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/

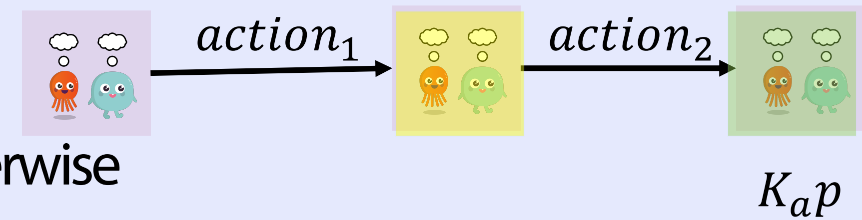
MODEL CHECKING

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)

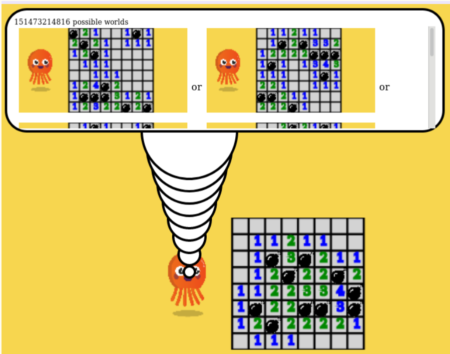
- Any type of action : PSPACE-complete (Aucher/Schwarzentruber 2013), (Pol et al. 2015)

State explosion problem

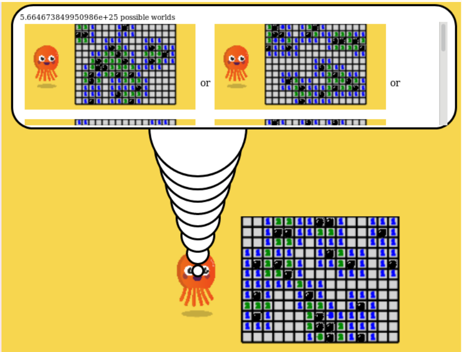
Example

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

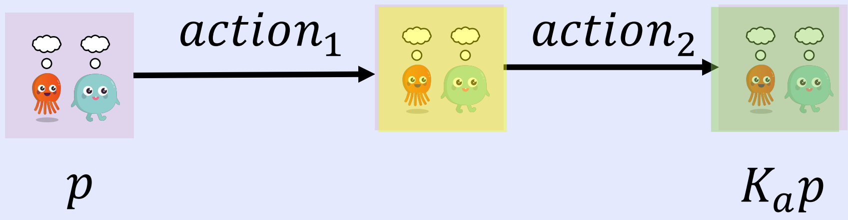
- Practical: Symbolic model checking implemented in Hintikka's world
  - S. Gamblin and A. Niveau
  - Using BDDs (binary decision diagrams)

THEOREM PROVING

Theorem proving (another point of view)

Motivation: parametrized verification

For all epistemic states in which p holds



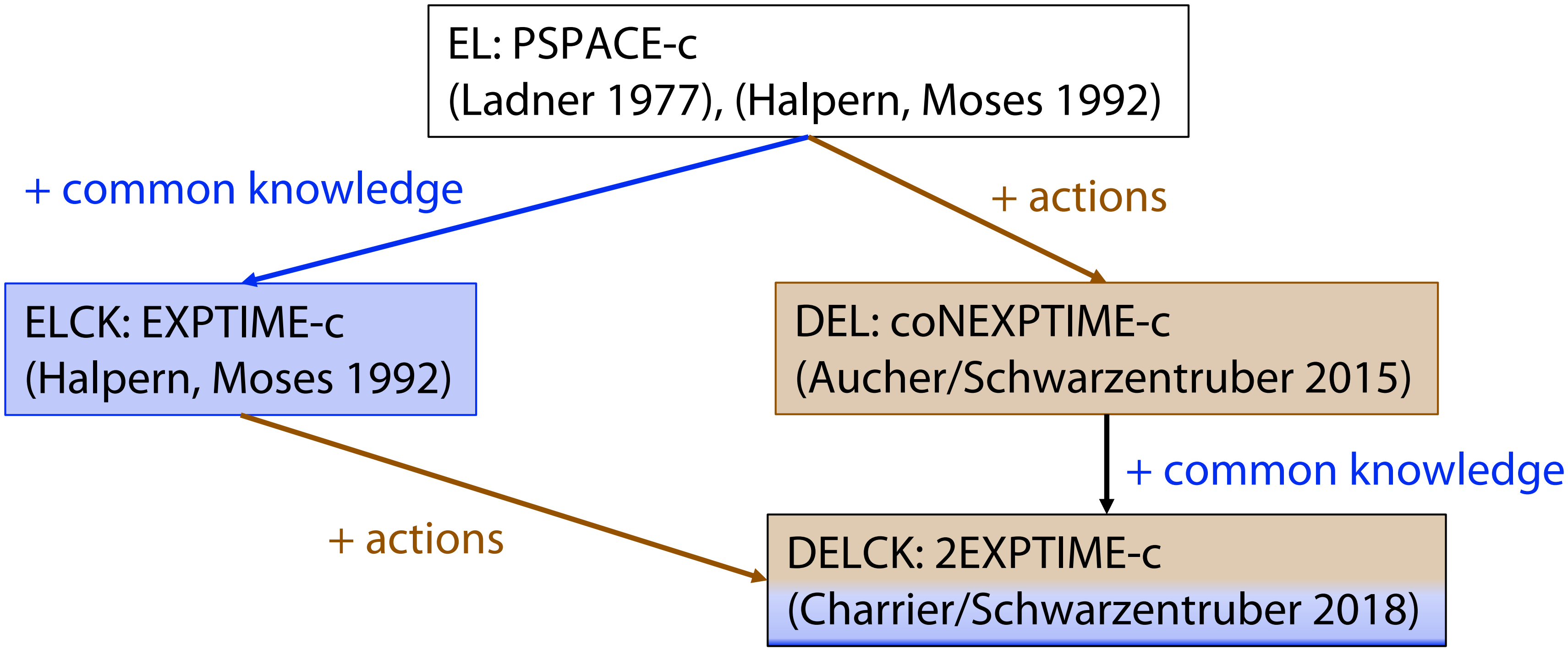
So: $p \rightarrow < action_1; action_2 > K_a p$ is a theorem (i.e. true in all states)

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



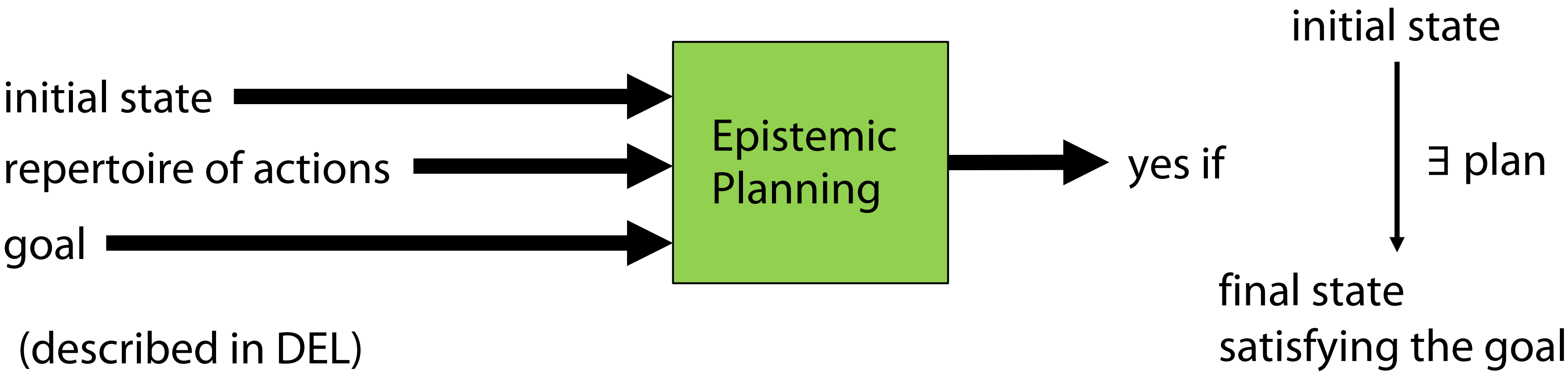
General Insights

- 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)



