Intelligent Agents

Dynamic Epistemic Logic – Part 2

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Todays lecture based on

- The AAMAS 2019 Tutorial **„EPISTEMIC REASONING IN MULTI-AGENT SYSTEMS“, Part 4: Dynamic Epistemic Logic**
  http://people.irisa.fr/Francois.Schwarzentruber/2019AAMAStutorial/

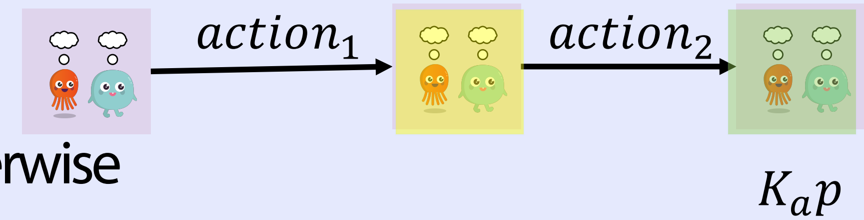
MODEL CHECKING

Model checking with actions

Definition

The model checking problem is given by :

- Input: an epistemic state
- A formula, e.g., $< action_1, action_2 > K_a p$
- Output: yes if
  no otherwise



Model checking complexity

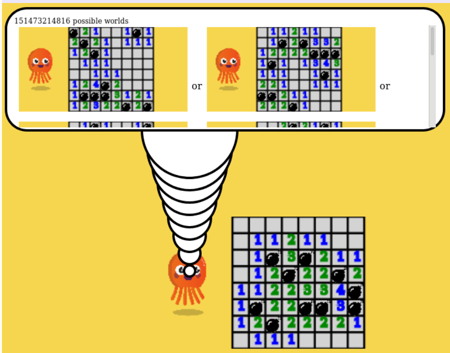
- Public actions: P-complete (van Benthem 2011)
- Any type of action : PSPACE-complete (Aucher/Schwarzentruber 2013), (Pol et al. 2015)

State explosion problem

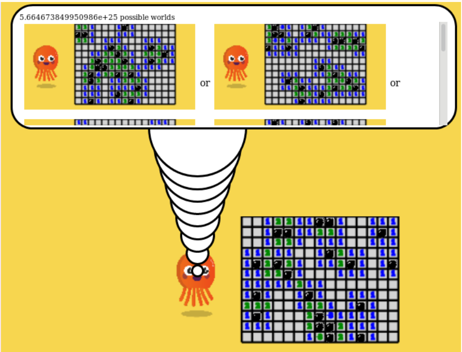
Example

Minesweeper

- 8×8 with 10 bombs:
  $> 10^{12}$ possible worlds



- 10×12 with 20 bombs:
  $> 10^{25}$ possible worlds



State explosion problem

- See (Benthem et al. 2015), (Benthem et al. 2018)

- Also see: (Charrier/S. 2017), (Charrier/S. 2018)
  - Succinct representations of epistemic states **and** actions
  - Easy to specify by means of accessibility programs;
  - Succinct model checking Pspace-complete (and so stays in PSPACE as for non-succinct case).

Impact

- Theoretical

Theorem (Maubert et al. 2019)

Existence of a (uniform) strategy in bounded[1)] imperfect info games is in PSPACE.

1) Example: public announcements do not expand the epistemic model

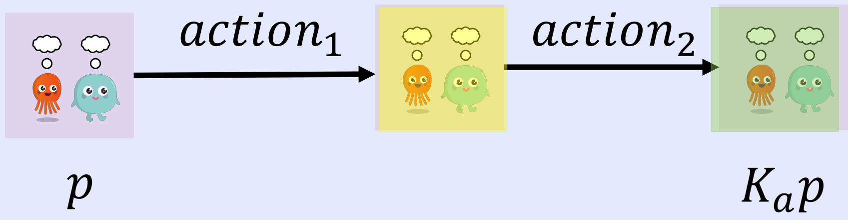
- Practical: Symbolic model checking implemented in Hintikka‘s world
  - S. Gamblin and A. Niveau
  - Using BDDs (binary decision diagrams)

THEOREM PROVING

Theorem proving (another point of view)

Motivation: parametrized verification

For all epistemic states in which p holds



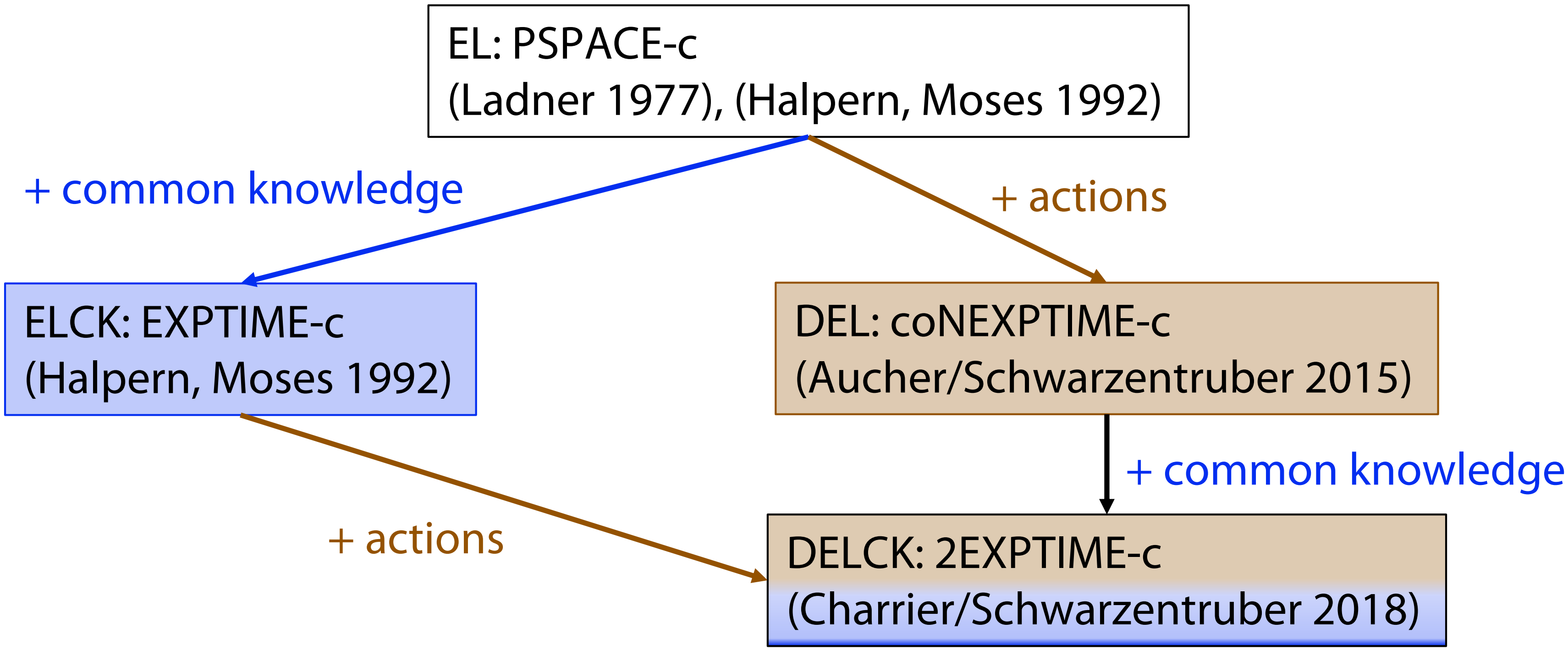
So: $p \rightarrow < action_1; action_2 > K_a p$ is a theorem (i.e. true in all states)

Definition

The theorem proving problem is given by :

- Input: a formula ϕ
- Output: yes if ϕ is a theorem , no otherwise

Theorem proving is highly intractable



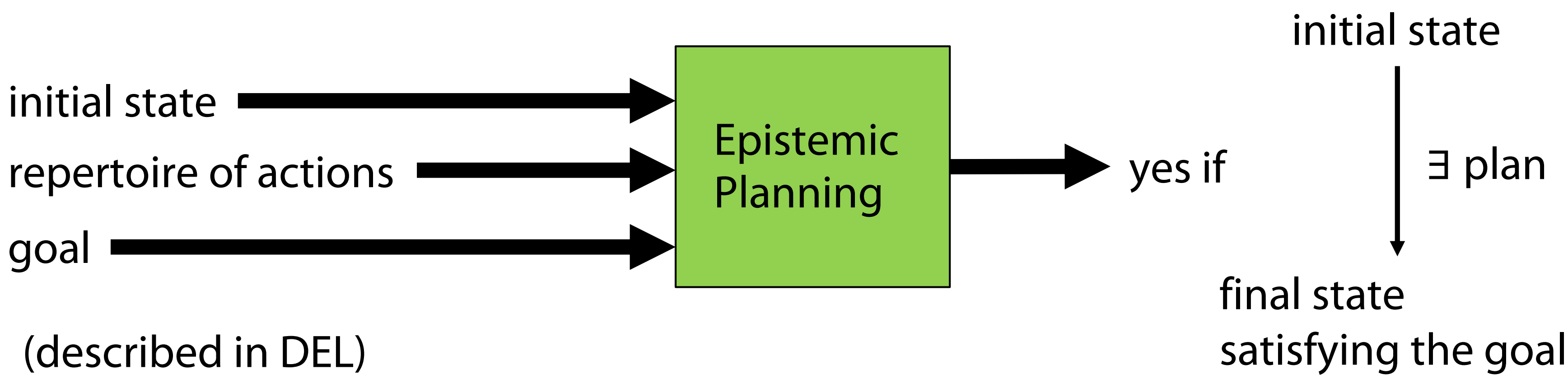
General Insights

- Semi-product modal logics have high complexities (Gabbay et al. 2003)
- Model checking more practical than theorem proving
- (Halpern/Vardi 1991)

