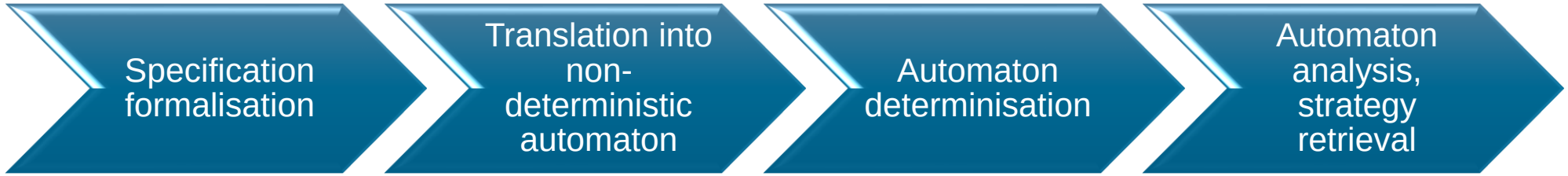
State Space Explosion

Standard synthesis procedure overview



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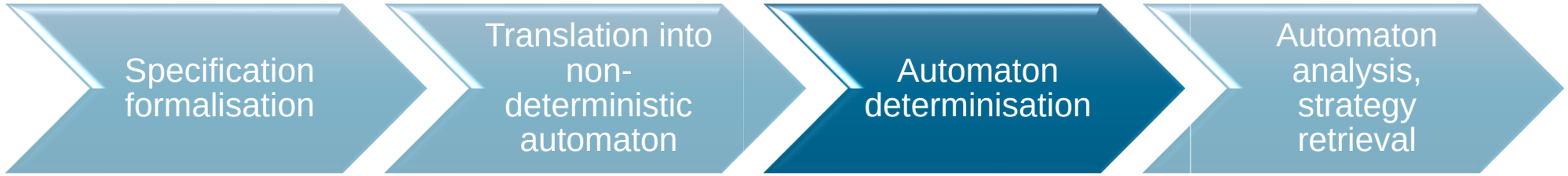

Expensive procedure!
(computational time, memory)
Resulting automaton is significantly bigger than specification! State space explosion!

State Space Explosion

Related Work to deal with state space explosion

Synthesis Input: Specification

Synthesis Procedure

Synthesis Output: Strategy

State Space Explosion

Related Work to deal with state space explosion

Synthesis Input: Specification

Synthesis Procedure

Synthesis Output: Strategy

Restriction to specifications of a special form, e.g.:

- GR(1) [1]
- Safety LTL [2]

[1] Piterman, Nir, Amir Pnueli, and Yaniv Sa'ar. "Synthesis of reactive (1) designs." *Verification, Model Checking, and Abstract Interpretation: 7th International Conference, VMCAI 2006, Charleston, SC, USA, January 8-10, 2006. Proceedings 7*. Springer Berlin Heidelberg, 2006.

[2] Zhu, Shufang, et al. "A symbolic approach to safety LTL synthesis." *Hardware and Software: Verification and Testing: 13th International Haifa Verification Conference, HVC 2017, Haifa, Israel, November 13-15, 2017, Proceedings 13*. Springer International Publishing, 2017.

State Space Explosion

Related Work to deal with state space explosion

Synthesis Input: Specification

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Restriction to specifications of a special form, e.g.:
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Tackling the internal representation of the problem, e.g.:
- Safraless approaches, e.g. [3]
- Symbolic approaches, e.g. [4]

[3] Kupferman, Orna, and Moshe Y. Vardi. "Safraless decision procedures." *46th Annual IEEE Symposium on Foundations of Computer Science (FOCS'05)*. IEEE, 2005.

[4] Filiot, Emmanuel, Naiyong Jin, and Jean-François Raskin. "An antichain algorithm for LTL realizability." *Computer Aided Verification: 21st International Conference, CAV 2009, Grenoble, France, June 26-July 2, 2009. Proceedings 21*. Springer Berlin Heidelberg, 2009.

State Space Explosion

Related Work to deal with state space explosion

Synthesis Input: Specification

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Restriction to specifications of a special form, e.g.:
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Tackling the internal representation of the problem, e.g.:
- „Safraless“ approaches
- Symbolic approaches

Restriction of the strategy size, e.g.:
- Bounded synthesis, e.g. [5]
- Lazy synthesis [6]

[5] Schewe, Sven, and Bernd Finkbeiner. "Bounded synthesis." *International symposium on automated technology for verification and analysis*. Berlin, Heidelberg: Springer Berlin Heidelberg, 2007.

[6] Finkbeiner, Bernd, and Swen Jacobs. "Lazy synthesis." *International Workshop on Verification, Model Checking, and Abstract Interpretation*. Berlin, Heidelberg: Springer Berlin Heidelberg, 2012.

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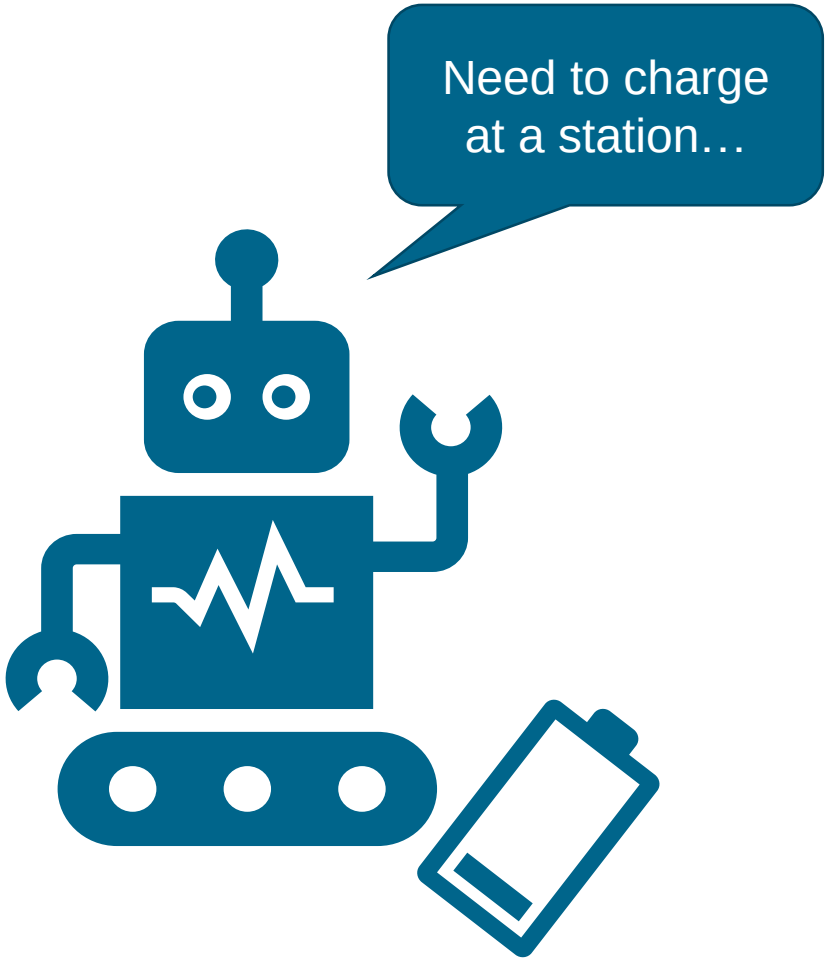
Window Counting Constraints



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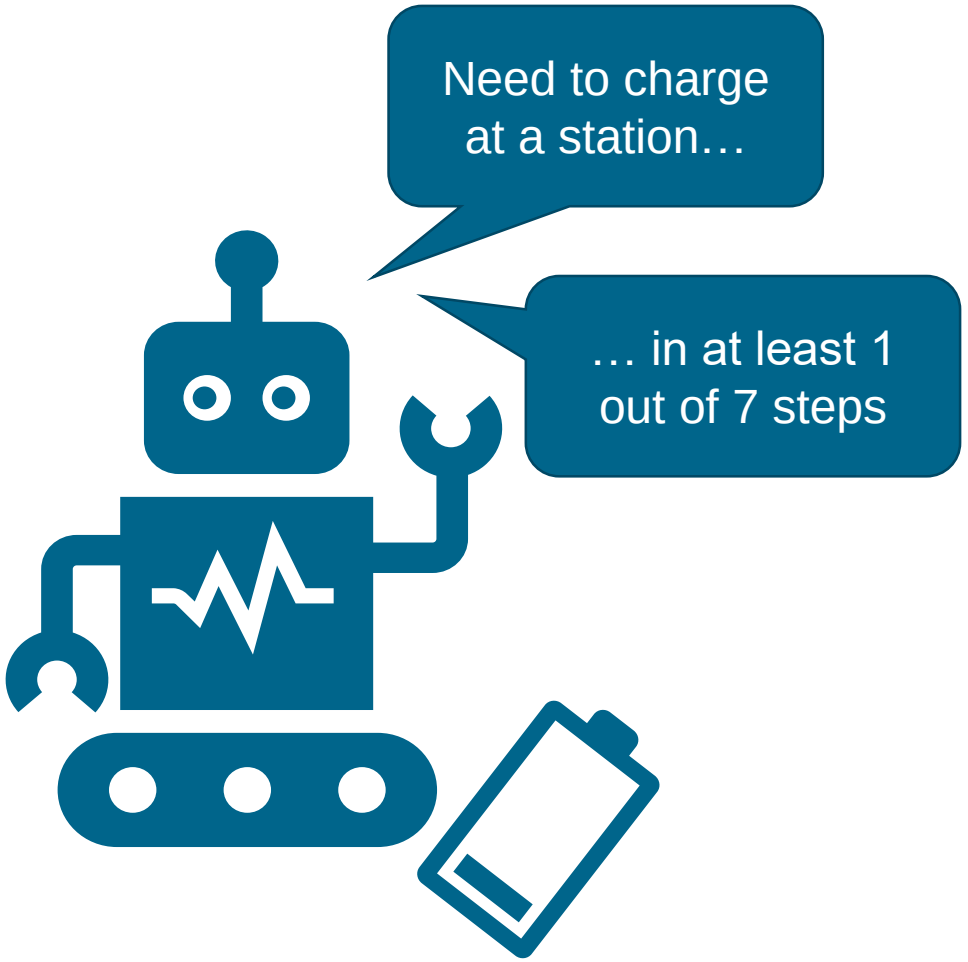
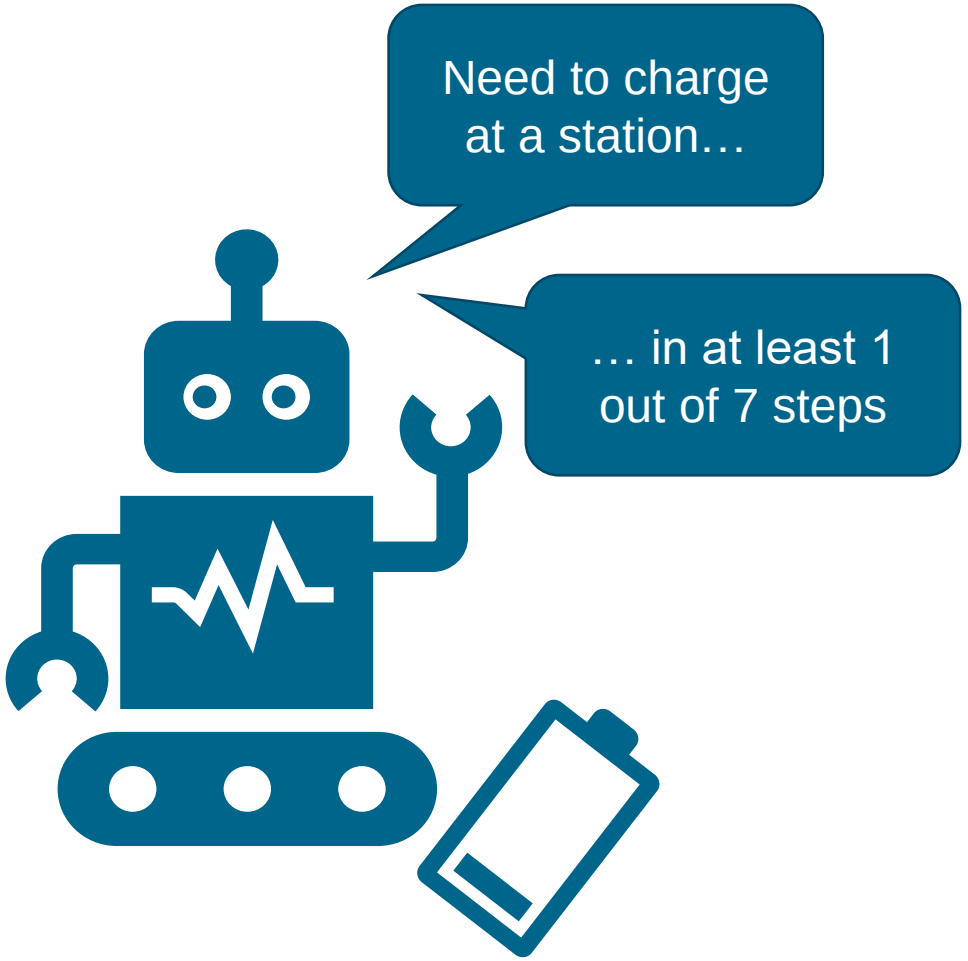