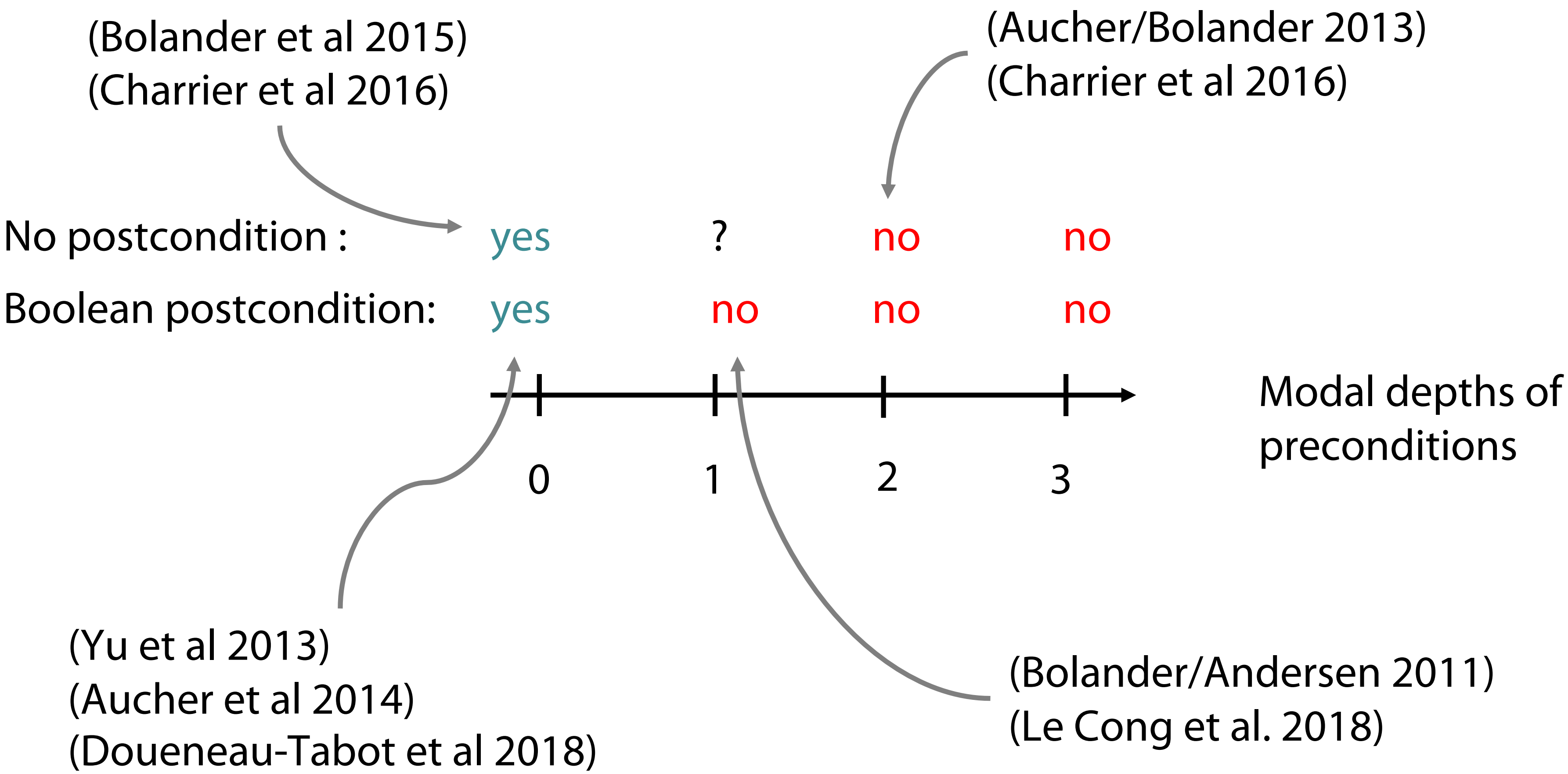
(Un-)Decidability of epistemic planning

	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

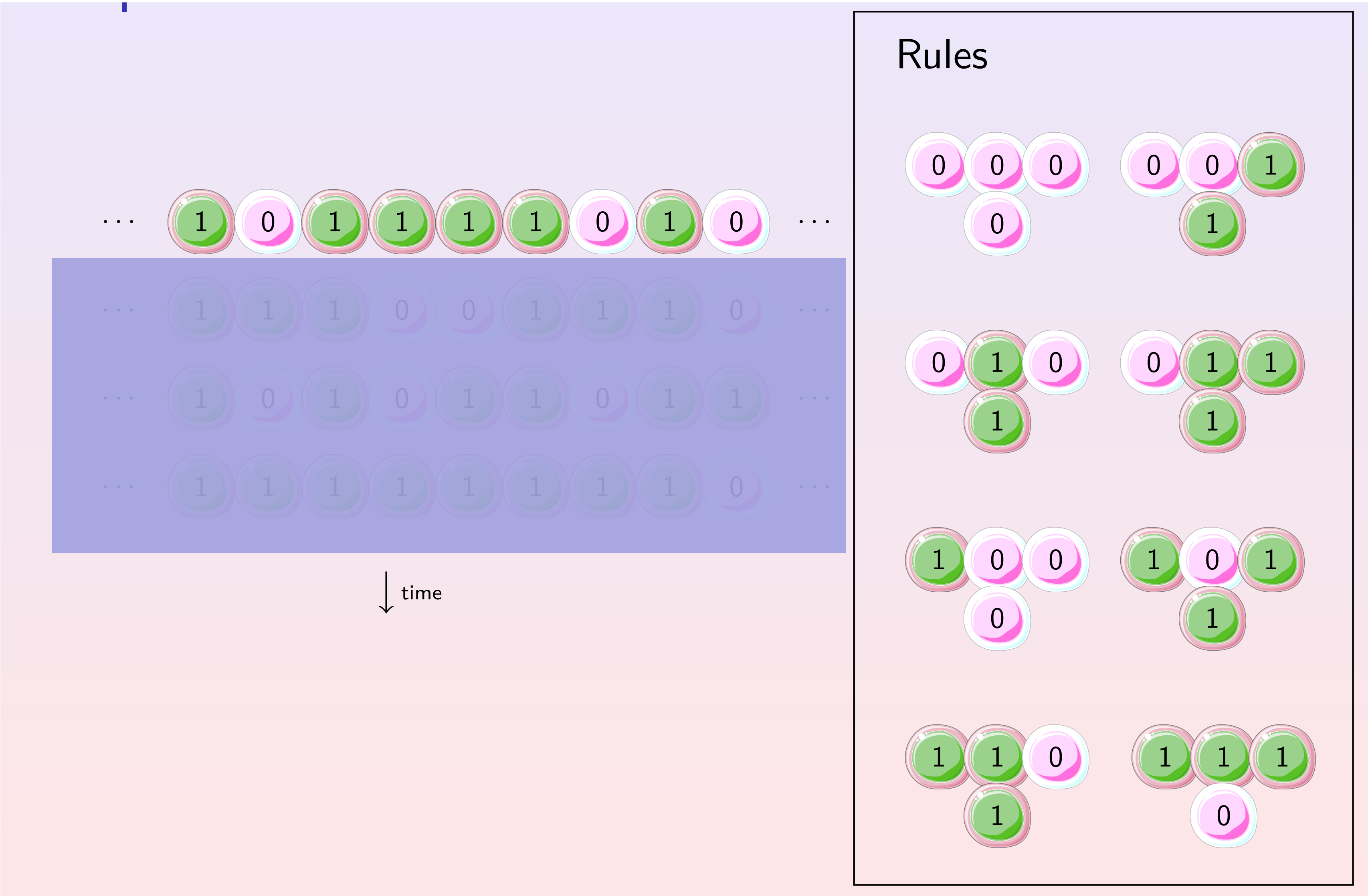
- two agents
- Boolean post conditions
- $\mathrm{m}d(pre) \leq 1$