EPISTEMIC PLANNING

The general scenario of epistemic planning

(Bolander/Andersen 2011)



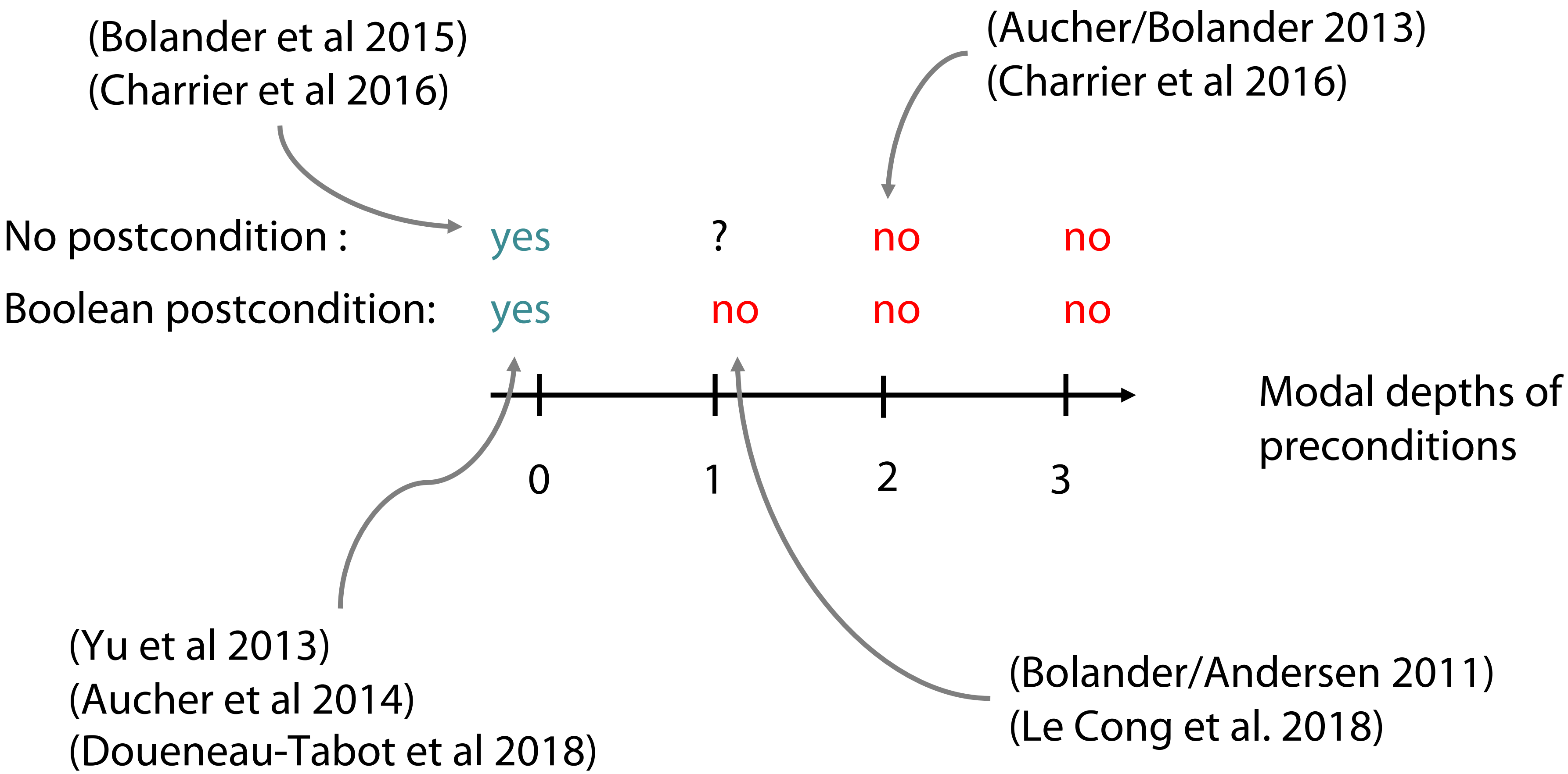
(Un-)Decidability of epistemic planning

Modal depths of preconditions	0	1	2	3
no postconditions :	yes	?	no	no
Boolean postcondition:	yes	no	no	no

modal depths of preconditions

e.g. $\mathrm{md}(K_a K_b K_a p) = 3$

(Un-)Decidability of epistemic planning



Undecidability

Theorem (Bolander/Andersen 2011)

Epistemic planning is undecidable for

- two agents
- Boolean post conditions
- $\mathrm{m}d(pre) \leq 1$

Theorem (Le Cong et al 2018)

Epistemic planning is undecidable for

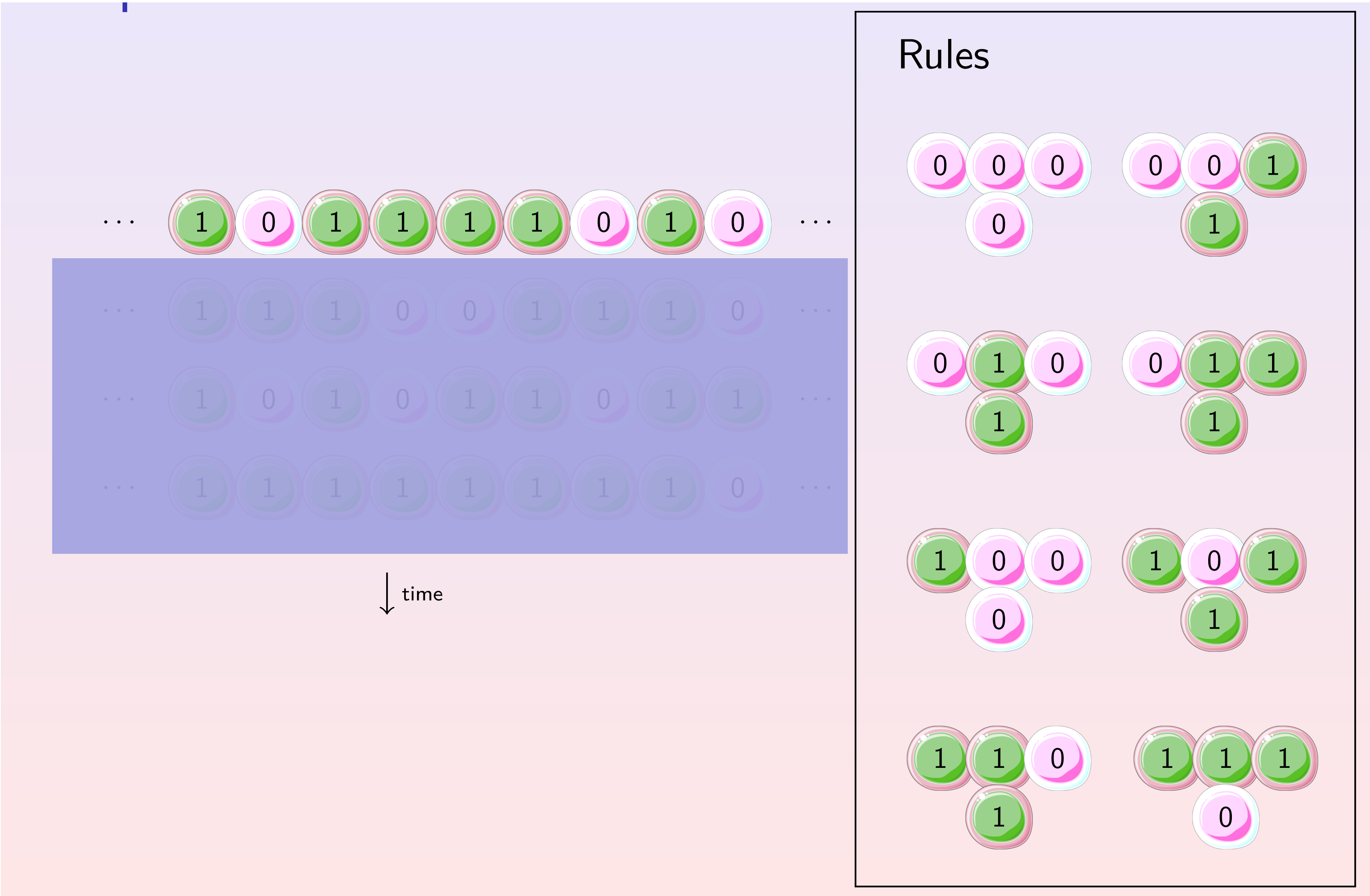
- two agents
- Boolean post conditions
- $\mathrm{m}d(pre) \leq 1$

even if

- there is only a fixed repertoire of one action and
- There are at most 6 atomic propositions