Window Counting Constraints

„The system plays an action c at least k times out of l turns.“



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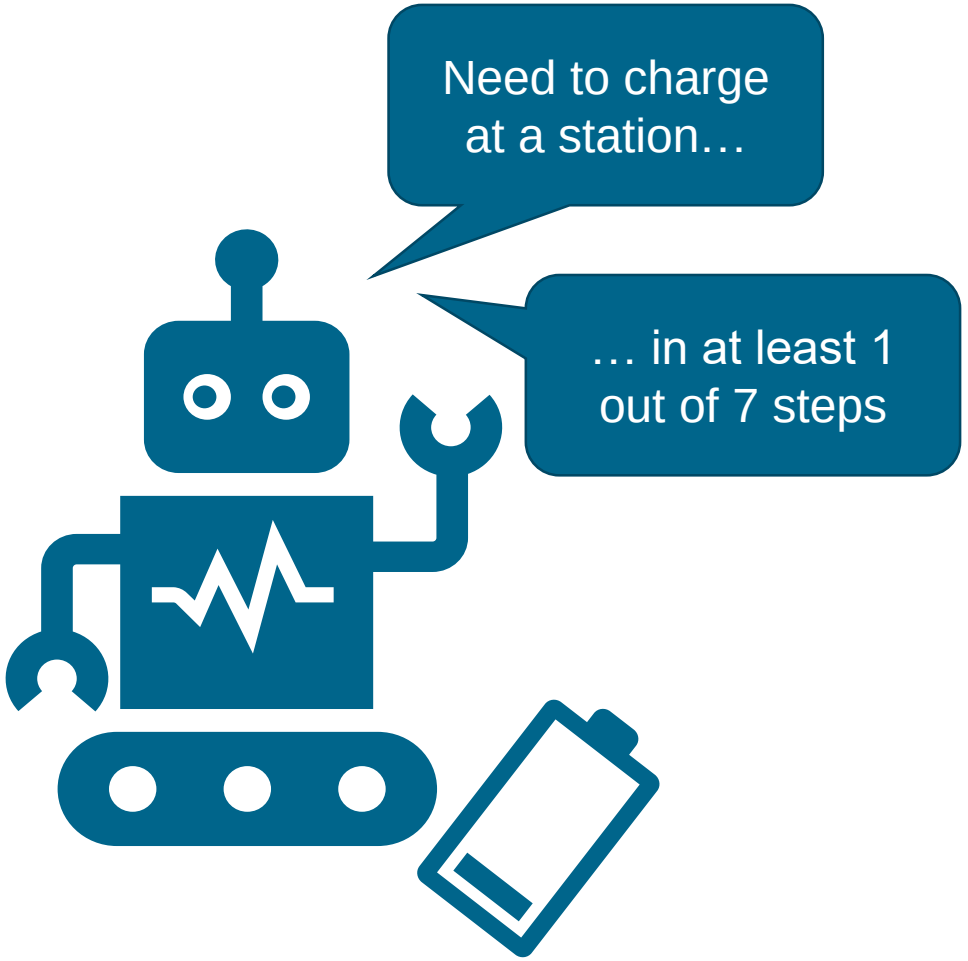

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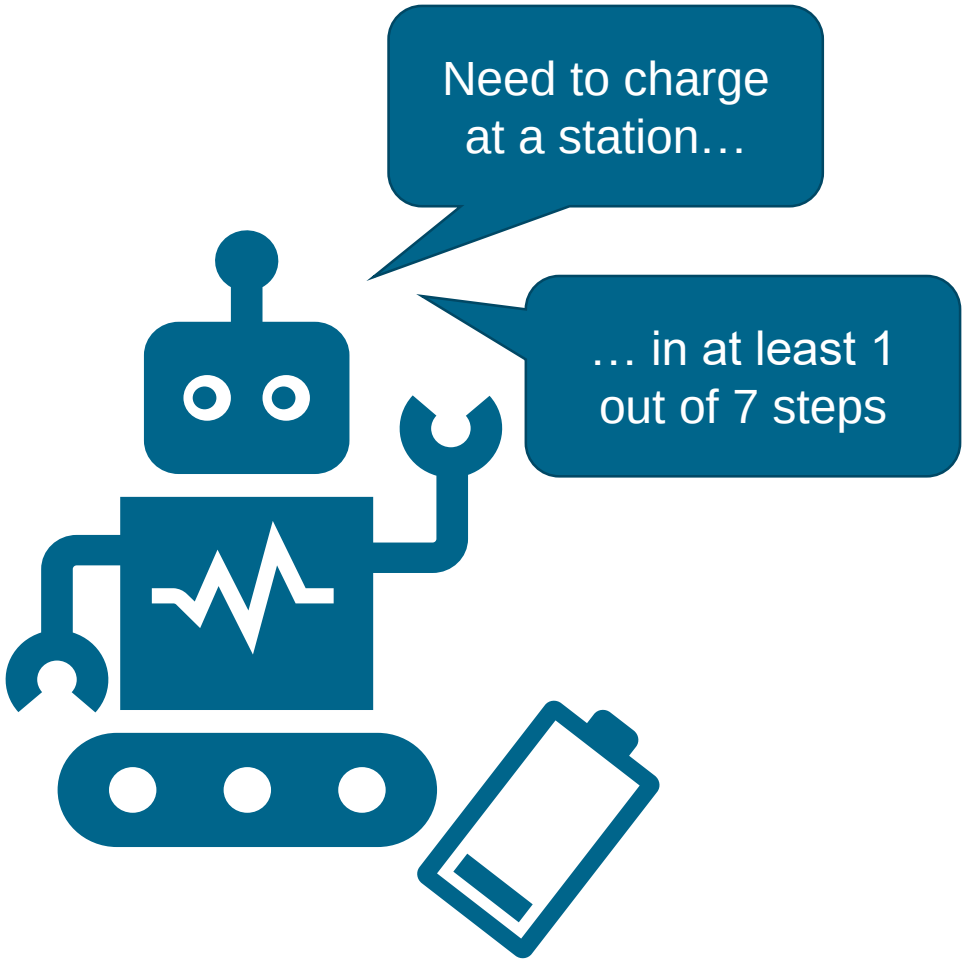
- *„at most“* instead of *„at least“* possible
- Constraint holds globally („sliding window“)
  …$bbcbbbcbbbbbbbcbbccccbbbc$…

  c at least 1 times out of 7 ✓



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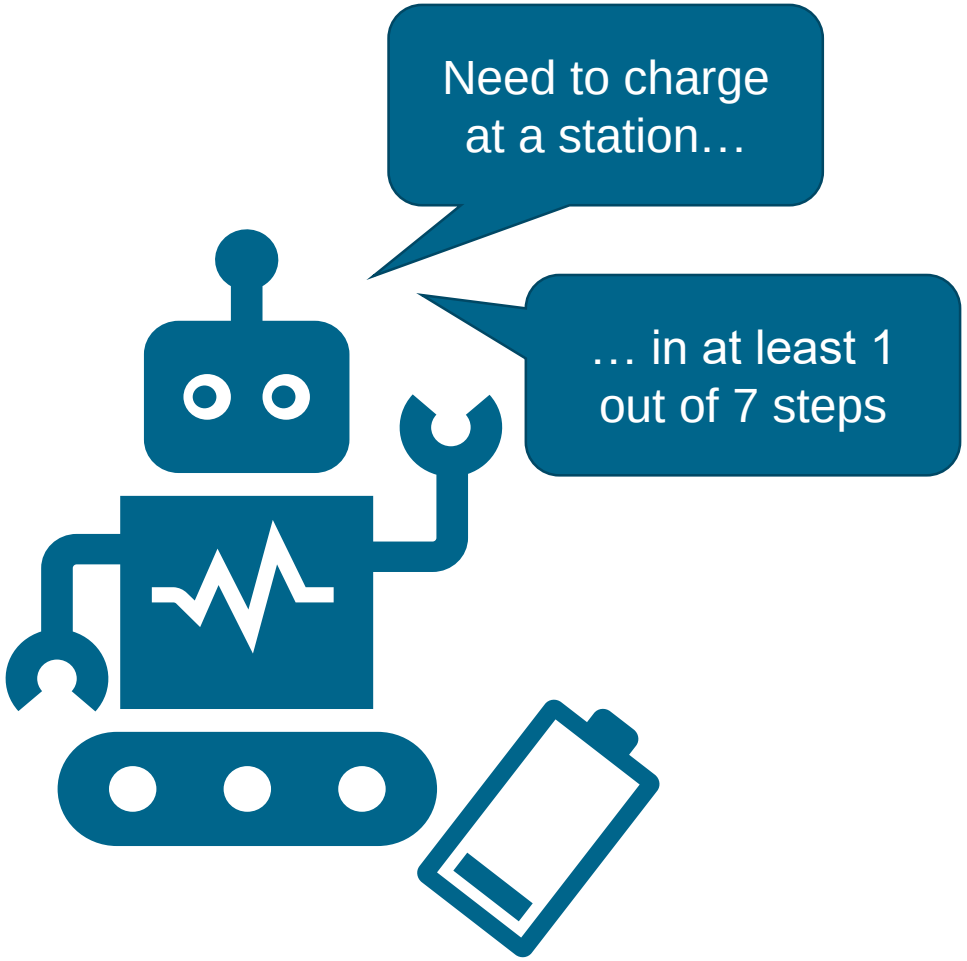