even if

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

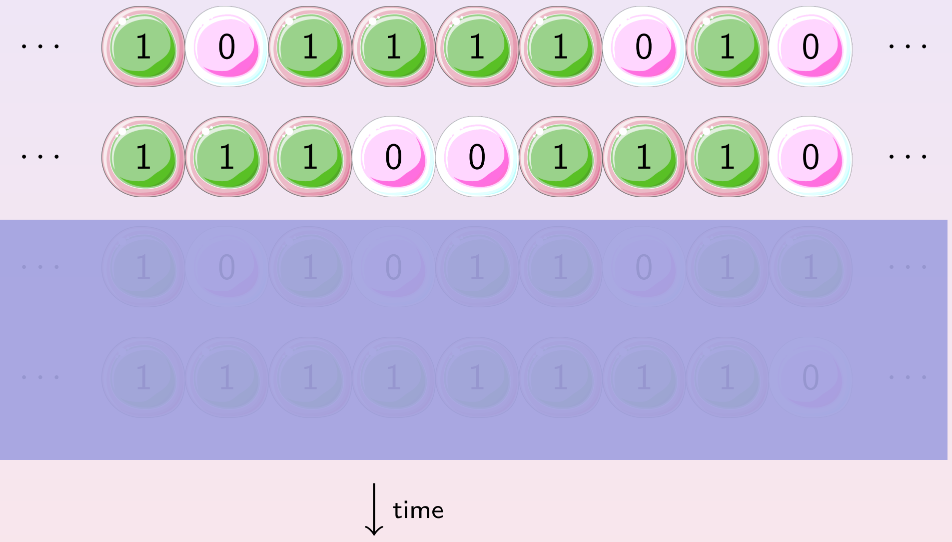
Proof idea: Reduction from halting problem of a small universal cellular automaton

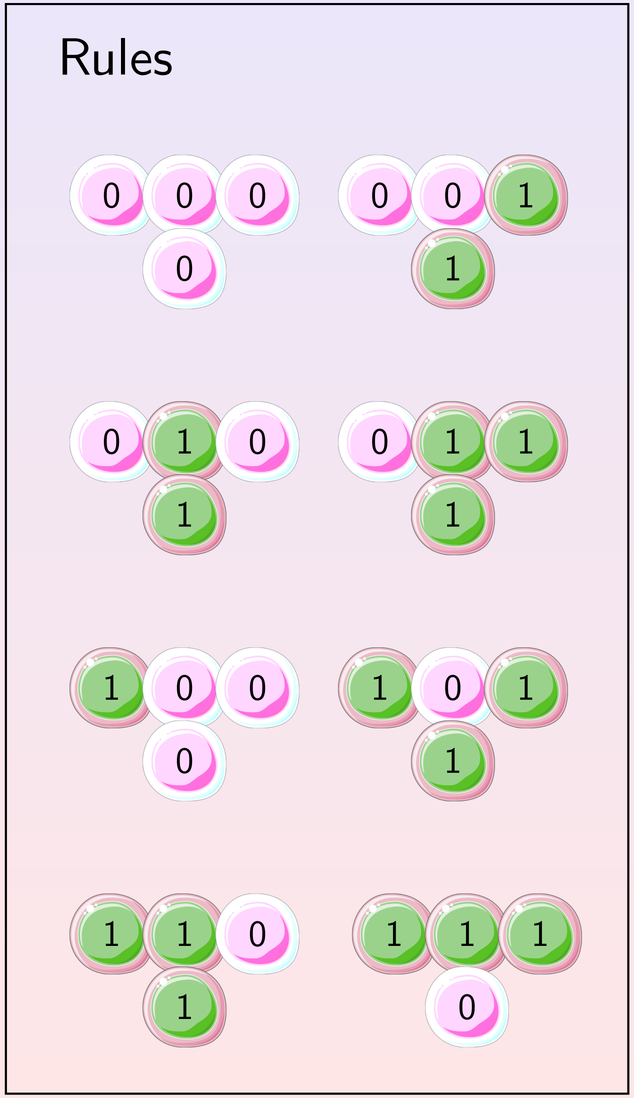
Example: the 110 Rule cellular automaton