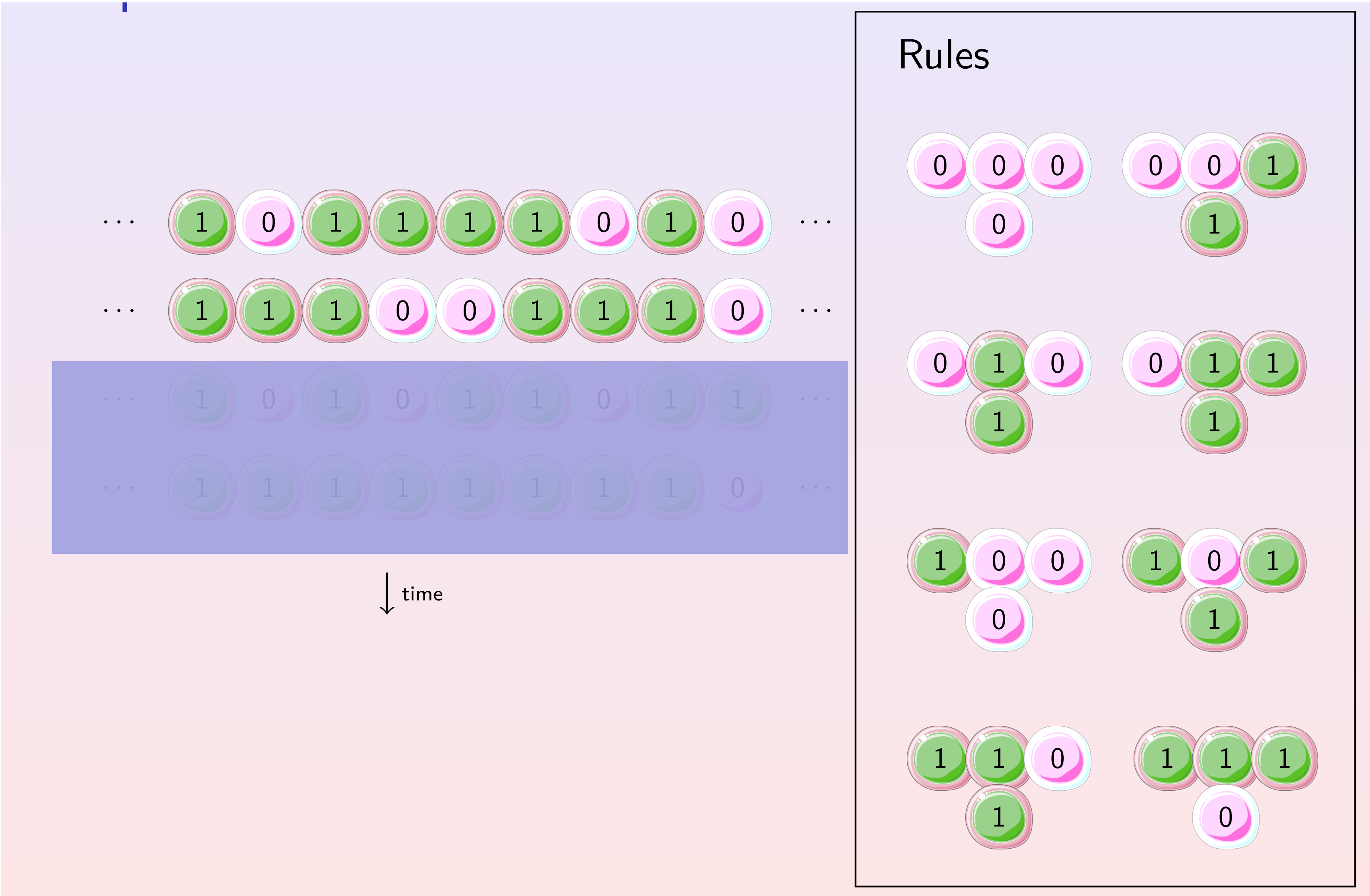
Proof idea: Reduction from halting problem of a small universal cellular automaton

Example: the 110 Rule cellular automaton



(von Neumann 1951) (Wolfram 2002)