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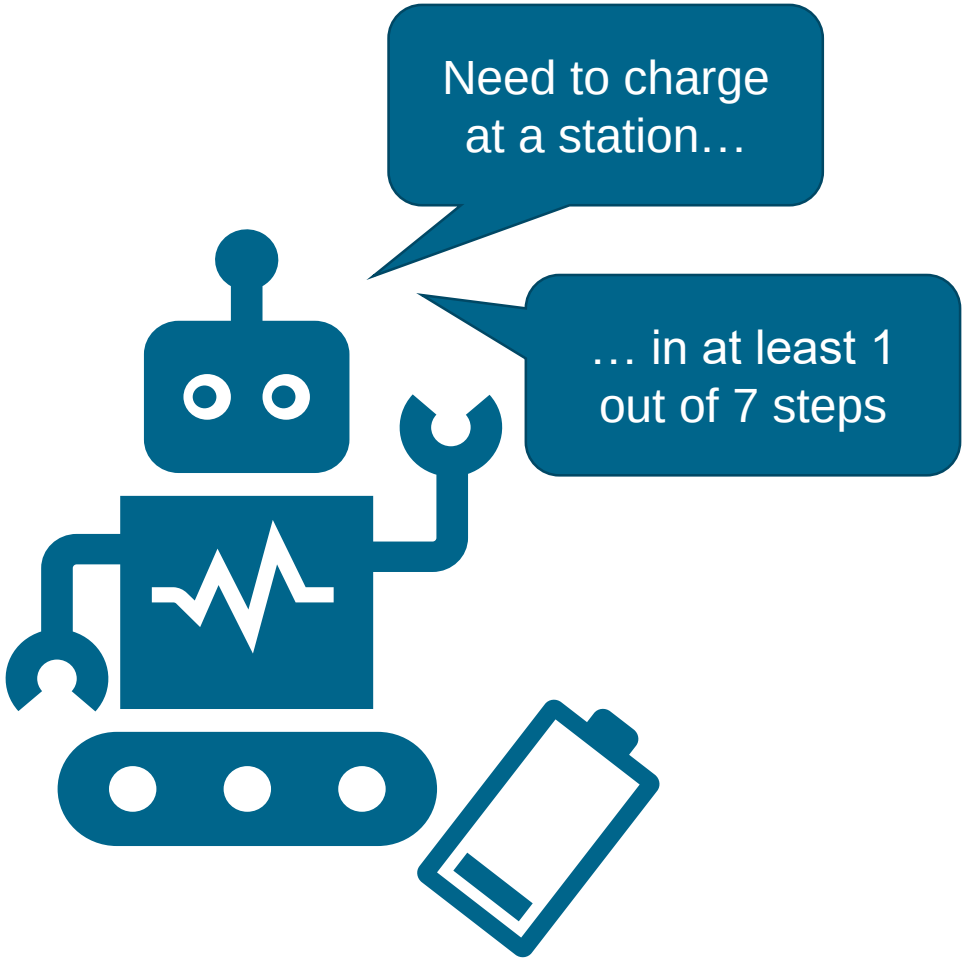

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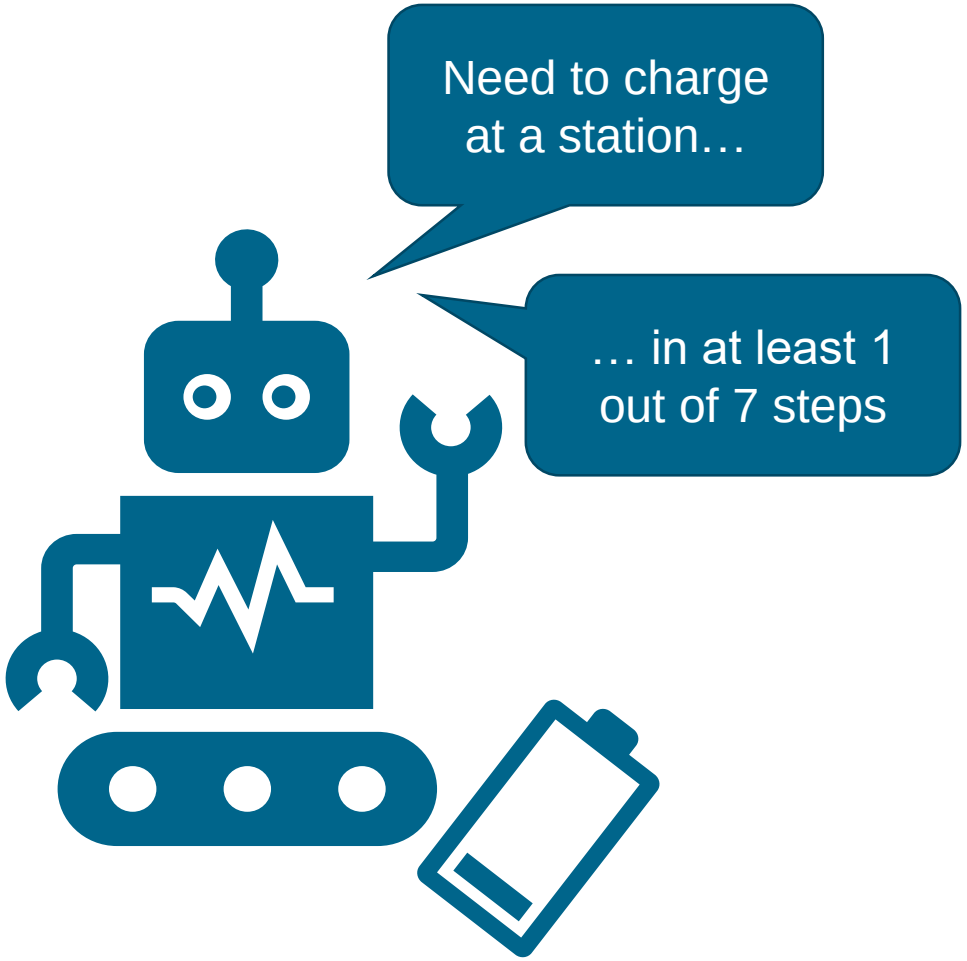
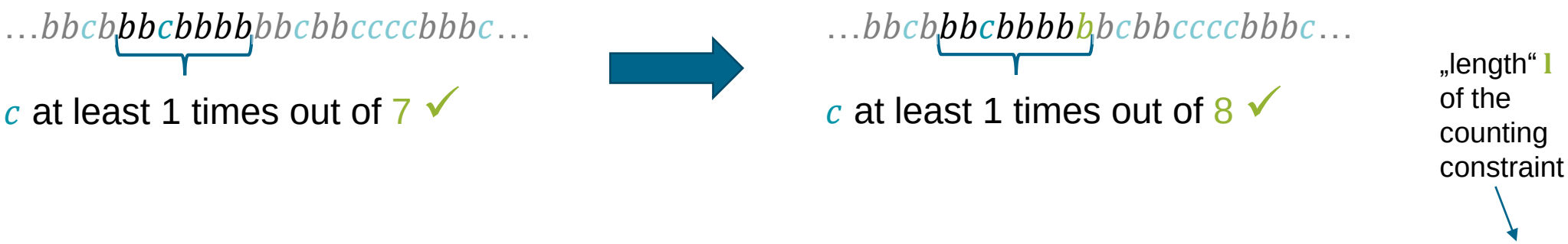


Synthesis with counting constraints in a nutshell



- A strategy that satisfies „The system plays an action c at least k times out of l turns.“ also satisfies „The system plays an action c at least k times out of m turns.“ for each $m > l$ (“monotone property”).

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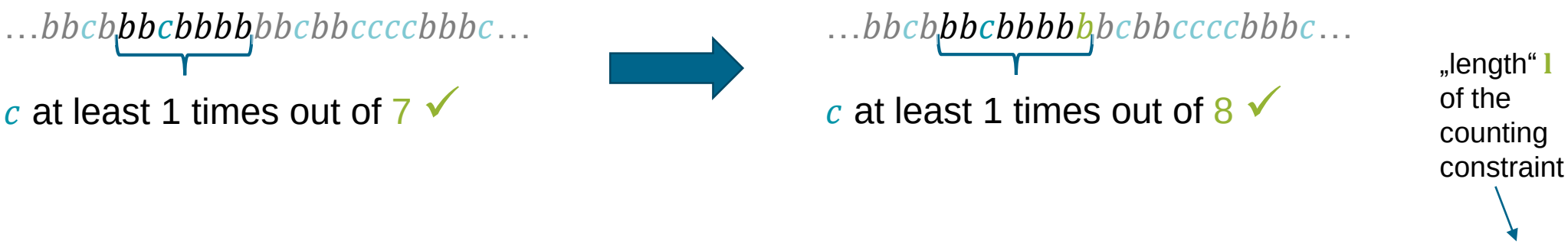

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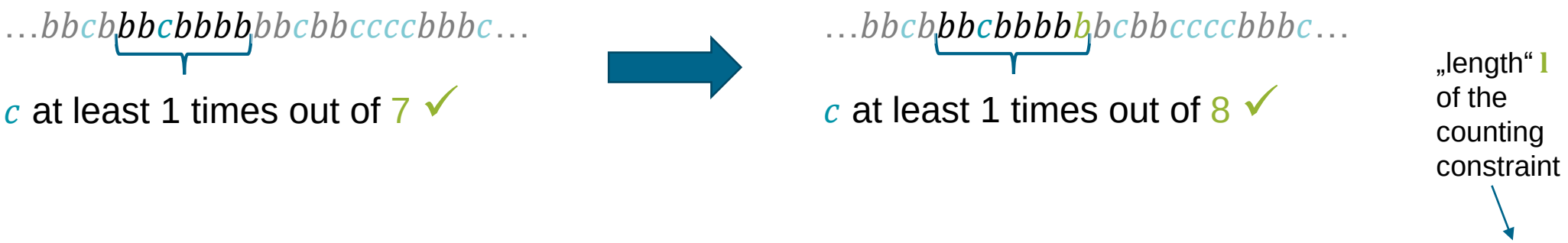

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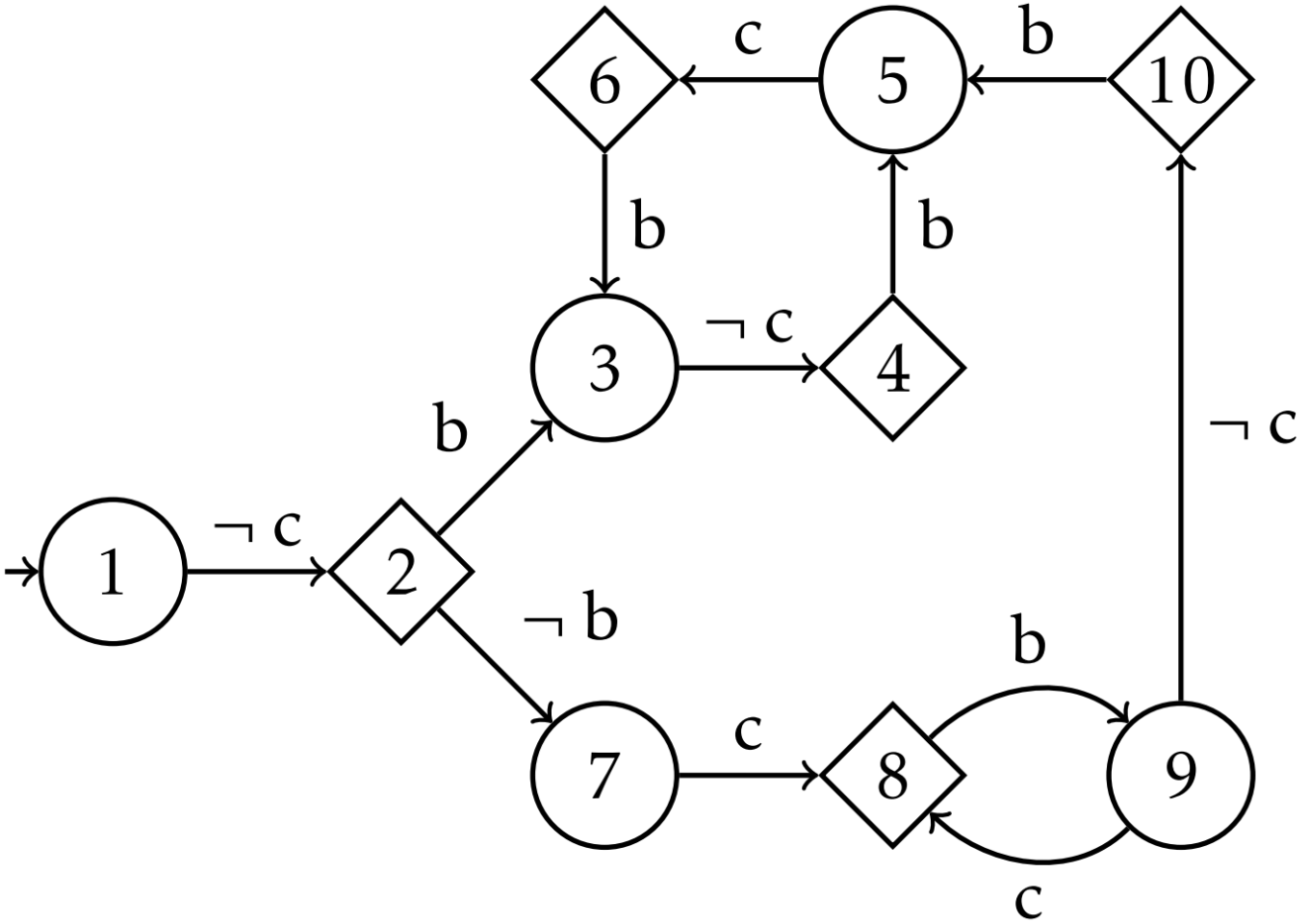
- Synthesis with iteration over counting constraint length

Synthesis with Counting Constraints - Example



EGO plays c at least 1 time in 7 turns.