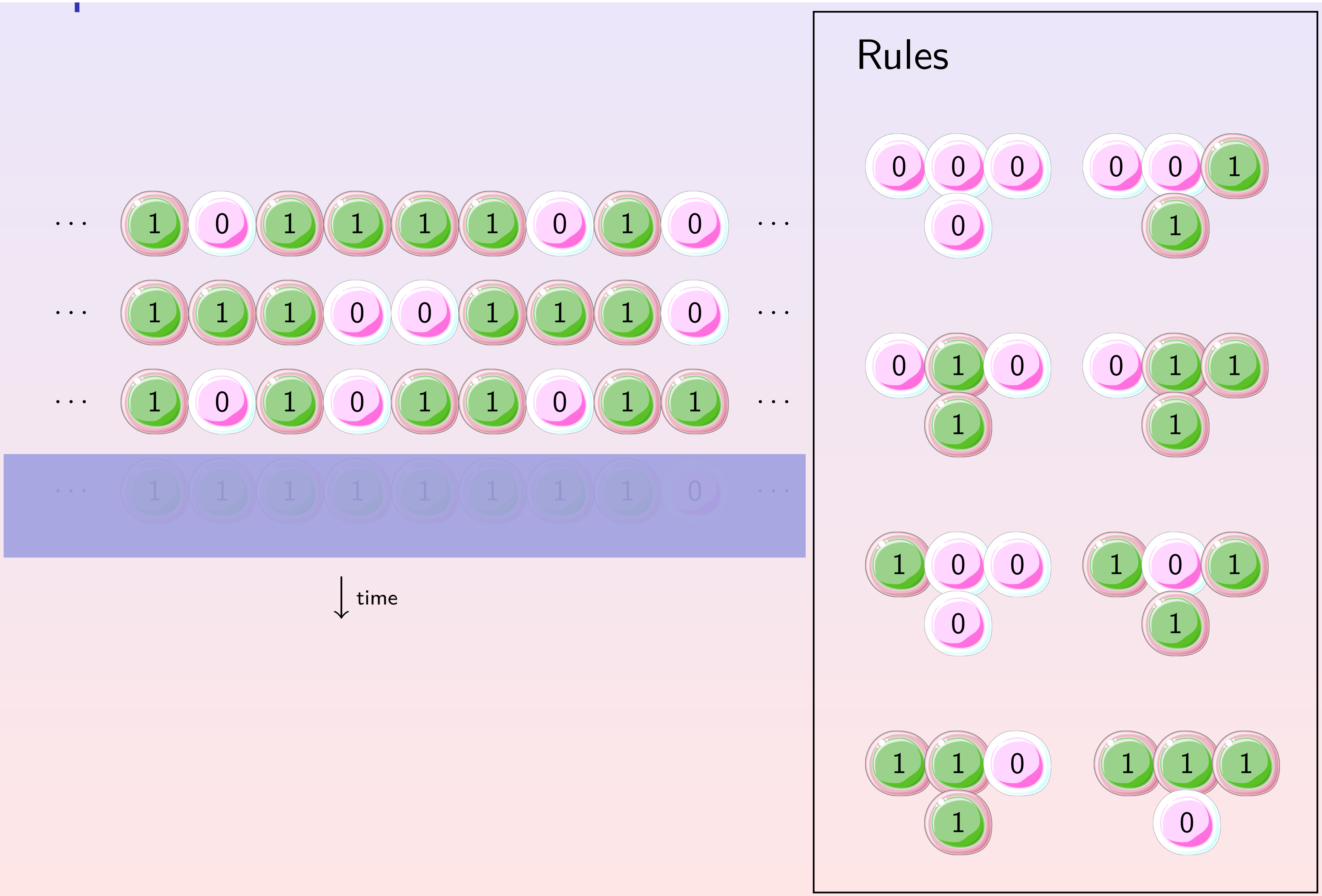
(von Neumann 1951) (Wolfram 2002)