Example: the 110 Rule cellular automaton



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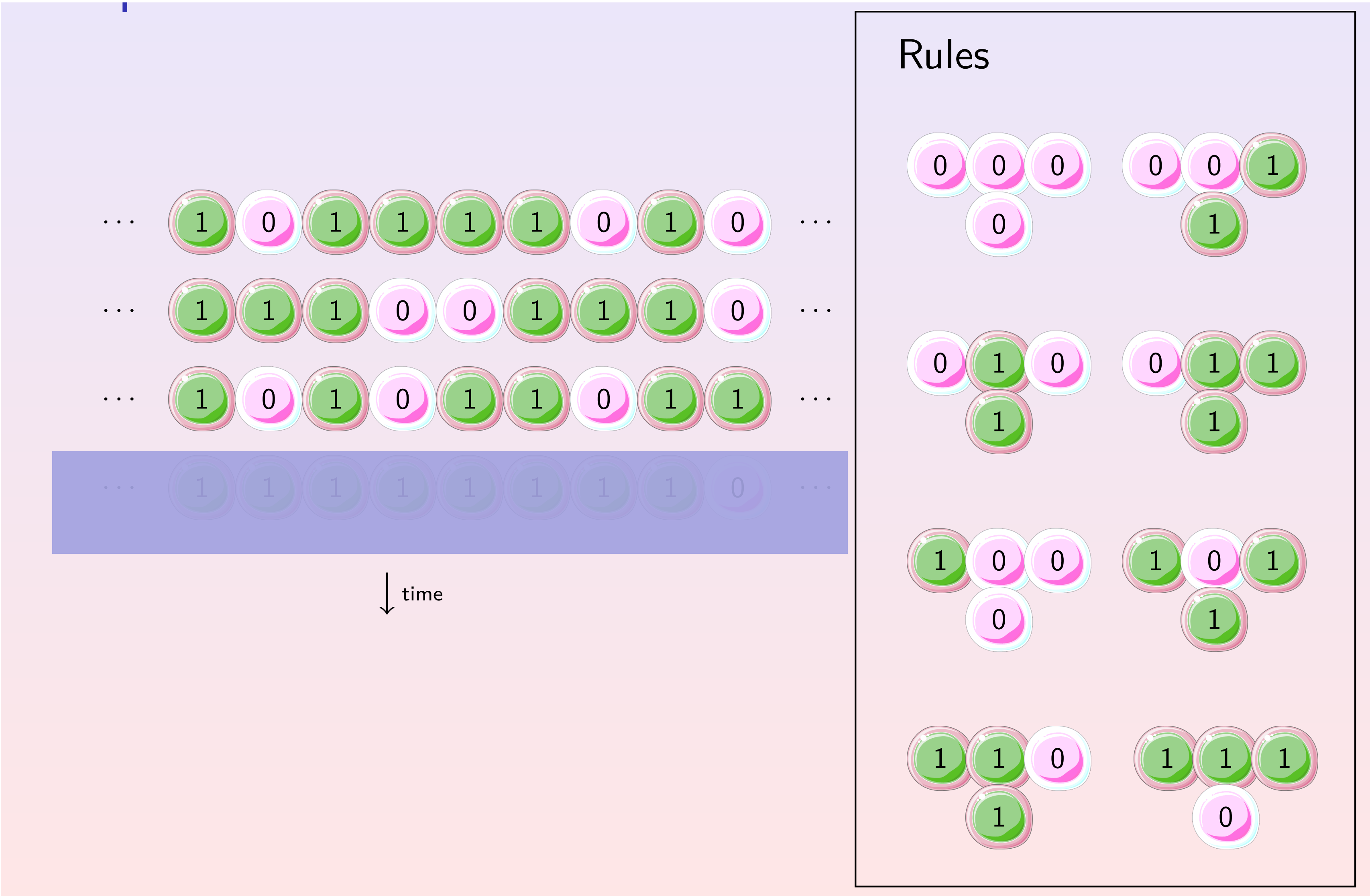
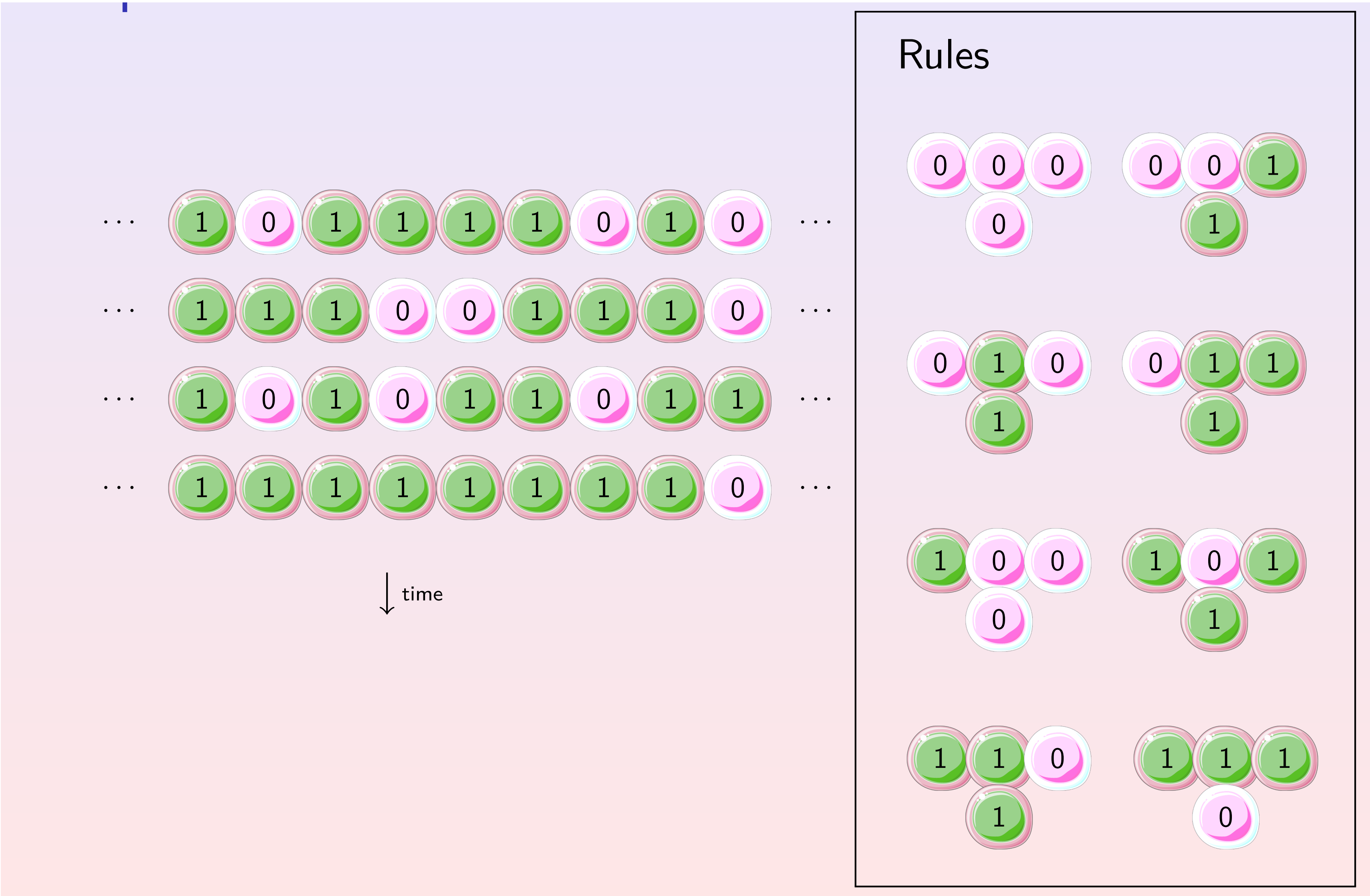
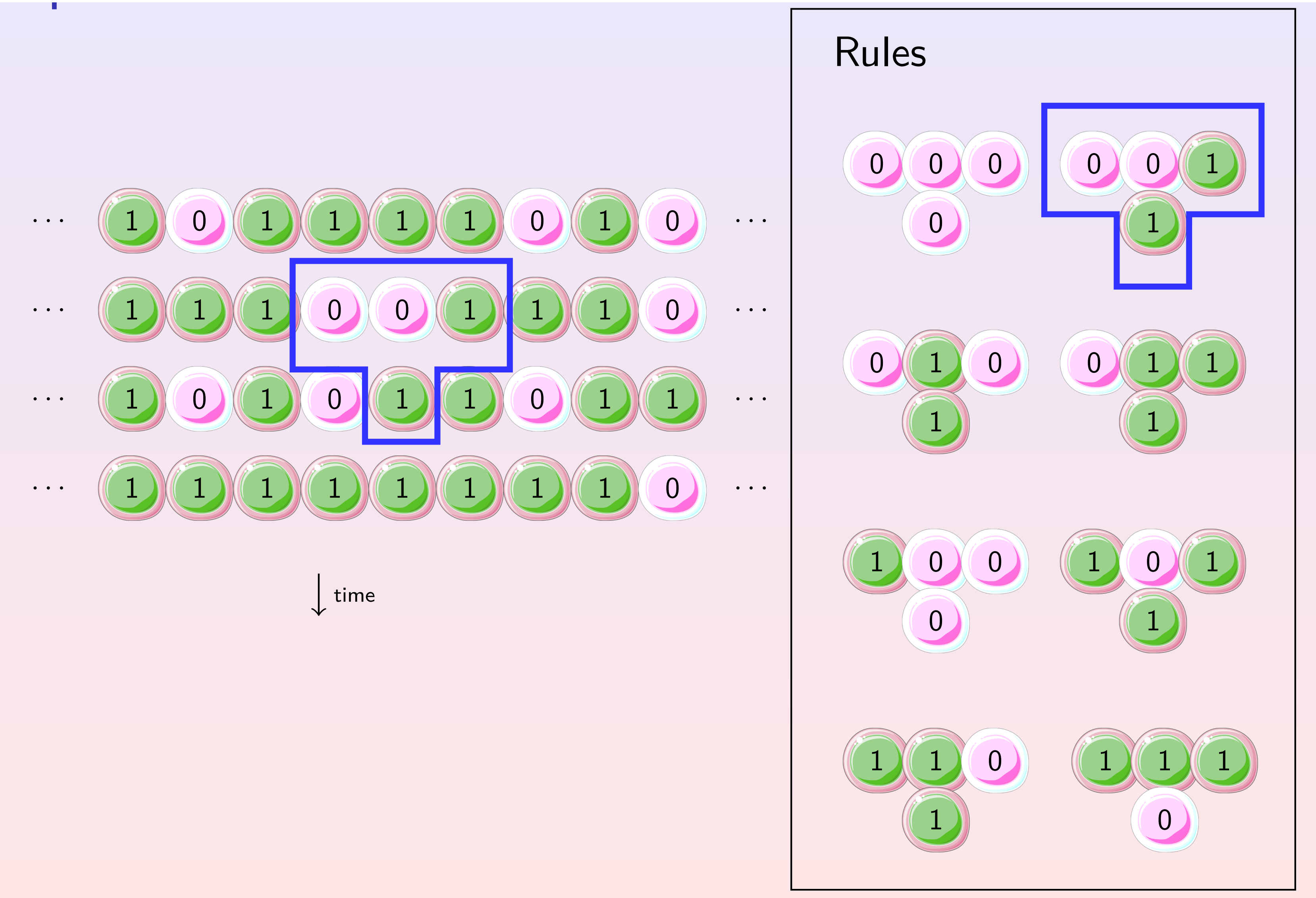