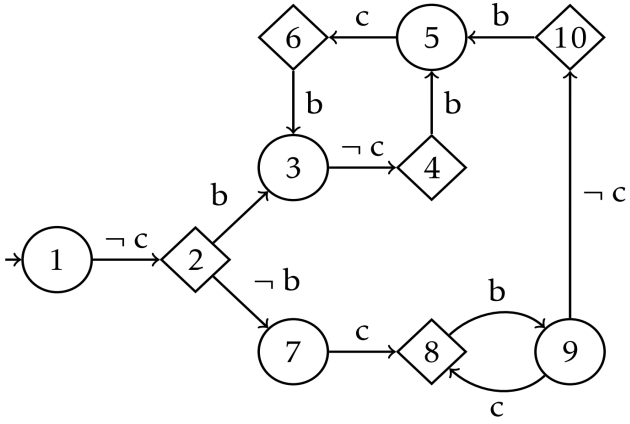
Synthesis with Counting Constraints - Example

Example

Algorithm

In: - EGO plays c at least k time in l turns.
- finite two-player game graph

Intermediate Results (Example)



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Synthesis with Counting Constraints - Example

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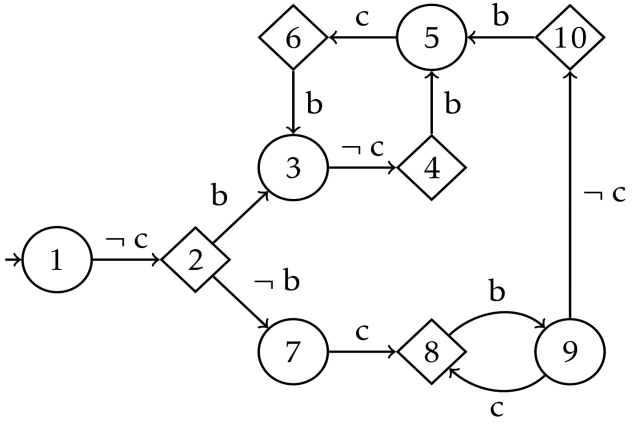

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$$l' \leftarrow k$$

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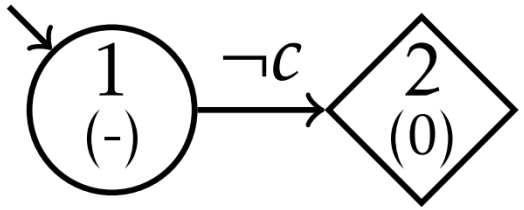

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(partly) construct game graph with memory l'

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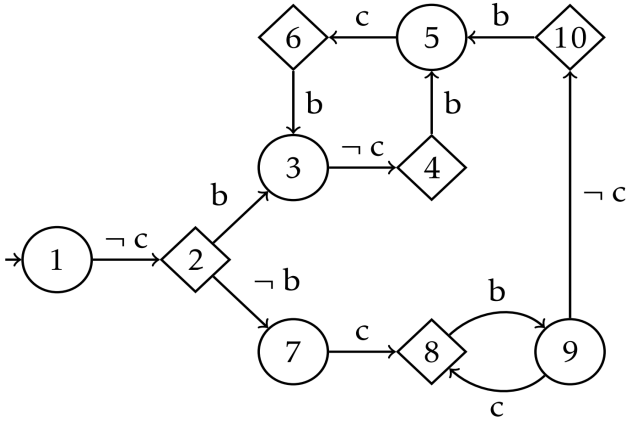

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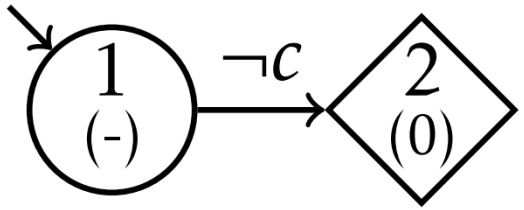

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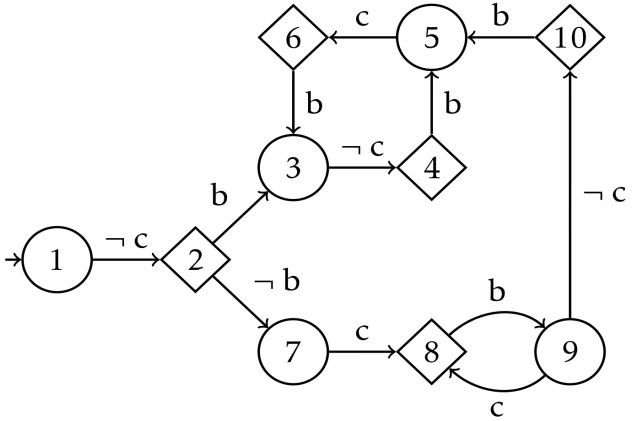

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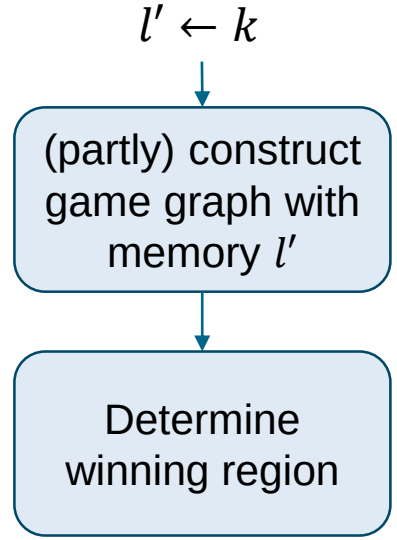

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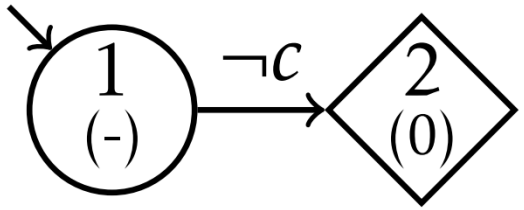

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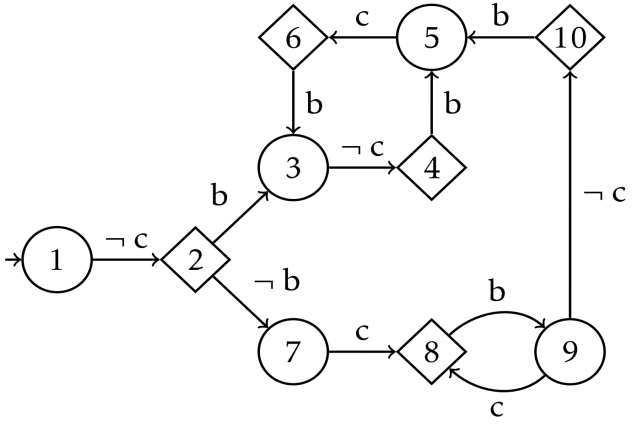

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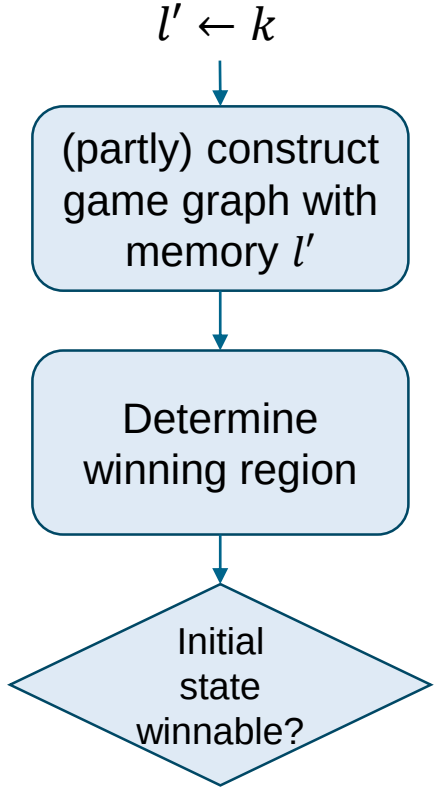

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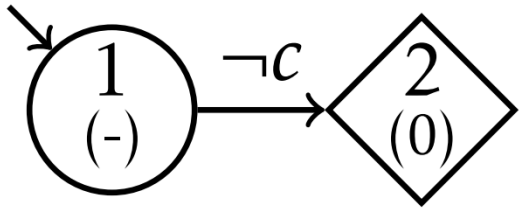

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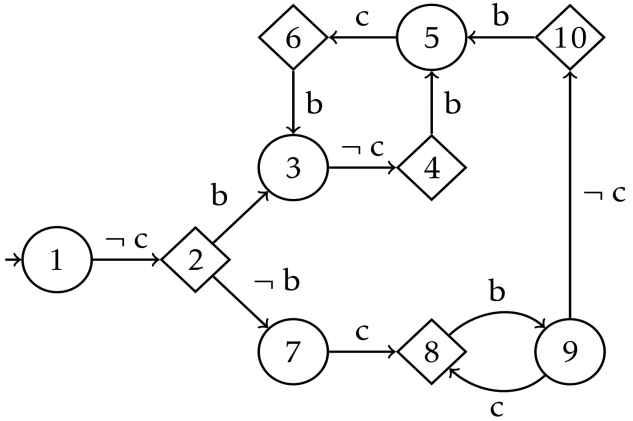

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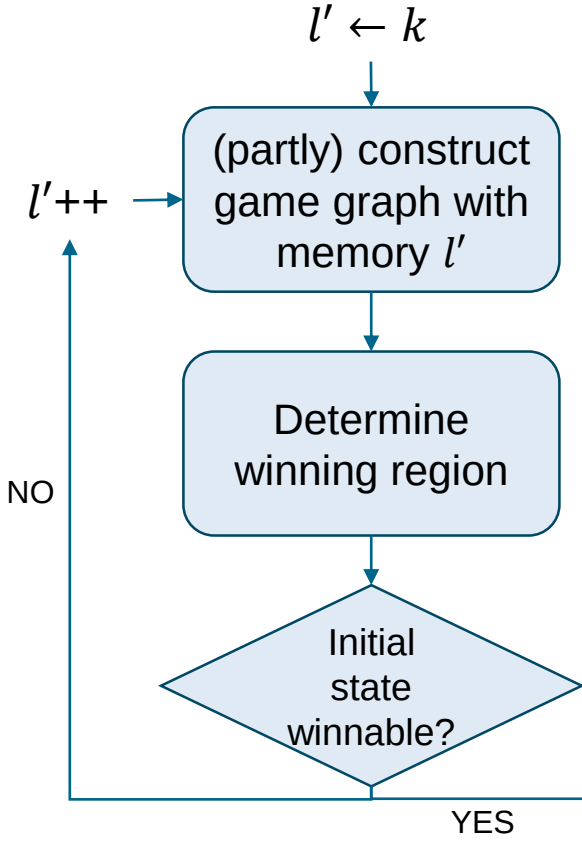
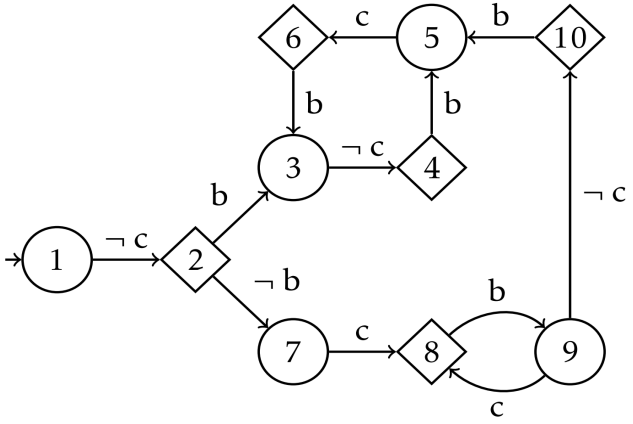


Synthesis with Counting Constraints - Example

Example

EGO plays c at least 1 time in 2 turns.