Example: the 110 Rule cellular automaton

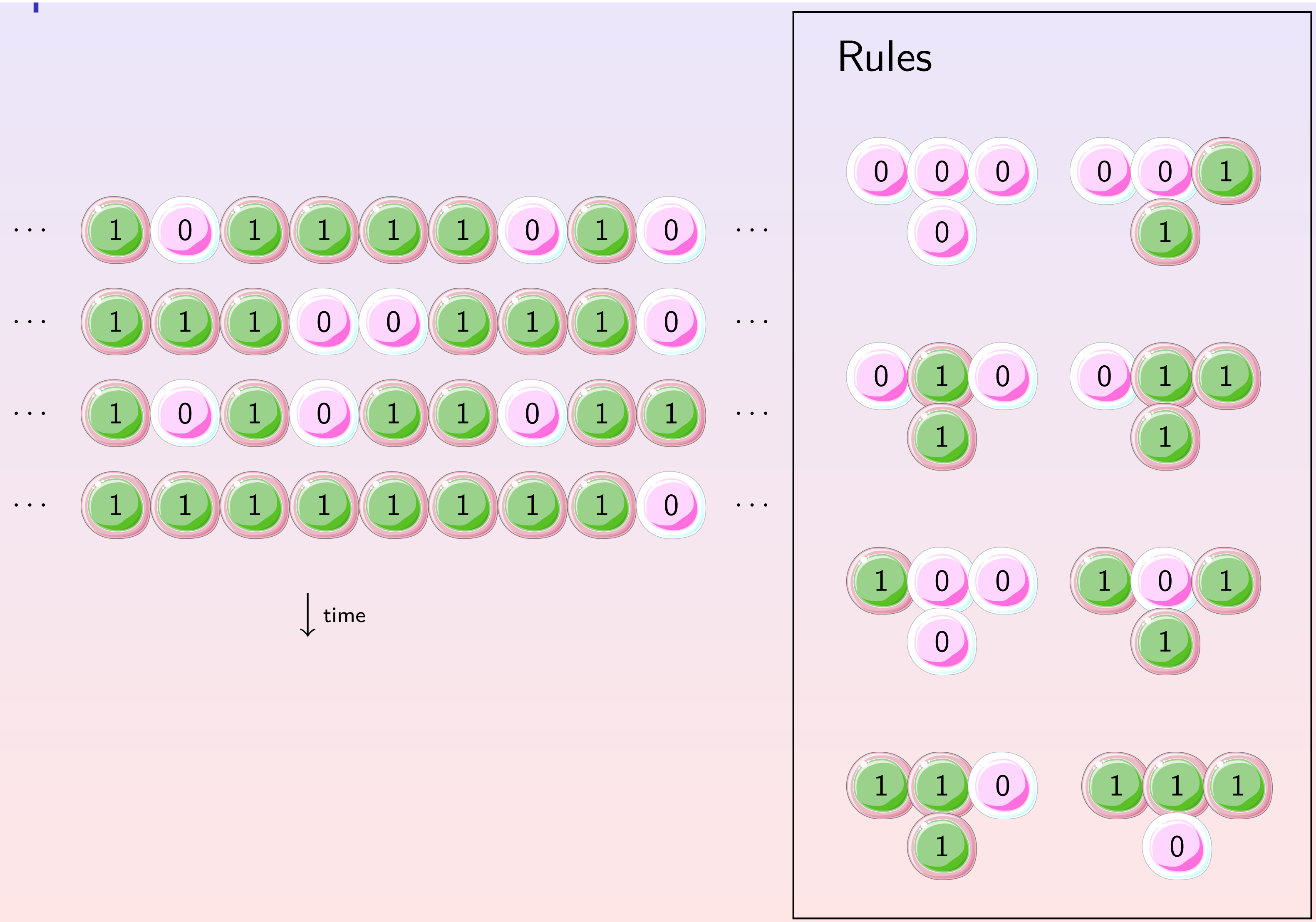




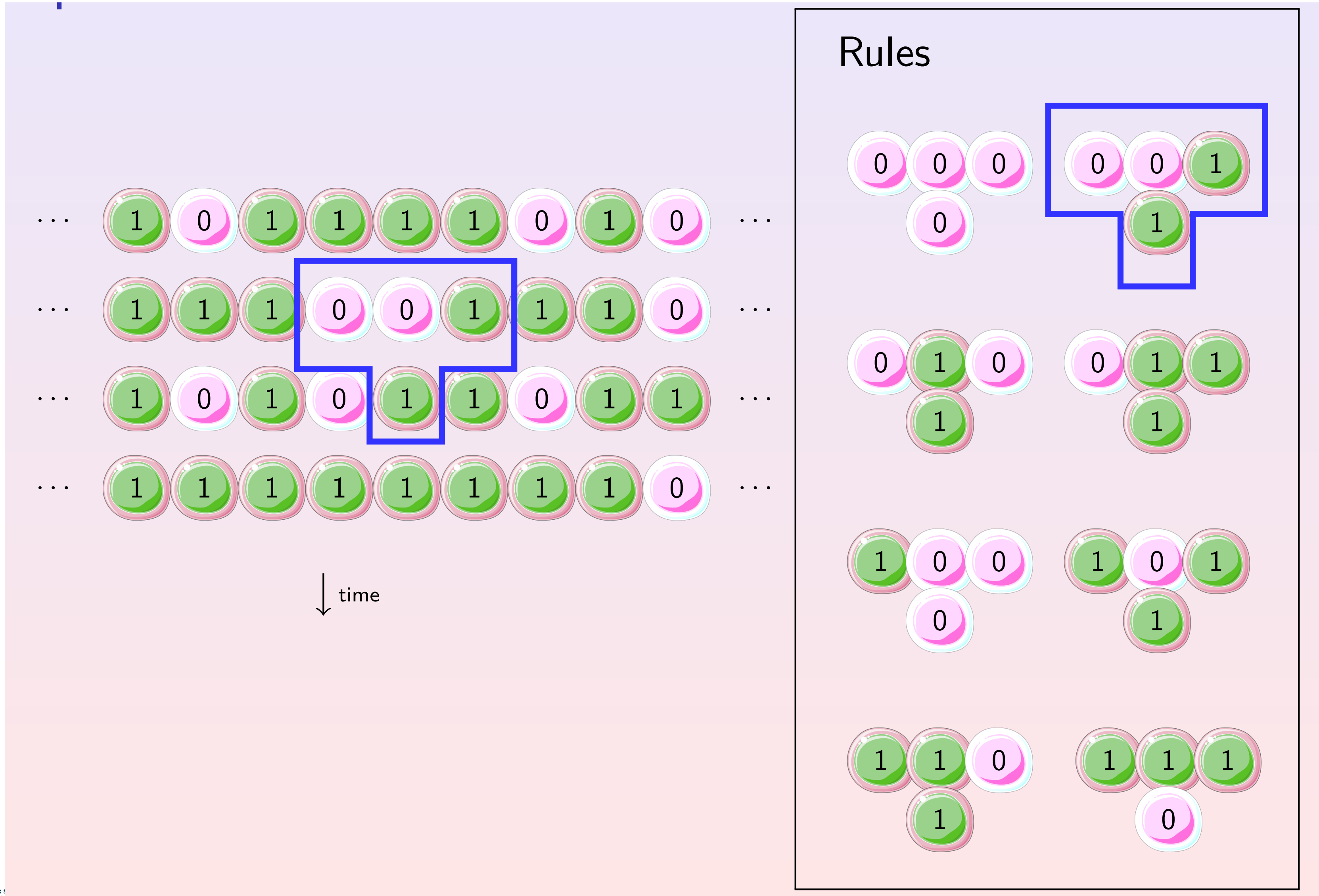
Example: the 110 Rule cellular automaton



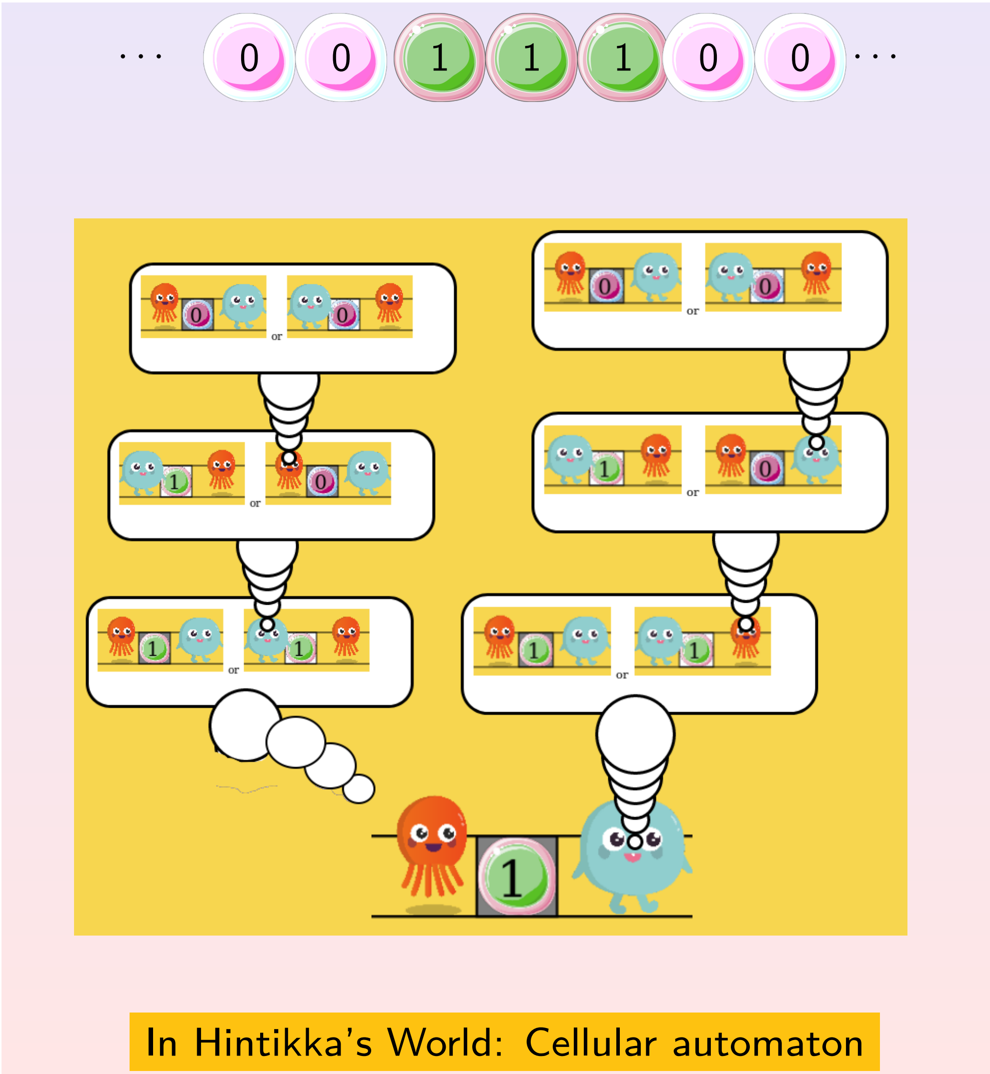
Example: the 110 Rule cellular automaton