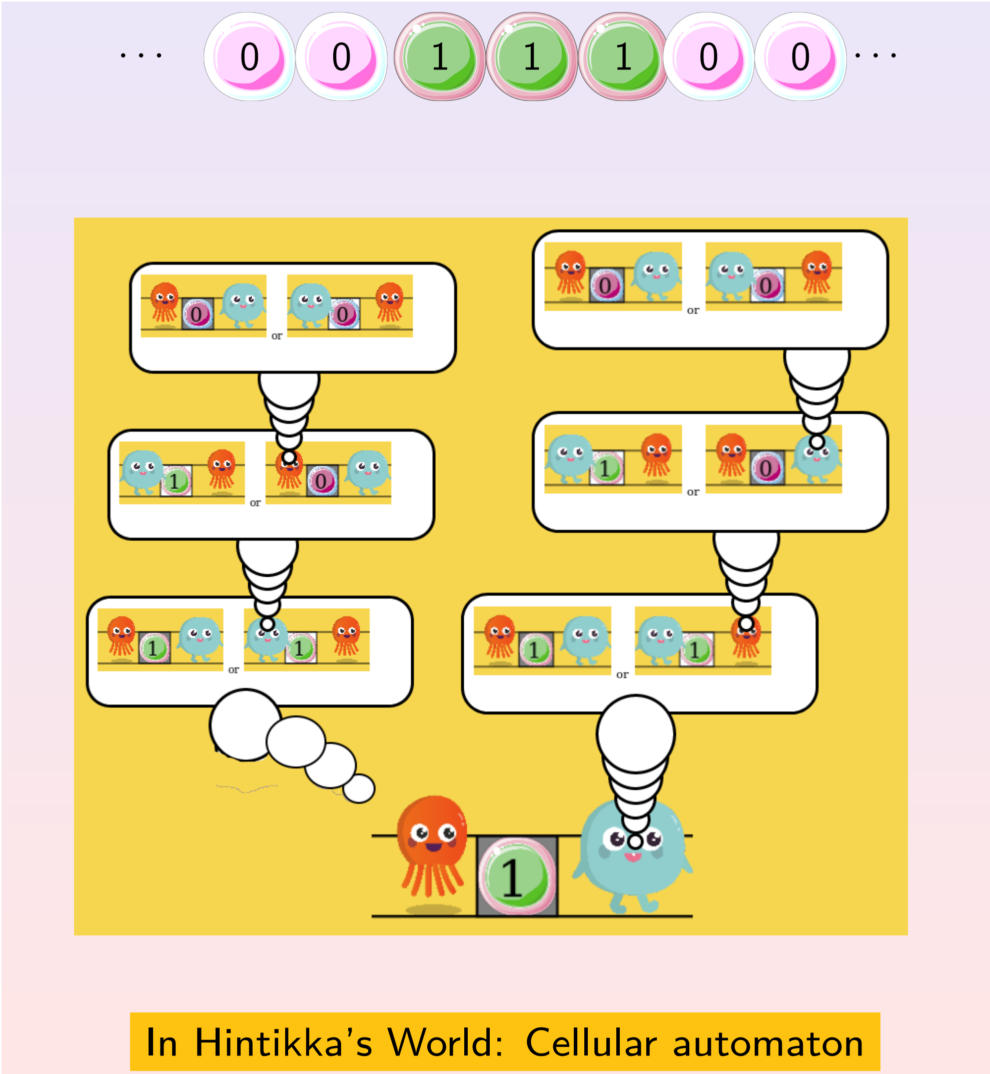
Example: the 110 Rule cellular automaton



Example: the 110 Rule cellular automaton



Encoding automaton configuration in a state



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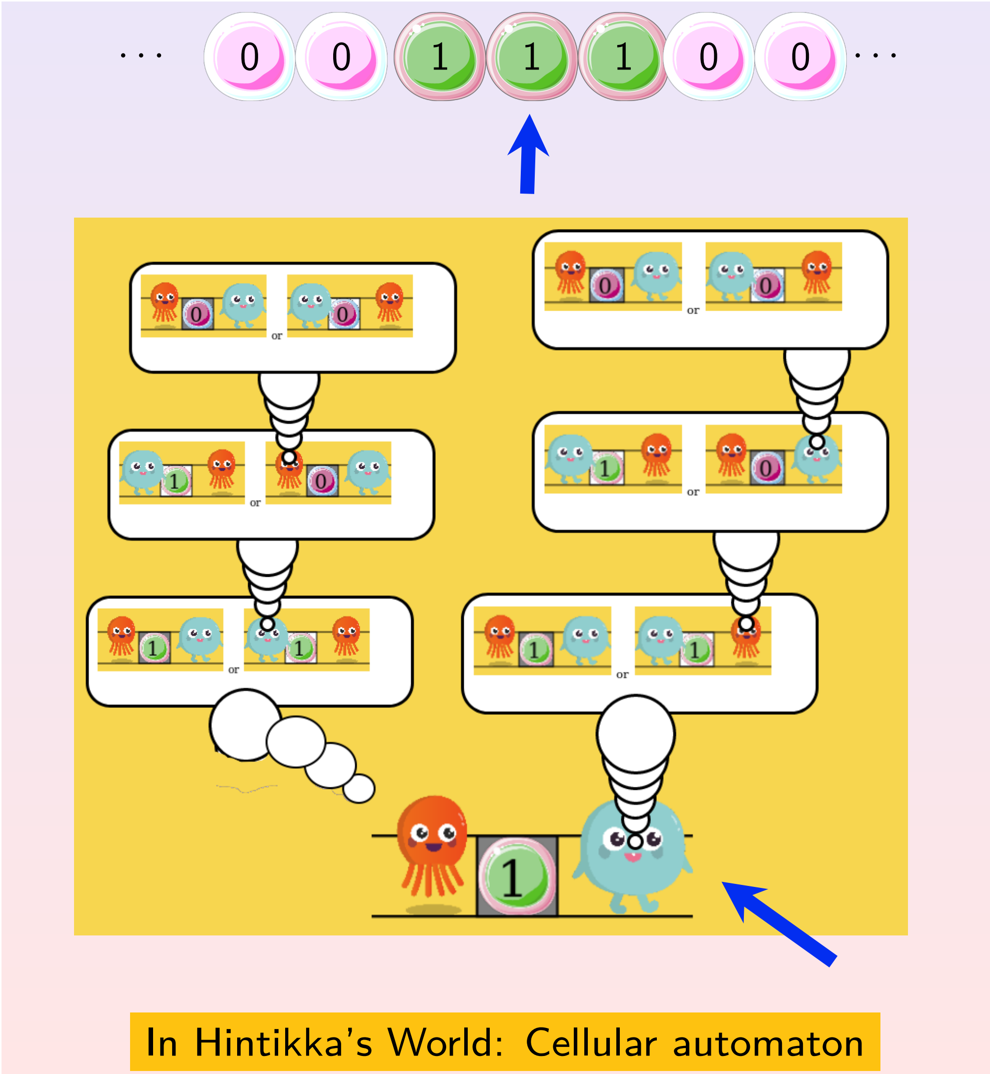
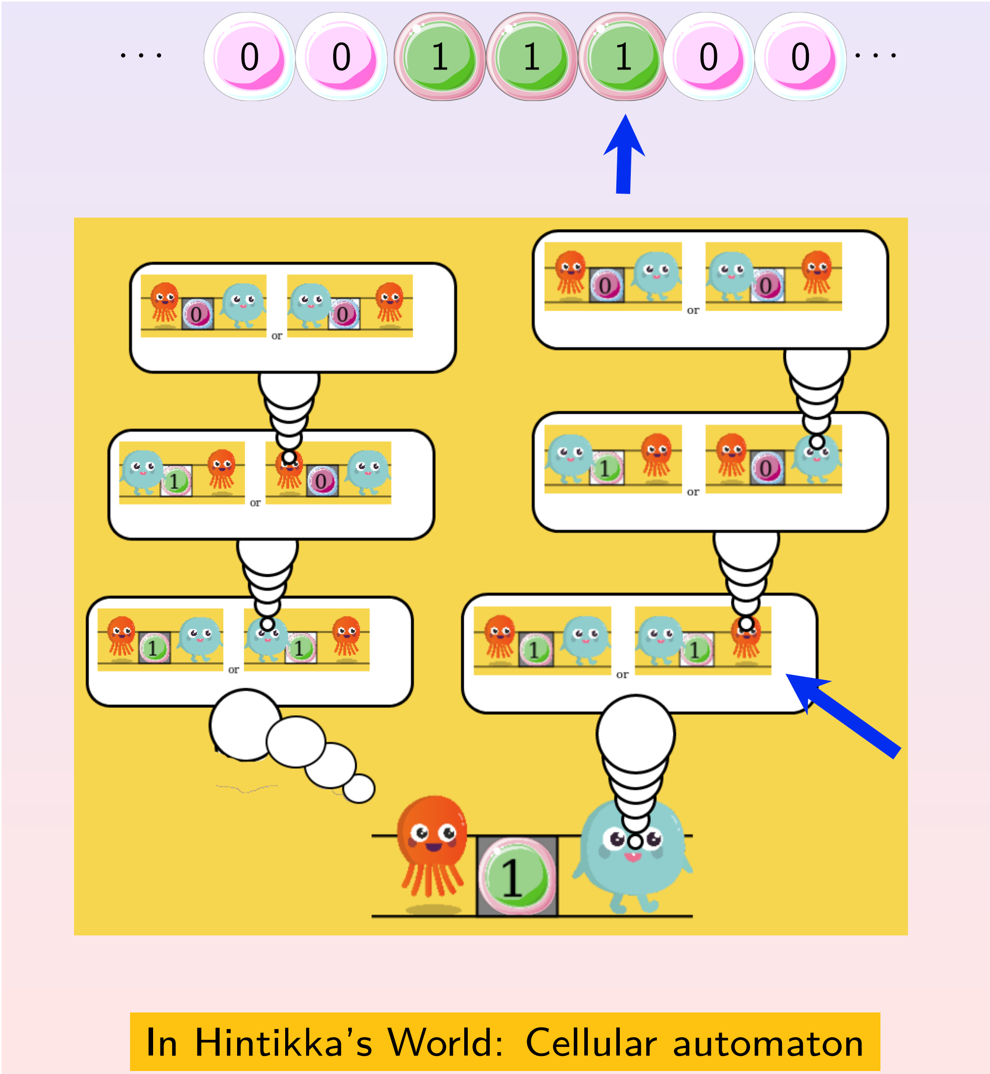