Intermediate Results (Example)



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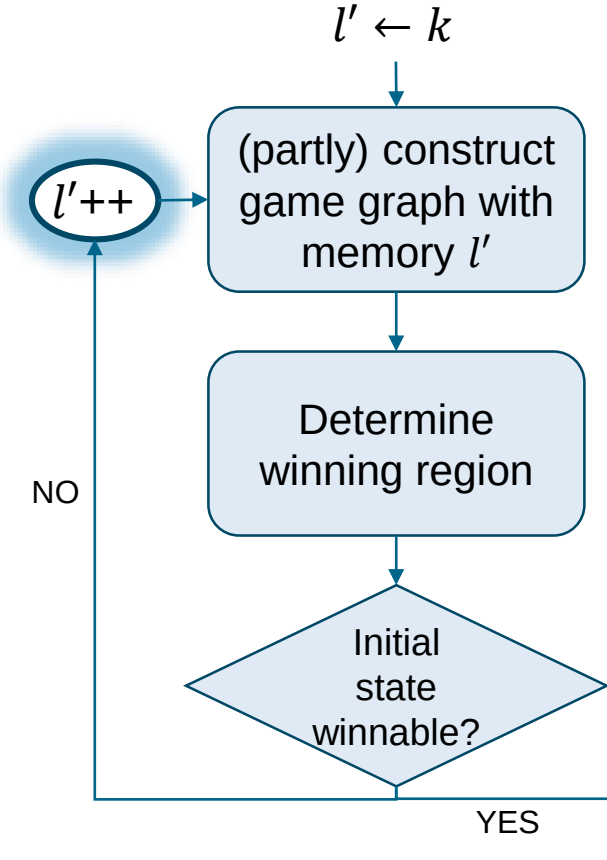

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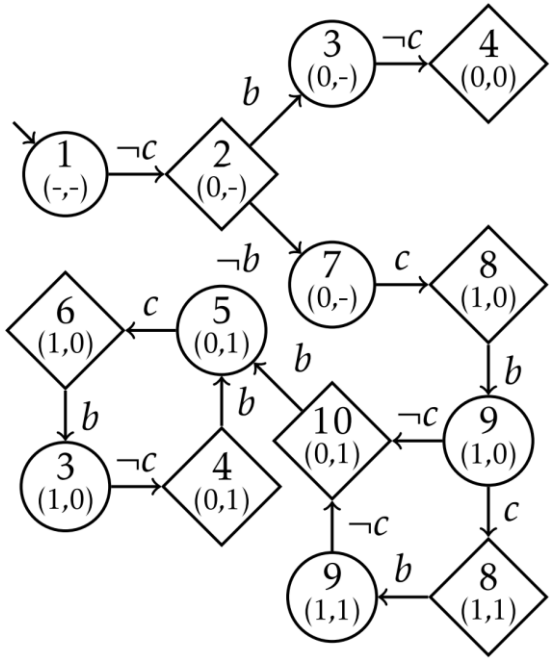

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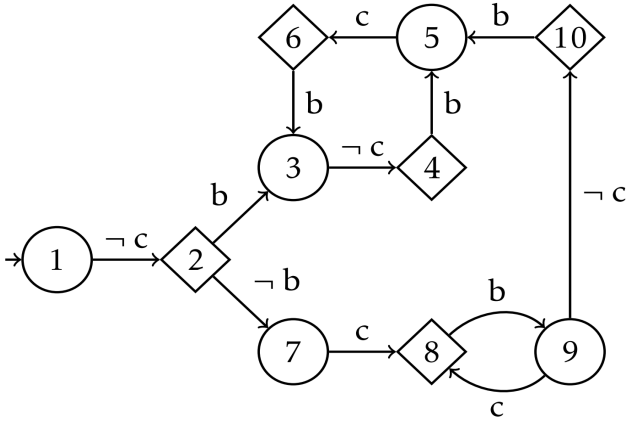

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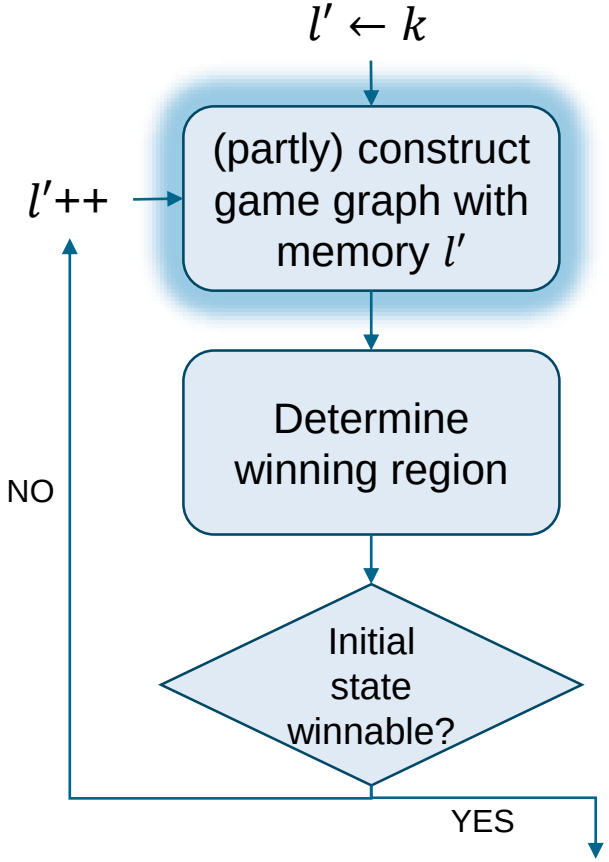

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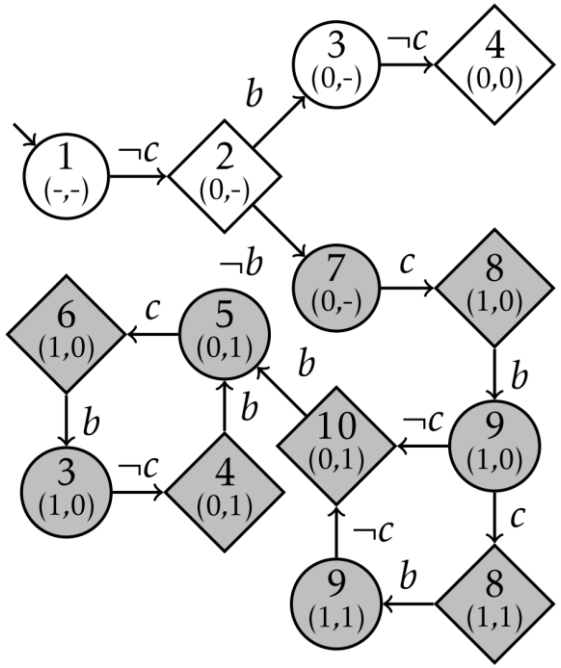

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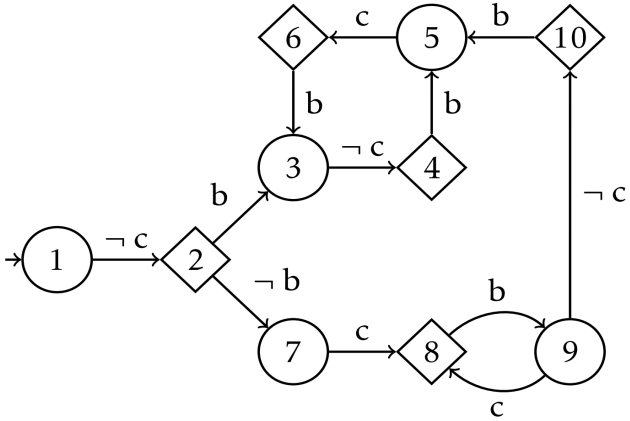

EGO plays c at least 1 time in 7 turns.

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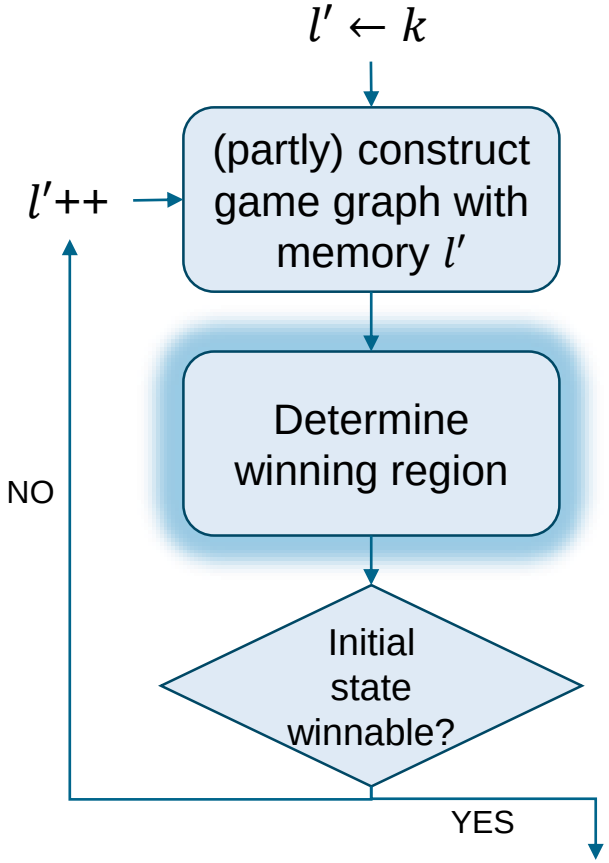

Synthesis with Counting Constraints - Example

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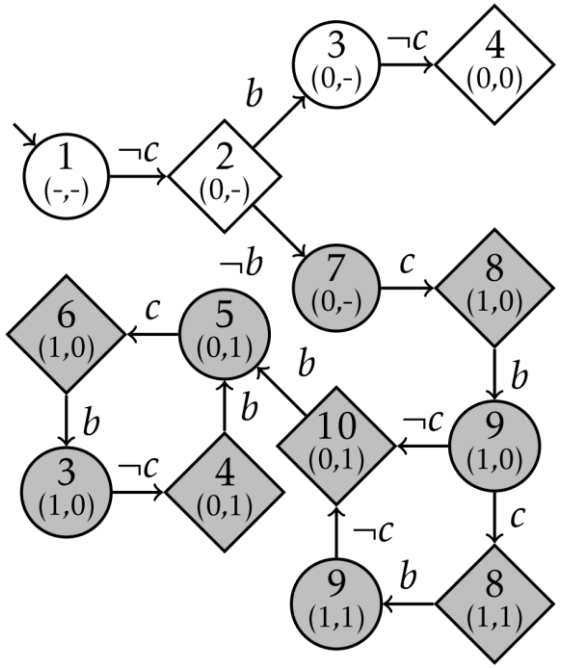
EGO plays c at least 1 time in 2 turns.