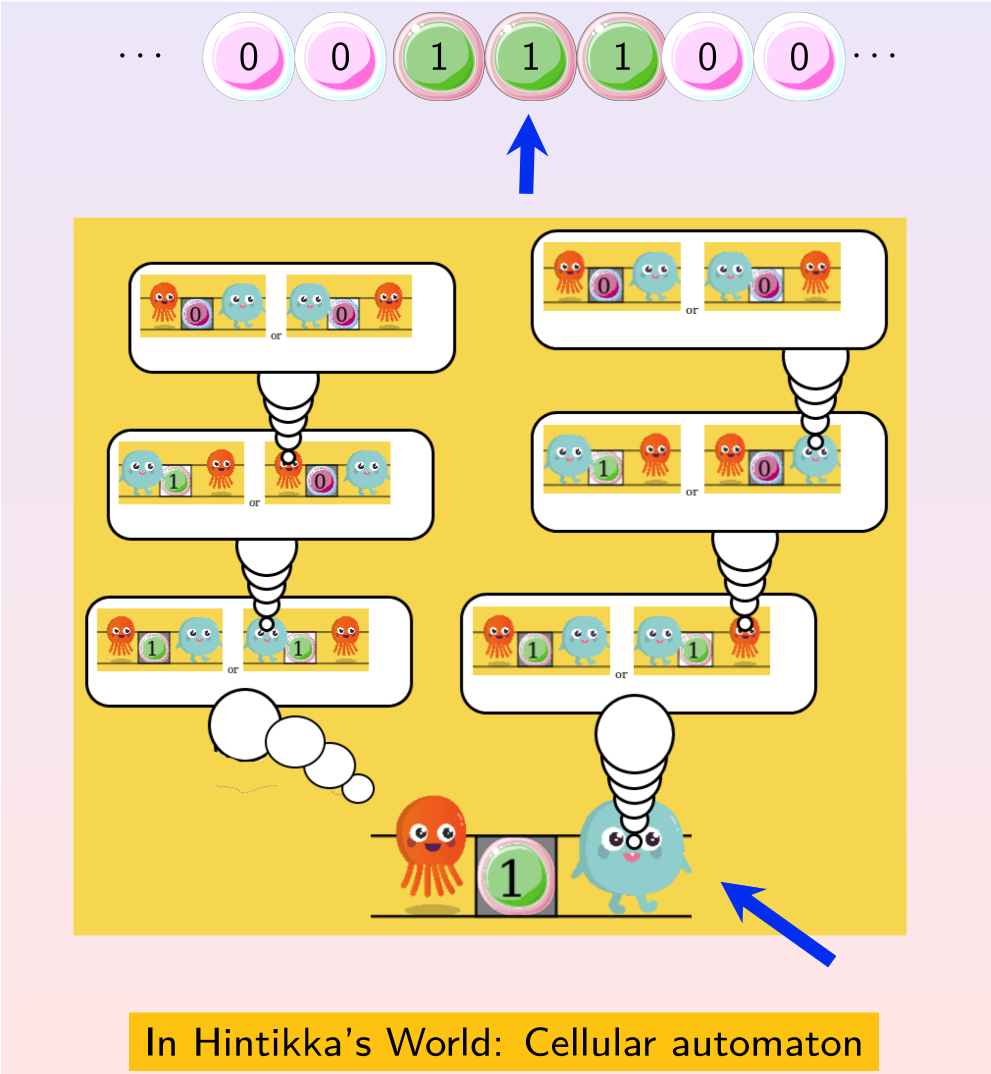
Example: the 110 Rule cellular automaton



Encoding automaton configuration in a state



Encoding automaton configuration in a state



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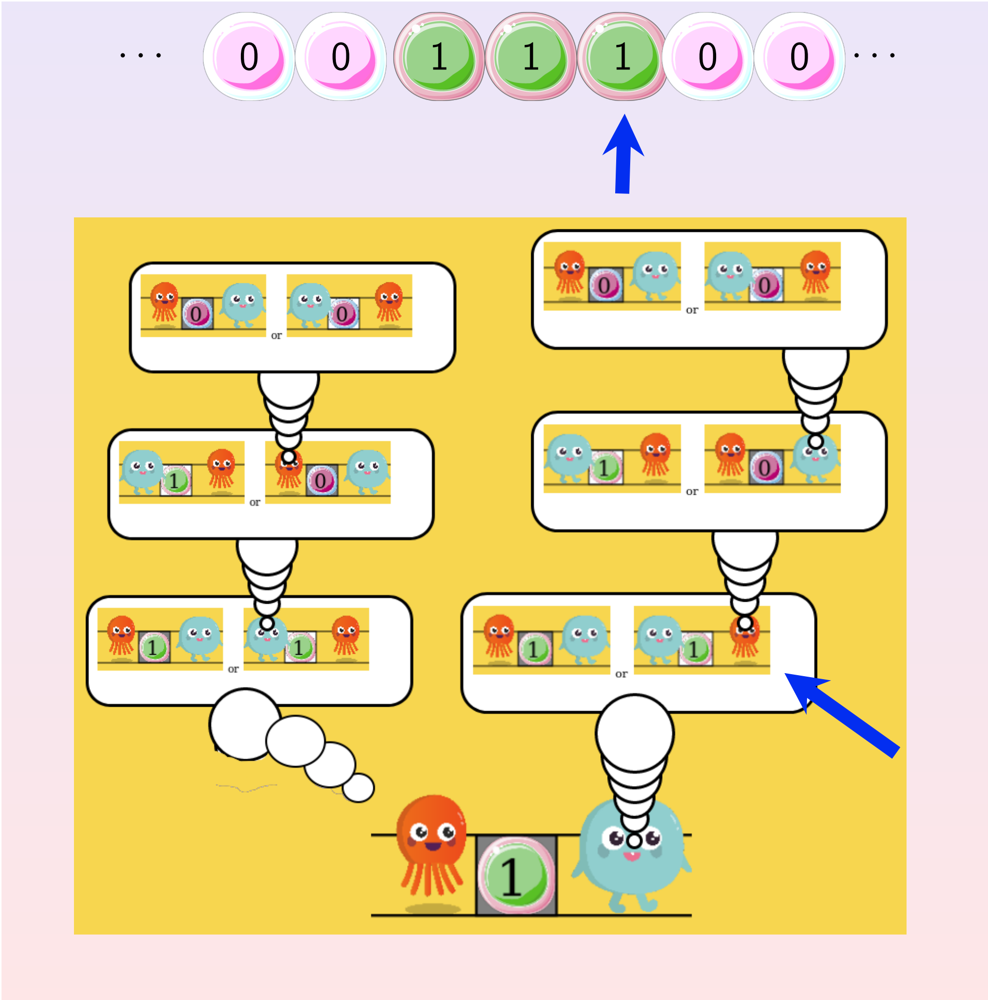
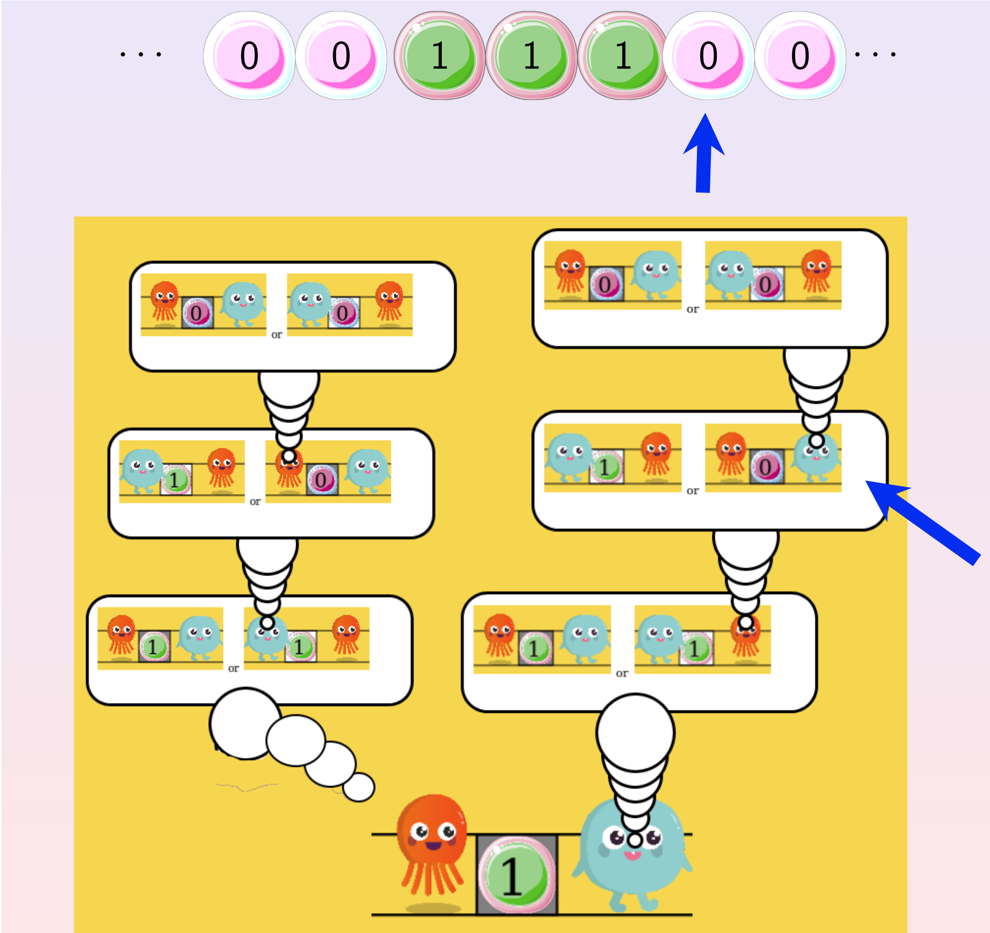