Encoding automaton configuration in a state



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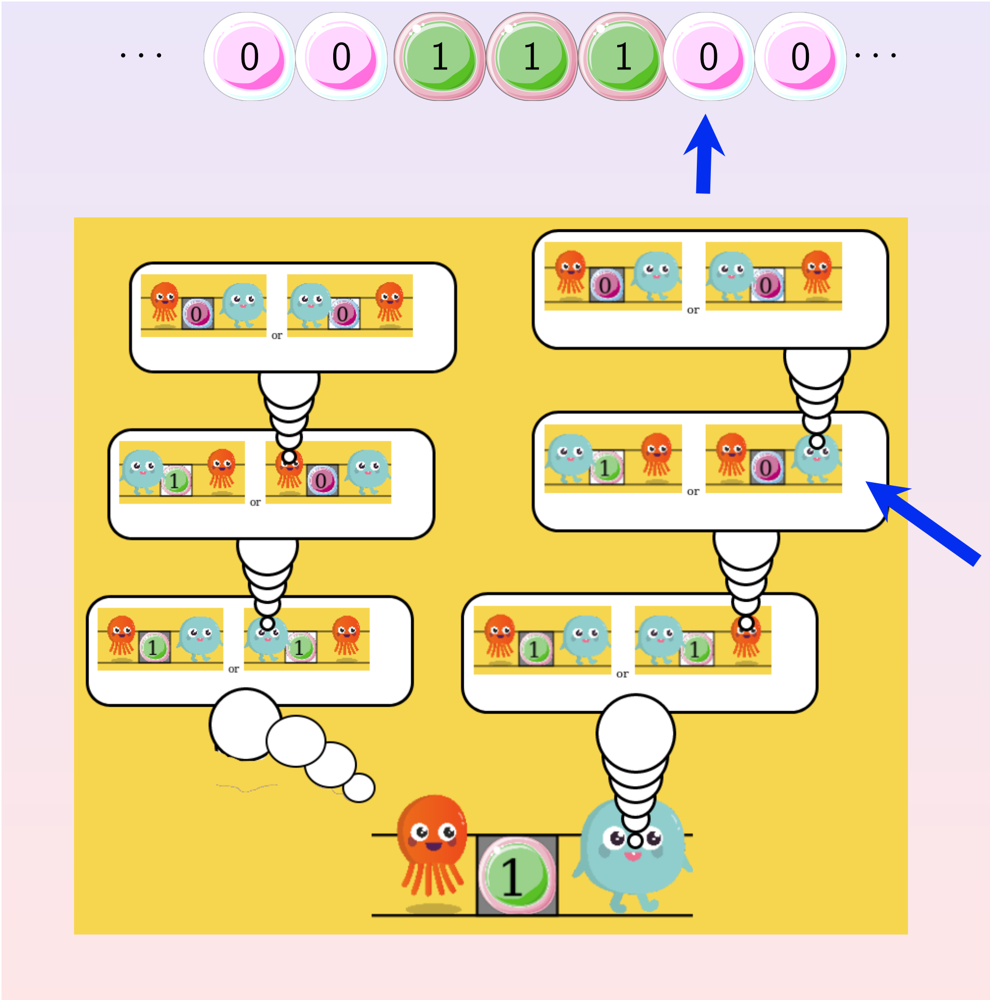
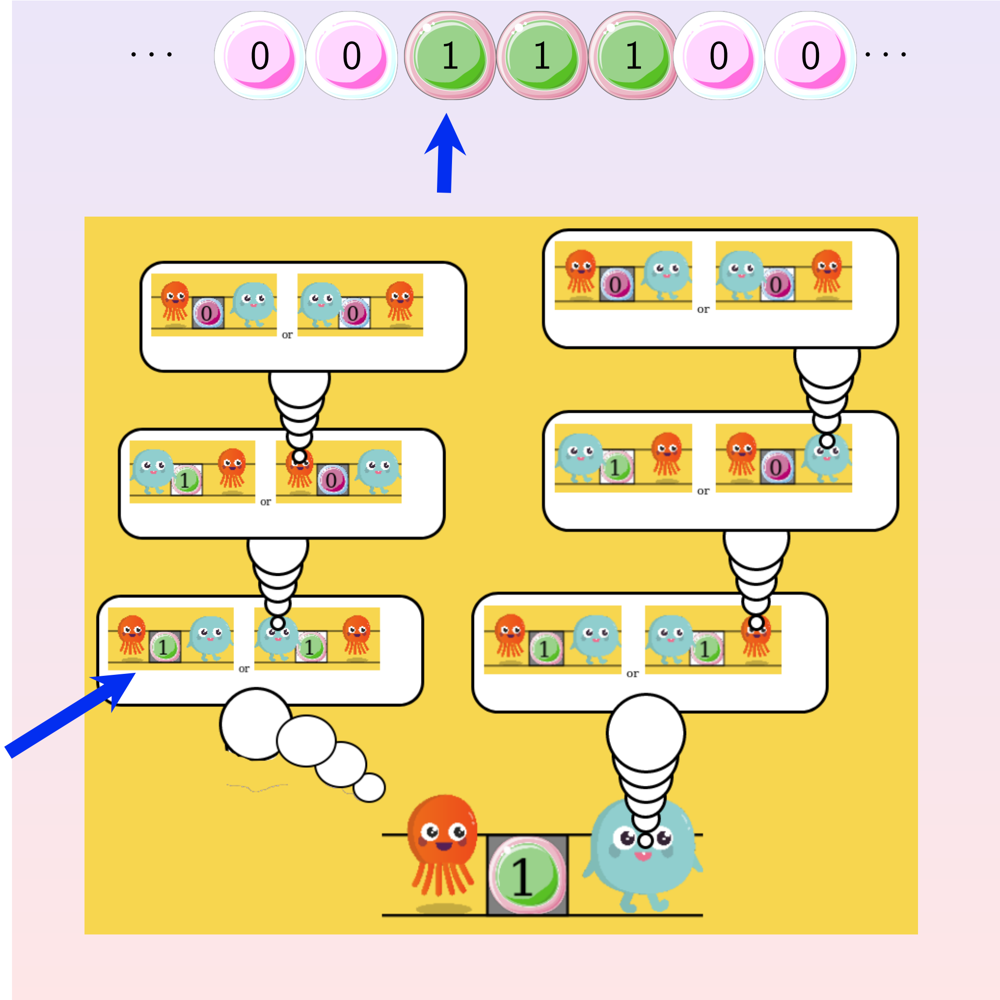