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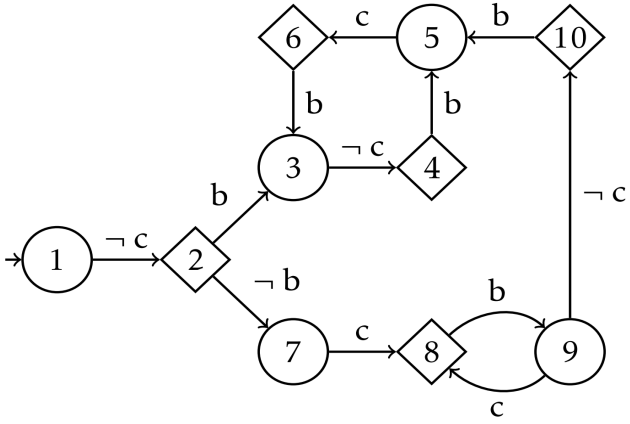

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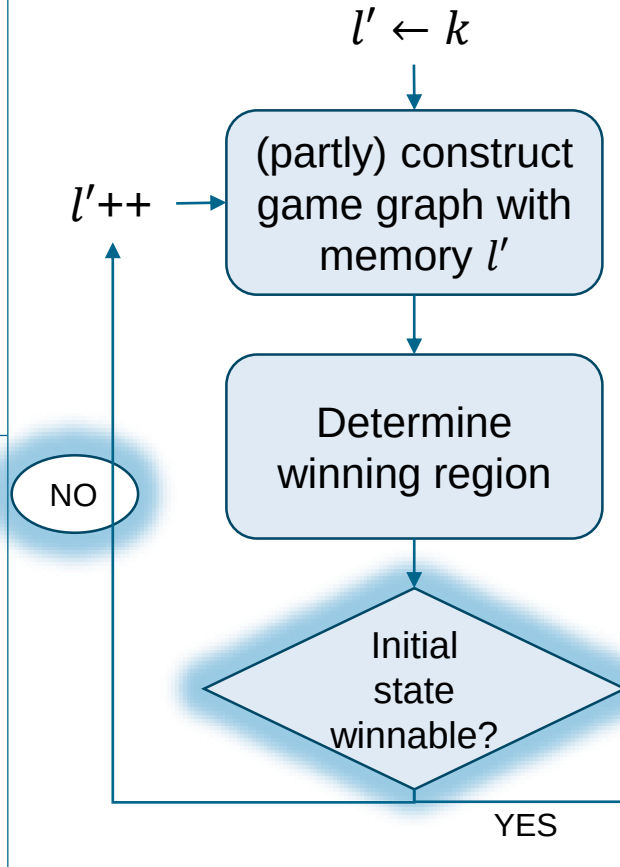

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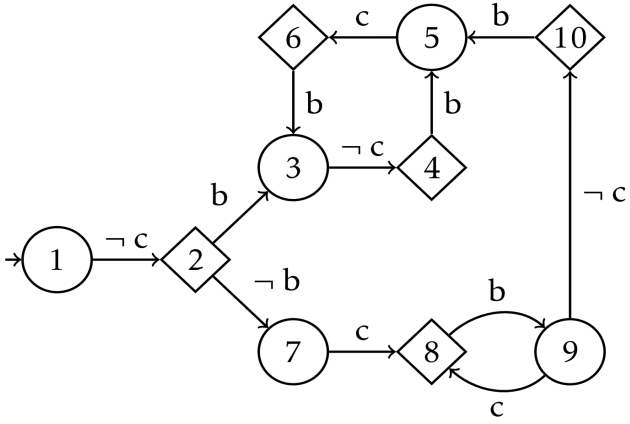

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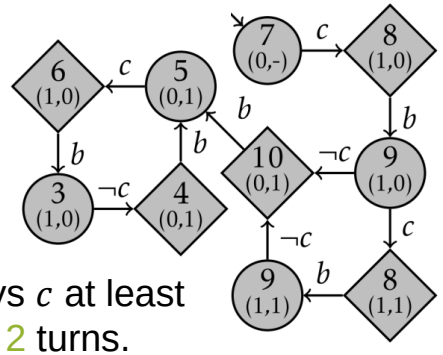

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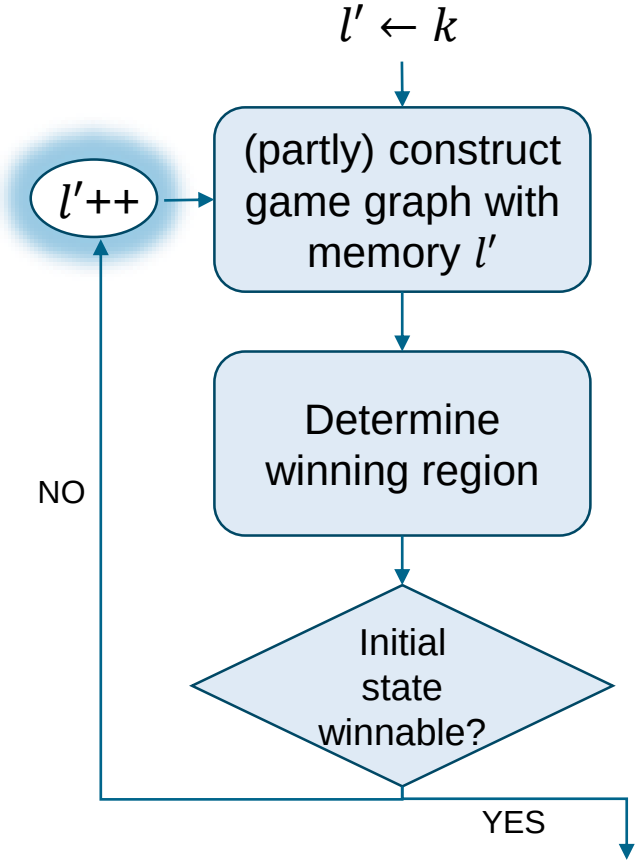

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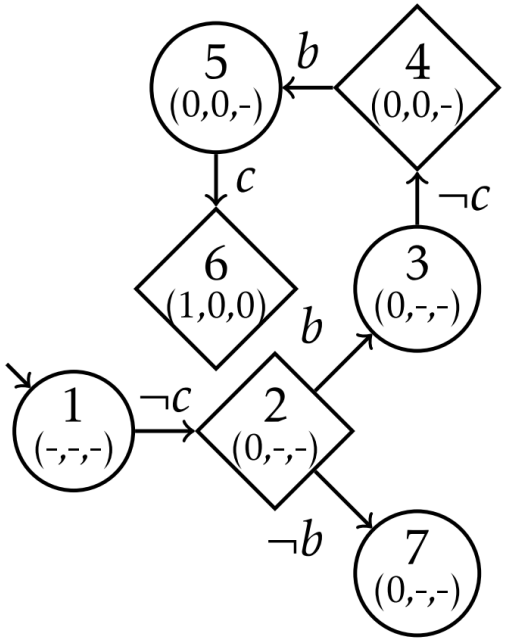

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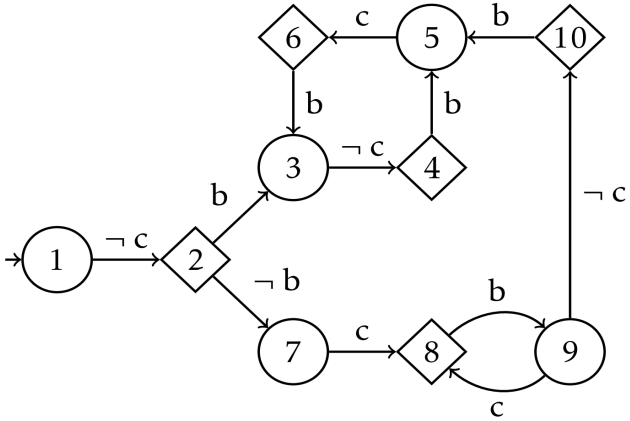

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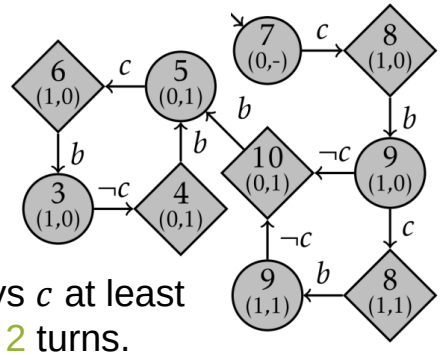

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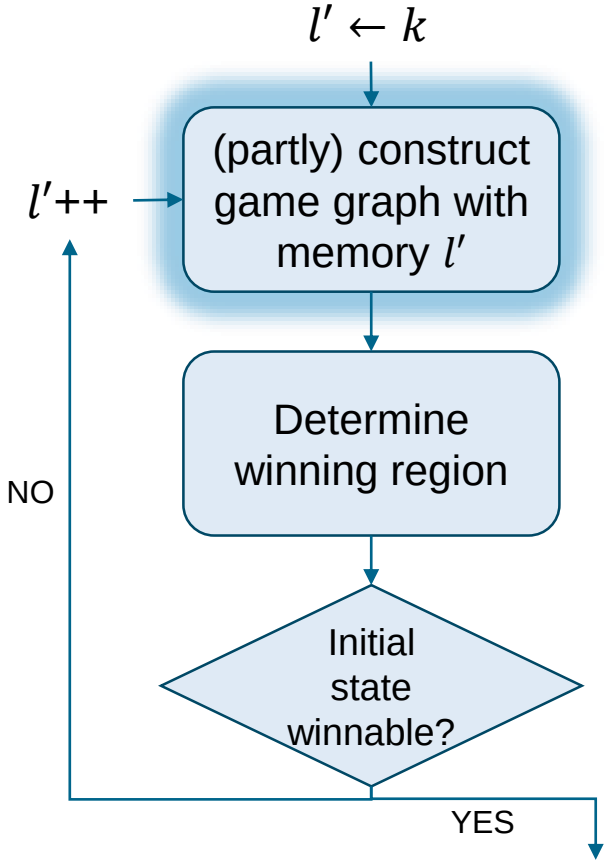

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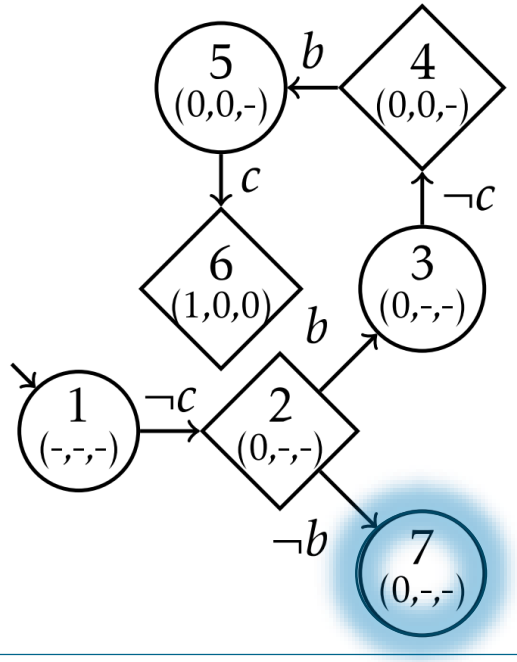