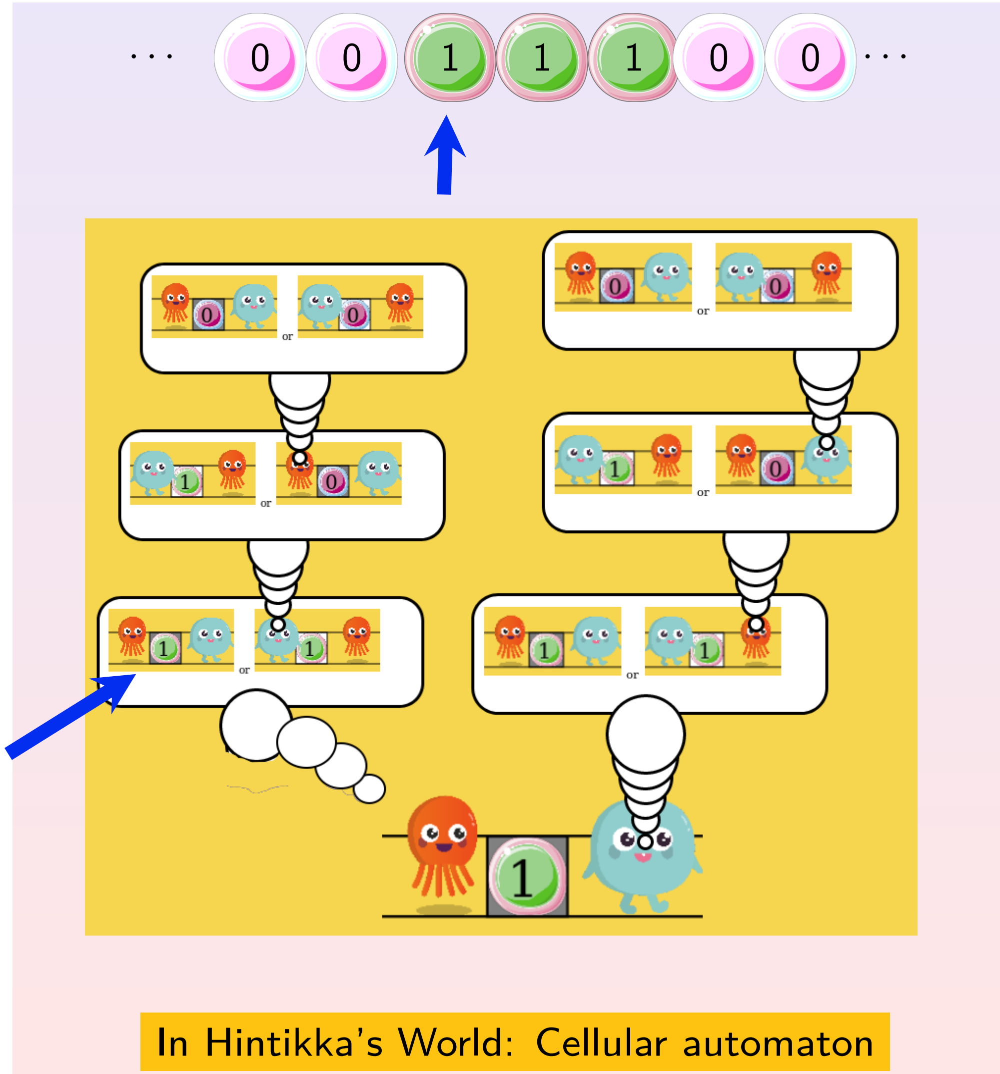
In Hintikka's World: Cellular automaton

Encoding automaton configuration in a state

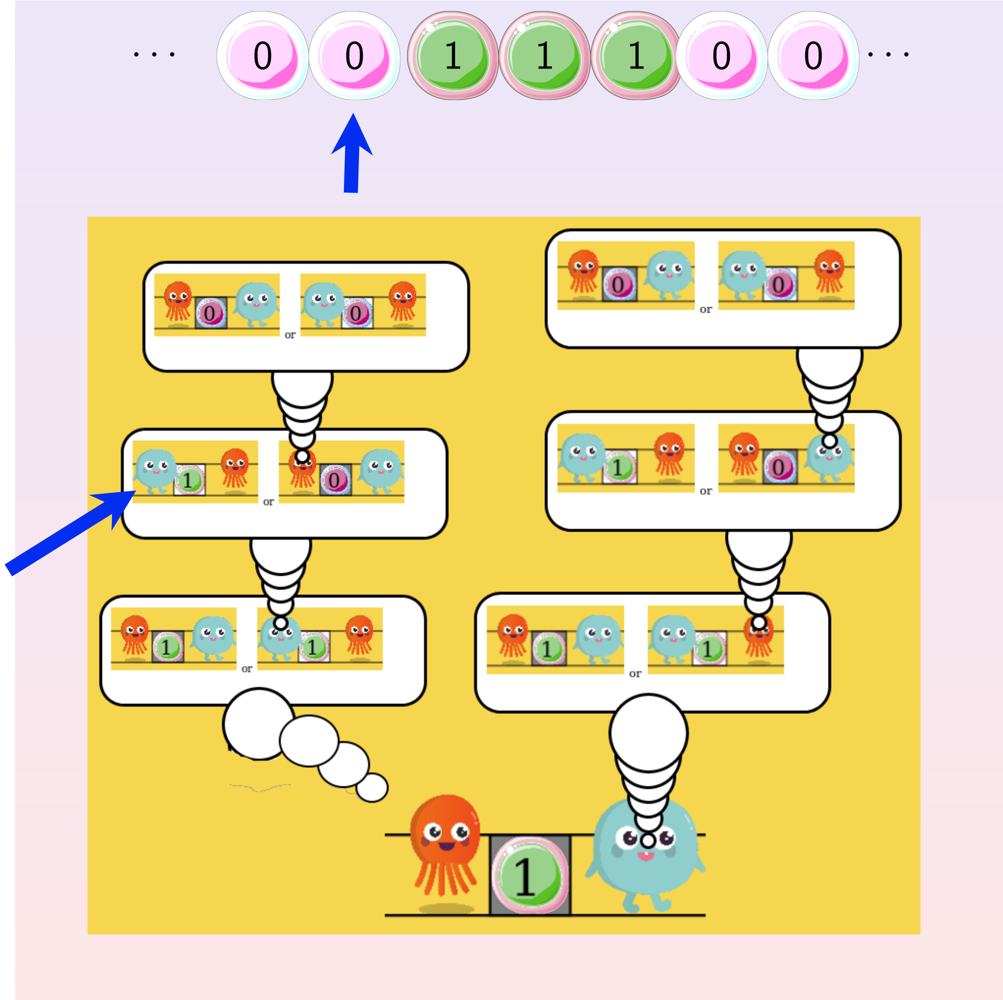


In Hintikka's World: Cellular automaton

Encoding automaton configuration in a state



Encoding automaton configuration in a state



In Hintikka's World: Cellular automaton

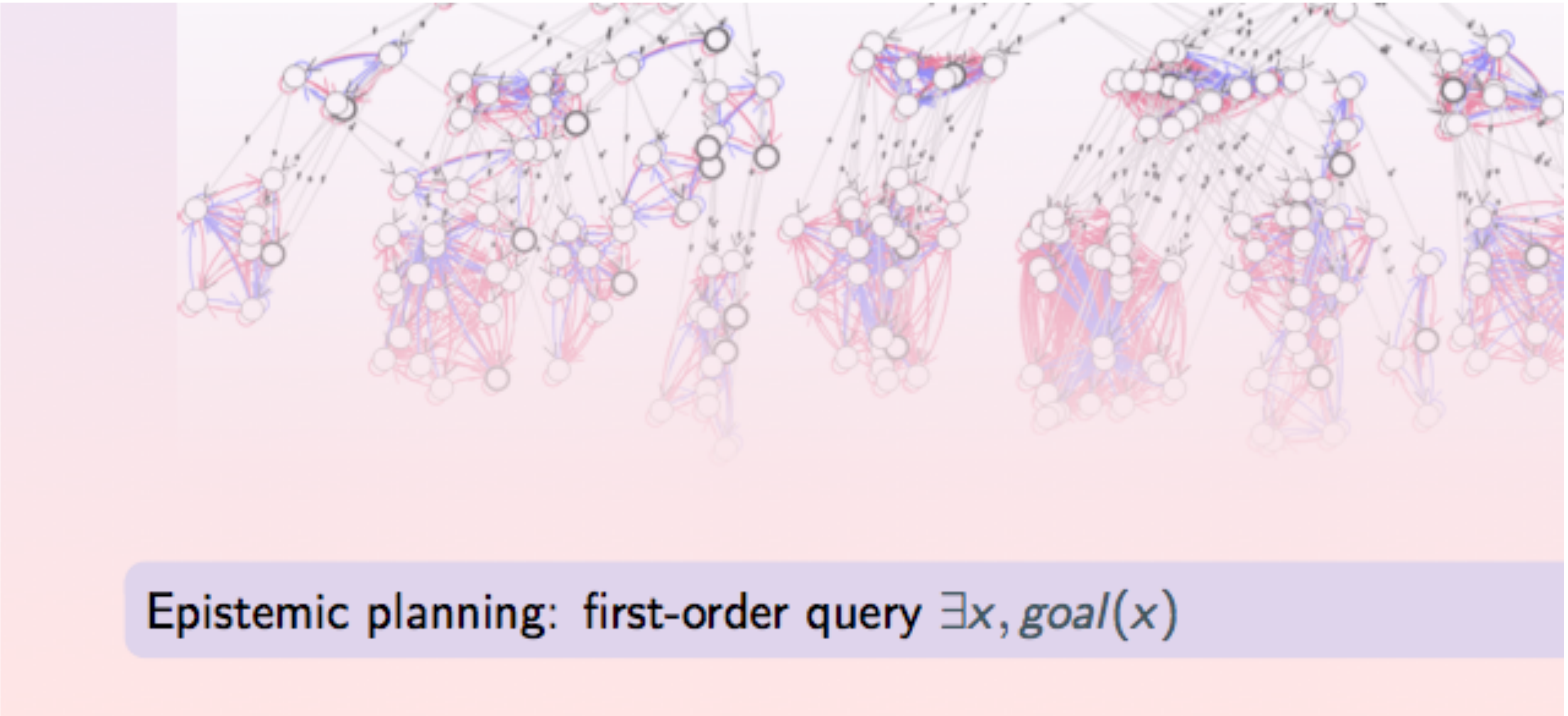
Wake-Up Question

1. Q: Which assumptions do we have to make such that the encoding of a cellular configuration is possible?
2. Q: Why is it OK to assume that in the precondition of the event model (which we did not specify) we can rely on formula of maximal depth 1?

Answers

1. Q: Which assumptions do we habe to make such that the encoding of a cellular configuration is possible?