In Hintikka's World: Cellular automaton

Encoding automaton configuration in a state



In Hintikka's World: Cellular automaton

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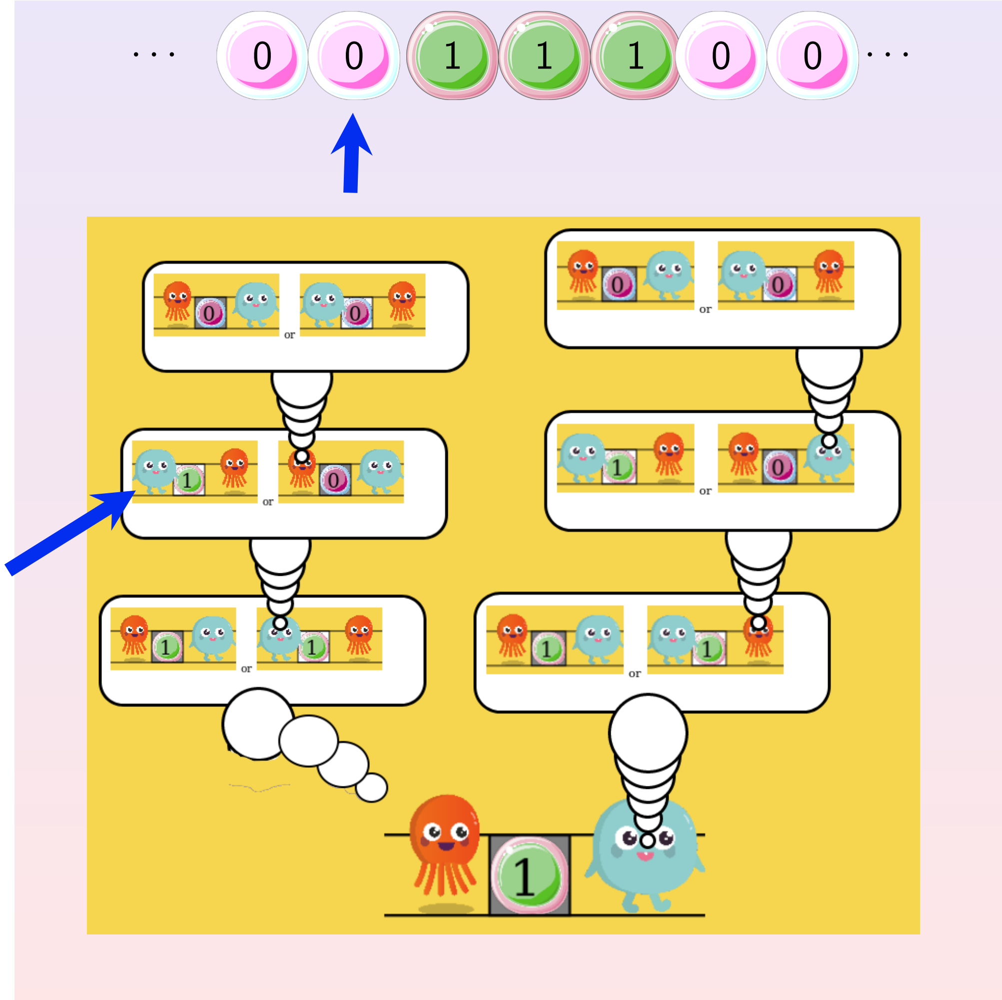
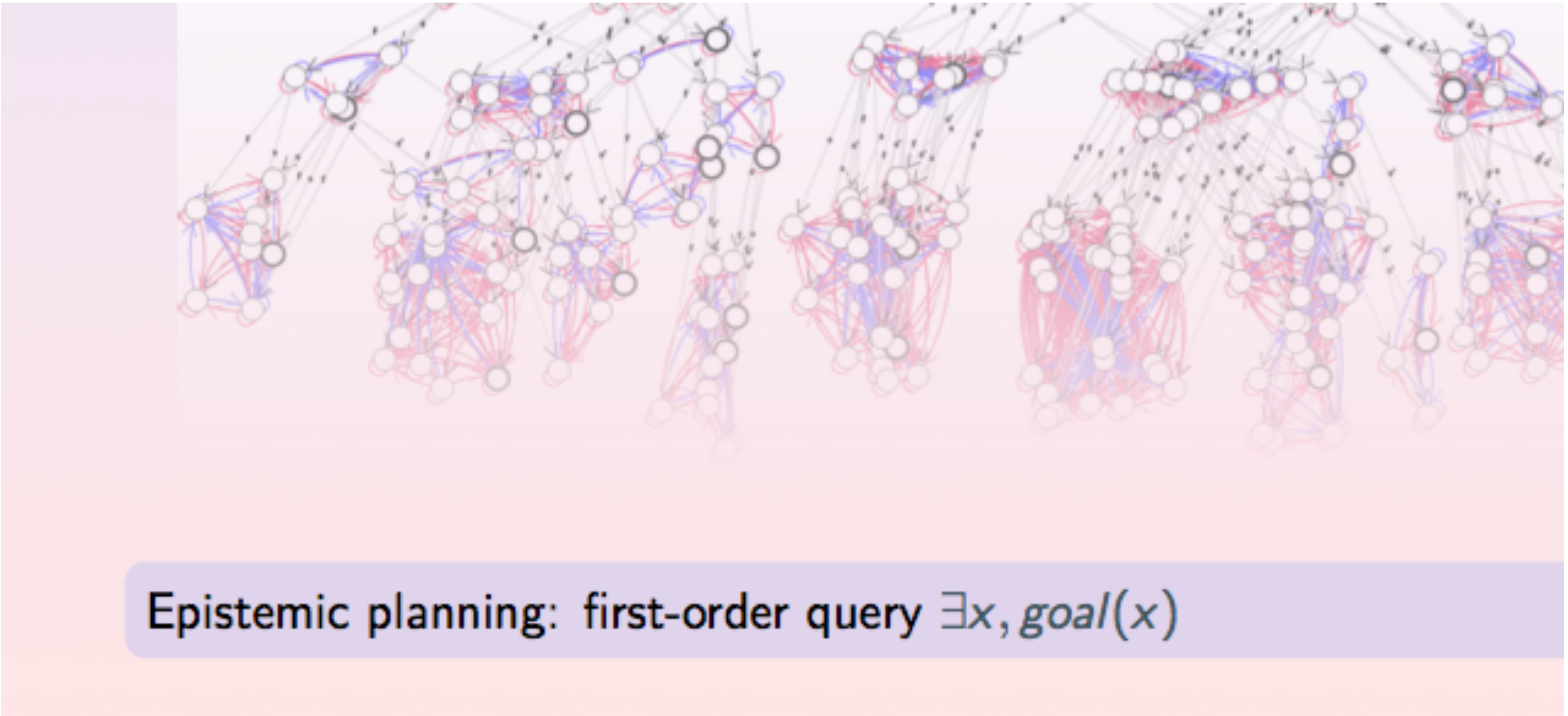


In Hintikka's World: Cellular automaton

(Infinite) Epistemic temporal structures



Epistemic planning: first-order query $\exists x.\, goal(x)$

Decidability when pre/post are Boolean

Theorem (Yu et al. 13, Aucher et al 14)

When pre/post conditions are Boolean, epistemic plaaning is decidable

Epistemic planning is a first-order query

↓

first-order query on automatic structures is decidable

↓

Epistemic temporal structures are automatic

Theorem (Doueneau-Tabot et al., 2018)

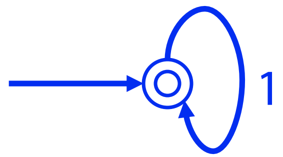
Even decidable for goals in epistemic linear μ-calculus[1)].

1) That is, for caclulus with (minimal) fixed point operator

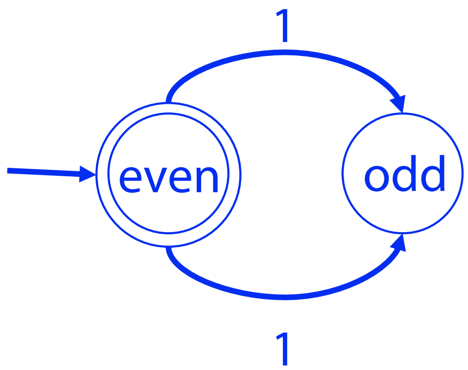
Automatic structure = defined by automata

$(\ \mathbb{N}\ ,\quad \boldsymbol{isEven}\ ,\quad \leq\ ) \longrightarrow (\ \mathcal{A}_{\mathbb{N}},\quad \mathcal{A}_{\boldsymbol{isEven}}\ ,\quad \mathcal{A}_{\leq}\ )$

- Enc: $\mathbb{N} \rightarrow \{\mathbf{1}\}^*$; $\boldsymbol{n} \mapsto \mathbf{1}^{\boldsymbol{n}}$;
- $\mathcal{A}_{\mathbb{N}}$:



- $\mathcal{A}_{\boldsymbol{isEven}}$



- $\mathcal{A}_{\leq}$

Automatic structure = defined by automata

$(\mathbb{N} , \quad \boldsymbol{isEven} , \quad \leq) \longrightarrow (\mathcal{A}_{\mathbb{N}}, \quad \mathcal{A}_{\boldsymbol{isEven}} , \quad \mathcal{A}_{\leq})$

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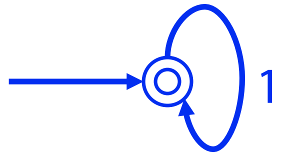
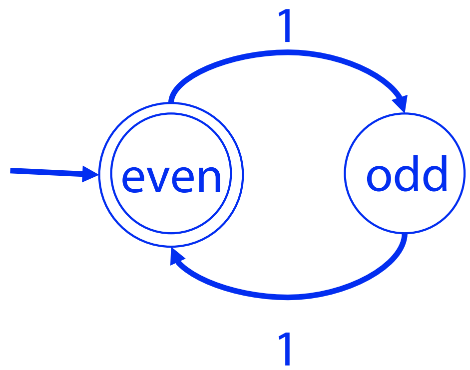


- $\mathcal{A}_{\boldsymbol{isEven}}$

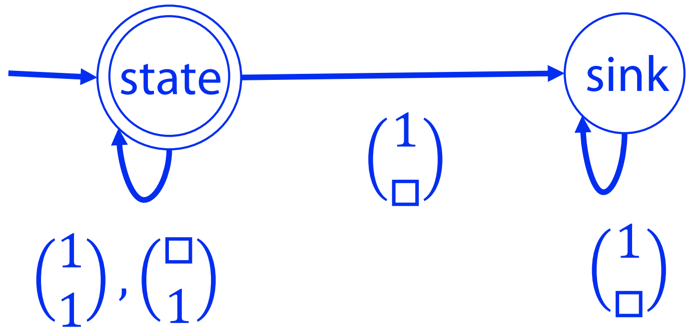


- $\mathcal{A}_{\leq}$

Automatic structure = defined by automata

$(\ \mathbb{N}\ ,\ \ \textit{isEven}\ ,\ \ \leq\ )$ ⟶ $(\ \mathcal{A}_{\mathbb{N}},\ \ \mathcal{A}_{\textit{isEven}}\ ,\ \ \mathcal{A}_{\leq}\ )$

- $\mathcal{A}_{\leq}$:



Idea:

- $2 \leq 5$ iff $11 \leq 11111$
- $2 \leq 5$ iff word $\binom{1}{1}, \binom{1}{1}, \binom{\square}{1}, \binom{\square}{1}, \binom{\square}{1}$ accepted by $\mathcal{A}_{\leq}$

Generalization to multi-player setting

Definition

A strategy for a player a is a function σ that maps any history $we_1, \ldots, e_n$ to a deterministic epistemic action in the repertoire of a

Definition

A uniform strategy for a player a is a strategy σ such that:

If $we_1 \ldots e_n \sim_a \mathrm{ue}'_1 \ldots e'_n$ then $\sigma(we_1 \ldots e_n) = \sigma(\mathrm{ue}'_1 \ldots e'_n)$

Undecidability even for Boolean pre/post

Theorem (Peterson /Reif 79, Coulombe/Lynch 18, Maubert et al 19)

The existence of uniform strategies for two players against an environment for achieving a goal is undecidable.