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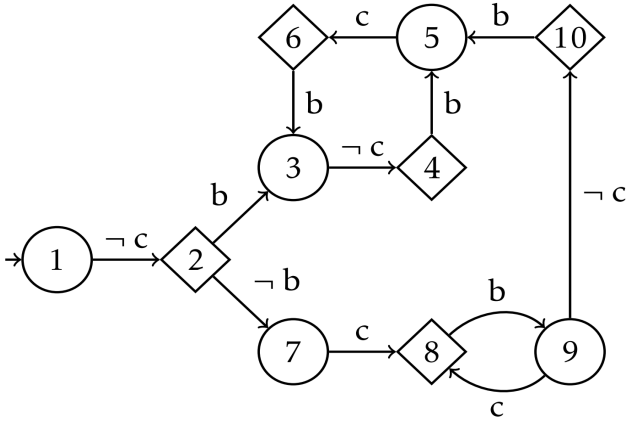

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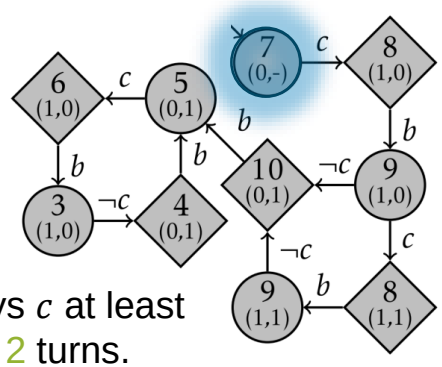

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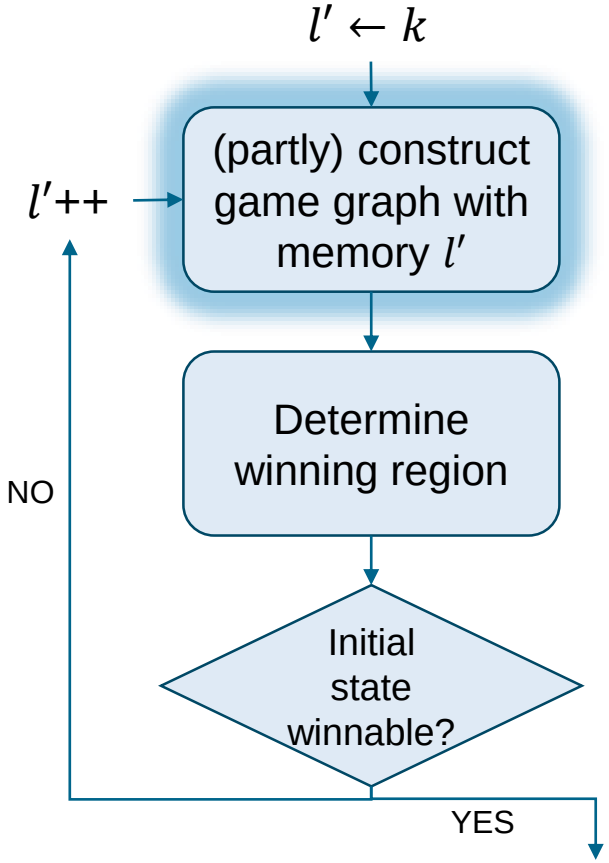

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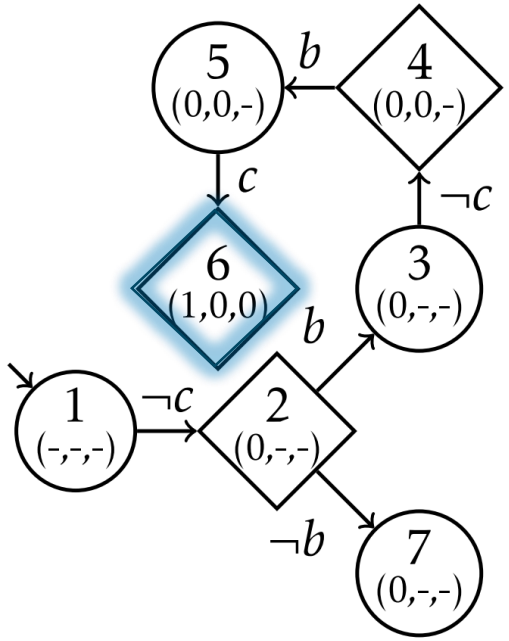

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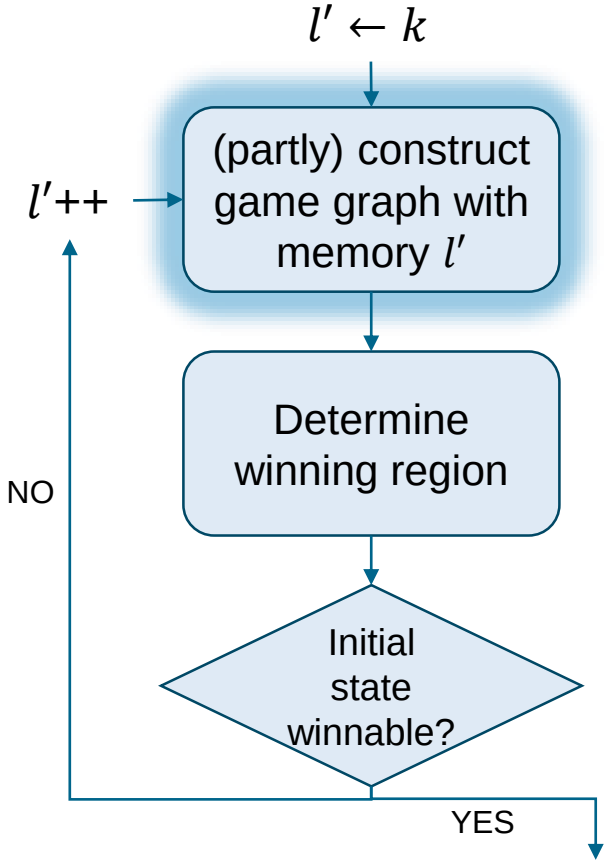

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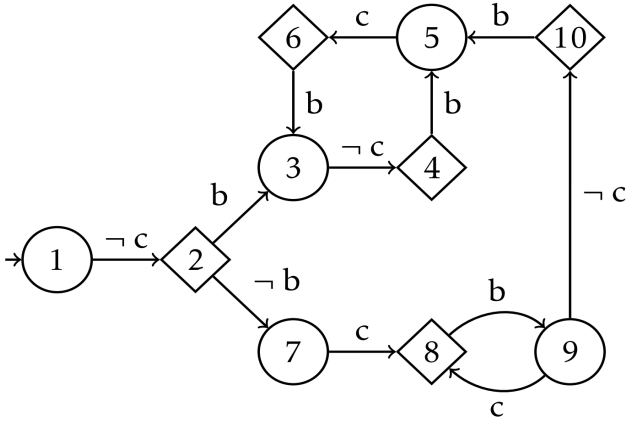

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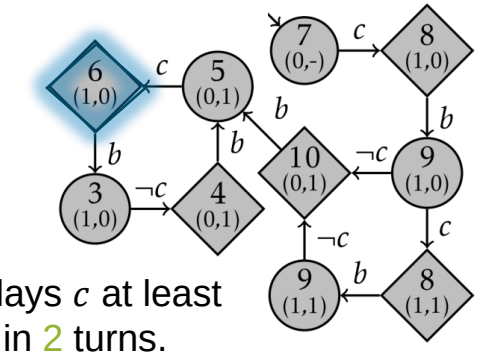

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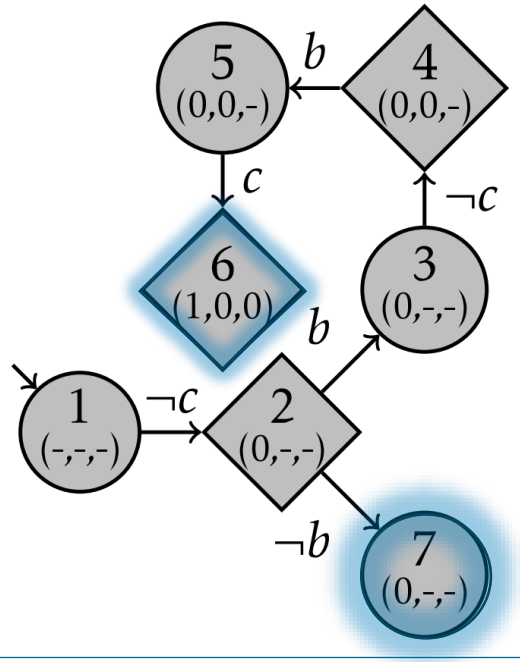

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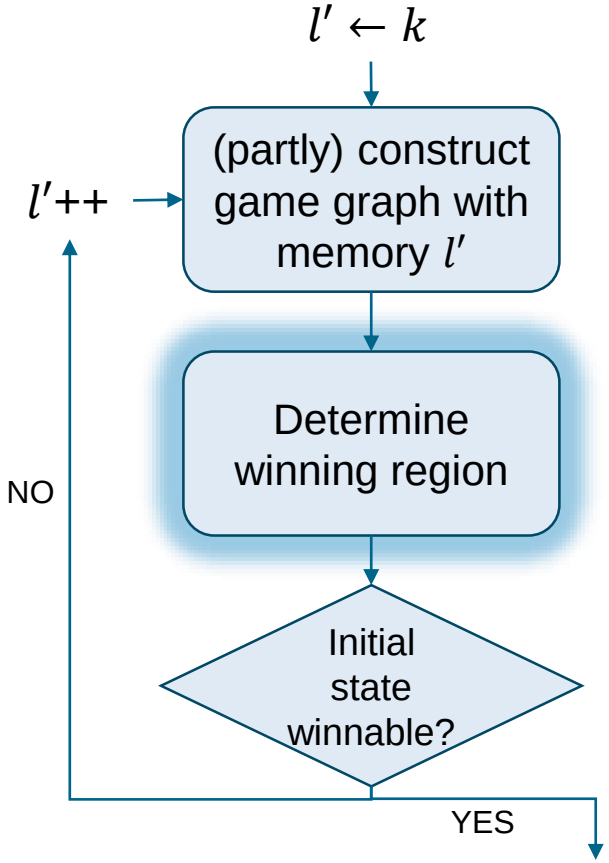

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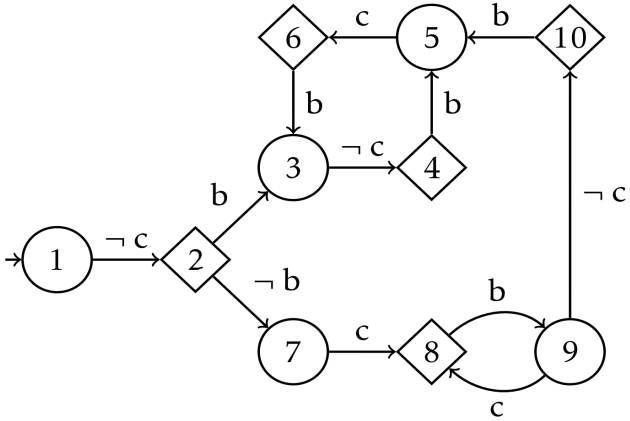

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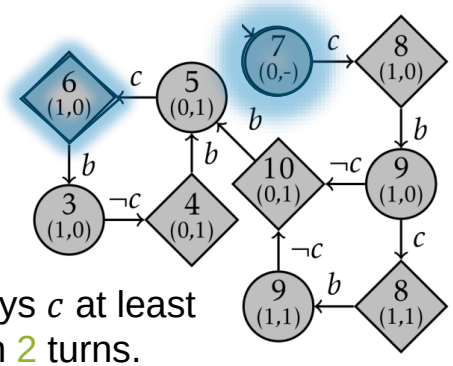