Theorem

Decidability of existence of uniform strategies holds when

- Only public actions are allowed (Belardenelli et al 17) (Maubert et al 19))
- Hierarchical information is assumed (Maubert/Muranio 18), Maubert et al 19)

Complexity results in epistemic planning

	One centralized planner (Bolander et al 2015)	Many players (Maubert et al 2019)
Public announcements	NP-c	PSPACE-c
Public actions	PSPACE-c	EXPTIME-c
Boolean pre/post	Decidable	undecidable
all	Undecidable	Undecidable (Peterson/Reif 79)

Uninformed semantics (not knowing about others‘ strategies) in case of many players

Perspectives: DEL and Formal Language theory

Question: Is epistemic planning one agent (pre: md 1, no post) decidable?

FOL query decidable on → FOL query Is NOT decidable on

Automatic structures

Pushdown automata?
Causal hierarchy?

Turing-complete structures

ÖÖ: See also descriptive complexity

- Connections with logics for reasoning about strategies such as Alternating temporal-time logic, Strategy logic et (Maubert et al. 2019)
- Describing protocols/policies

Uhhh, a lecture with a hoepfully useful

APPENDIX

References

- J. van Benthem. Logical Dynamics of Information and Interaction. Cambridge University Press, 2011.
- G. Aucher and F. Schwarzentruber. On the complexity of dynamic epistemic logic. In B. C. Schipper, editor, Proceedings of the 14th Conference on Theoretical Aspects of Rationality and Knowledge (TARK 2013), Chennai, India, January 7-9, 2013, 2013.
- I. van de Pol, I. van Rooij, and J. Szymanik. Parameterized complexity results for a model of theory of mind based on dynamic epistemic logic. In R. Ramanujam, editor, Proceedings Fifteenth Conference on Theoretical Aspects of Rationality and Knowledge, TARK 2015, Carnegie Mellon University, Pittsburgh, USA, June 4-6, 2015, volume 215 of EPTCS, pages 246–263, 2015.
- J. van Benthem, J. van Eijck, M. Gattinger, and K. Su. Symbolic model checking for dynamic epistemic logic. In W. van der Hoek, W. H. Holliday, and W.-f. Wang, editors, Logic, Rationality, and Interaction, pages 366–378, Berlin, Heidelberg, 2015. Springer Berlin Heidelberg.
- J. Van Benthem, J. Van Eijck, M. Gattinger, and K. Su. Symbolic model checking for dynamic epistemic logic — s5 and beyond. Journal of Logic and Computation, 28(2):367–402, Mar. 2018.
- T. Charrier and F. Schwarzentruber. A succinct language for dynamic epistemic logic. In K. Larson, M. Winikoff, S. Das, and E. H. Durfee, editors, Proceedings of the 16th Conference on Autonomous Agents and MultiAgent Systems, AAMAS 2017, S̃ ao Paulo, Brazil, May 8-12, 2017, pages 123–131. ACM, 2017.
- T. Charrier and F. Schwarzentruber. Complexity of dynamic epistemic logic with common knowledge. In G. Bezhanishvili, G. D'Agostino, G. Metcalfe, and T. Studer, editors, Advances in Modal Logic 12, proceedings of the 12th conference on "Advances in Modal Logic," held in Bern, Switzerland, August 27-31, 2018, pages 103–122. College Publications, 2018.
- B. Maubert, S. Pinchinat, and F. Schwarzentruber. Reachability games in dynamic epistemic logic. In Proceedings of the Twenty-Eighth International Joint Conference on Artificial Intelligence, IJCAI-19, pages 499–505. International Joint Conferences on Artificial Intelligence Organization, 7 2019.

References

- J. von Neumann. The general and logical theory of automata. In Cerebral Mechanisms in Behavior: The Hixon Symposium, pages 1–41. John Wiley & Sons Ltd., 1951.
- Stephen Wolfram. A New Kind of Science. Wolfram Media Inc., Champaign, Ilinois, USA, 2002.
- D. M. Gabbay, A. Kurucz, F. Wolter, and M. Zakharyaschev. Many-Dimensional Modal Logics: Theory and Applications. Elsevier, 2003.
- J. Y. Halpern and M. Y. Vardi. Model checking vs. theorem proving: A manifesto. In Proceedings of the Second International Conference on Principles of Knowledge Representation and Reasoning, KR'91, pages 325–334, San Francisco, CA, USA, 1991. Morgan Kaufmann Publishers Inc.
- T. Bolander and M. B. Andersen. Epistemic planning for single- and multi-agent systems. Journal of Applied Non-Classical Logics, 21(1):9–34, 2011.
- T. Bolander, M. H. Jensen, and F. Schwarzentruber. Complexity results in epistemic planning. In IJCAI, 2015
- T. Charrier, B. Maubert, and F. Schwarzentruber. On the impact of modal depth in epistemic planning. In Proceedings of the Twenty-Fifth International Joint Conference on Artificial Intelligence, IJCAI'16, pages 1030–1036. AAAI Press, 2016
- G. Aucher and T. Bolander. Undecidability in epistemic planning. In IJCAI, 2013.
- Q. Yu, X. Wen, and Y. Liu. Multi-agent epistemic explanatory diagnosis via reasoning about actions. In Proceedings of the Twenty-Third International Joint Conference on Artificial Intelligence, IJCAI '13, pages 1183–1190. AAAI Press, 2013.
- G. Aucher, B. Maubert, and S. Pinchinat. Automata techniques for epistemic protocol synthesis. In F. Mogavero, A. Murano, and M. Y. Vardi, editors, Proceedings 2nd International Workshop on Strategic Reasoning, SR 2014, Grenoble, France, April 5-6, 2014, volume 146 of EPTCS, pages 97–103, 2014.
- G. Doueneau-Tabot, S. Pinchinat, and F. Schwarzentruber. Chain-monadic second order logic over regular automatic trees and epistemic planning synthesis. In G. Bezhanishvili, G. D'Agostino, G. Metcalfe, and T. Studer, editors, Advances in Modal Logic 12, proceedings of the 12th conference on "Advances in Modal Logic," held in Bern, Switzerland, August 27-31, 2018, pages 237–256. College Publications, 2018.
- S. L. Cong, S. Pinchinat, and F. Schwarzentruber. Small undecidable problems in epistemic planning. In J. Lang, editor, Proceedings of the Twenty-Seventh International Joint Conference on Artificial Intel- ligence, IJCAI 2018, July 13-19, 2018, Stockholm, Sweden, pages 4780–4786. ijcai.org, 2018.

References

- [G. L. Peterson and J. H. Reif. Multiple-person alternation. In 20th Annual Symposium on Foundations of Computer Science (sfcs 1979), pages 348–363, 1979.
- M. J. Coulombe and J. Lynch. Cooperating in Video GamesI Impossible! Undecidability of Team Mul- tiplayer Games. In H. Ito, S. Leonardi, L. Pagli, and G. Prencipe, editors, 9th International Conference on Fun with Algorithms (FUN 2018), volume 100 of Leibniz International Proceedings in Informatics (LIPIcs), pages 14:1–14:16, Dagstuhl, Germany, 2018. Schloss Dagstuhl–Leibniz-Zentrum fuer Infor- matik.
- F. Belardinelli, A. Lomuscio, A. Murano, and S. Rubin. Verification of multi-agent systems with imper- fect information and public actions. AAMAS '17, pages 1268–1276, Richland, SC, 2017. International Foundation for Autonomous Agents and Multiagent Systems.
- B. Maubert and A. Murano. Reasoning about knowledge and strategies under hierarchical information. In M. Thielscher, F. Toni, and F. Wolter, editors, Principles of Knowledge Representation and Reason- ing: Proceedings of the Sixteenth International Conference, KR 2018, Tempe, Arizona, 30 October - 2 November 2018, pages 530–540. AAAI Press, 2018.

Color Convention in this course

- Formulae, when occurring inline
- Newly introduced terminology and definitions
- Important results (observations, theorems) as well as emphasizing some aspects
- Examples are given with standard orange with possibly light orange frame
- Comments and notes
- Algorithms