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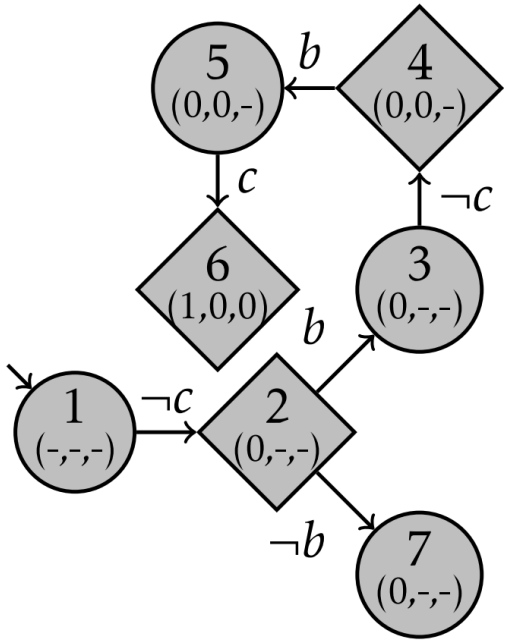

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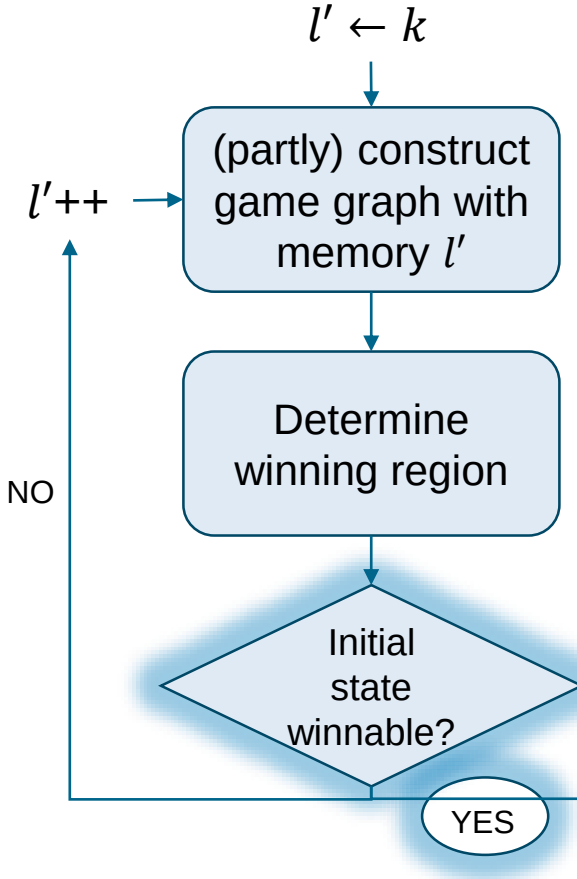

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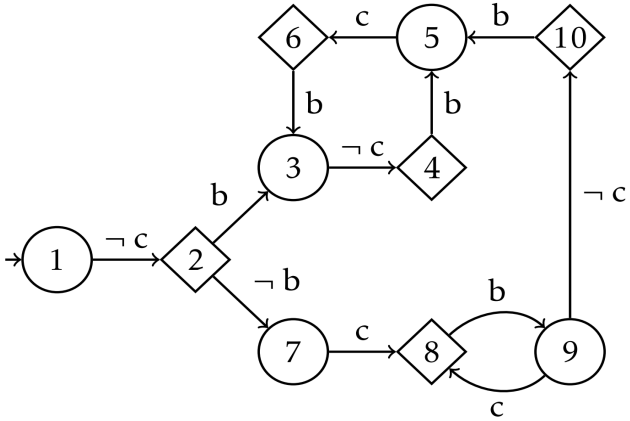

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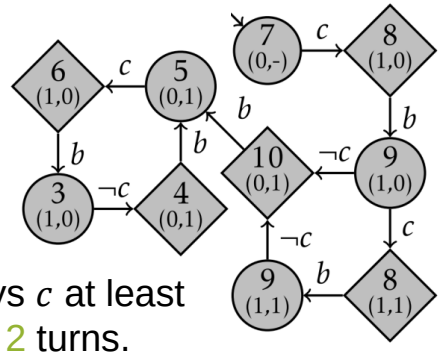

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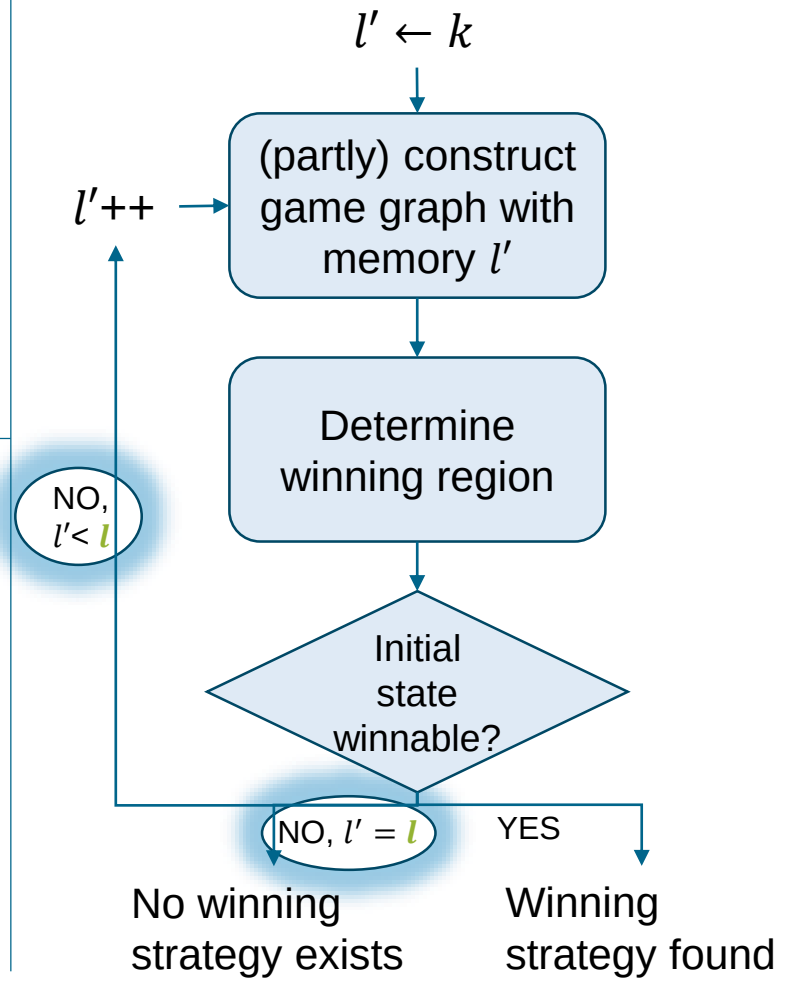

Experimental Results

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- Counting constraint „The system plays c at least 3 times in 10 turns.“
- Game graph with 1.8M states & 2.7M transitions

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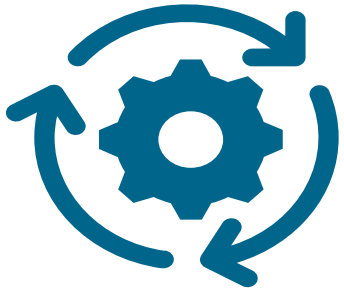

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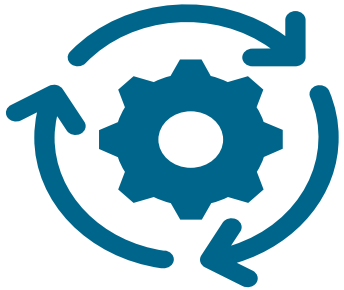

Reduction of time for synthesis

4 times faster

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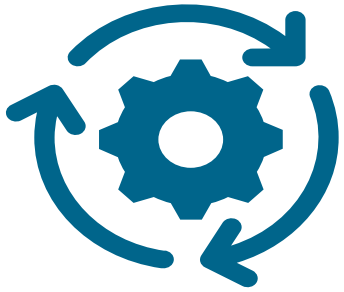
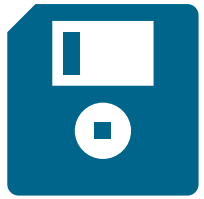
Implementation in Python	Reduction of time for synthesis	Reduction of number of states
	 4 times faster	 60% less states

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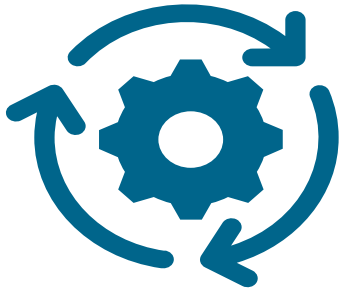
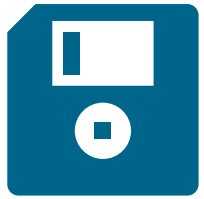
	 4 times faster	 60% less states

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- Proof of concept successful

Future Work

Towards cooperative games

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- Level of cooperation and synchonisation between players to be determined

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Symbolic representation

- Avoid explicit representation of states in game graph
- Comparision of explicit and symbolic synthesis

Conclusion

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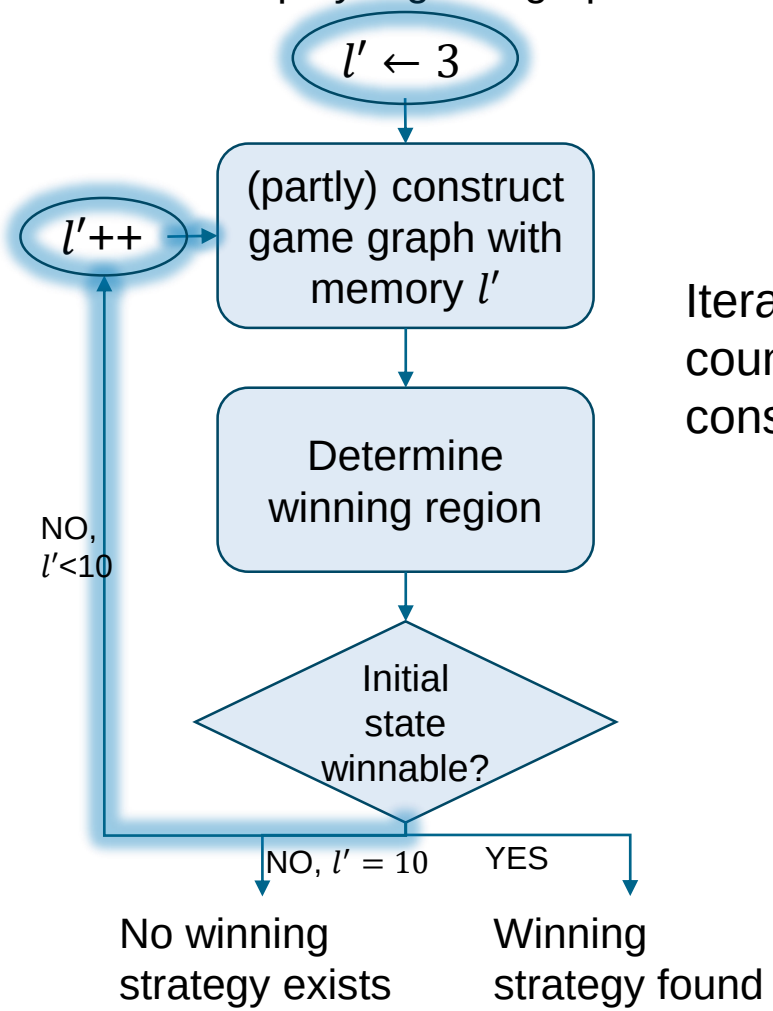
Thanks for your attention.
Questions are welcome!

BACKUP

Comparison for the Experiment

In: - EGO plays c at least 3 time in **10** turns.
- finite two-player game graph



Iteration over counting constraints

In: - EGO plays c at least 3 time in **8** turns.
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Algorithm for comparison