   A: Fine support (otherwise we would get an infinite state).
2. Q: Why is it OK to assume that in the precondition of the event model (which we did not specify) we can rely on formula of maximal depth 1?
   A: Rules in a cellular automaton consider only one cell lefto the left and right of the current cell.

(Infinite) Epistemic temporal structures

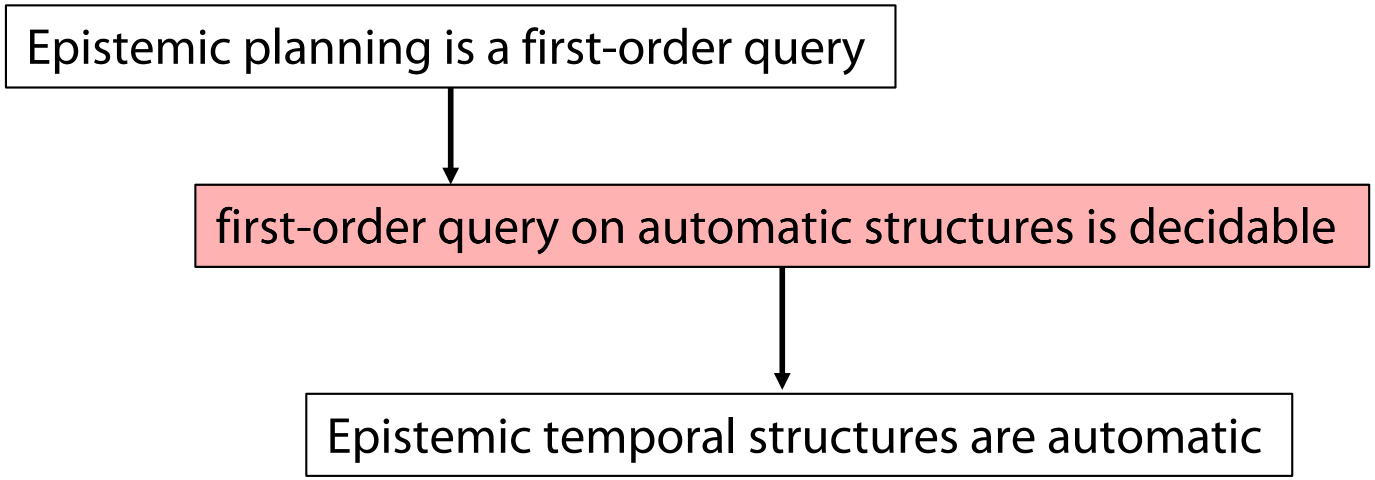


Epistemic planning: first-order query $\exists x.\, goal(x)$

Decidability when pre/post are Boolean

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

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



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

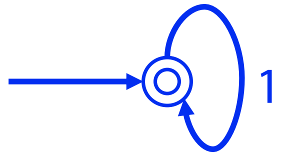
Automatic Structures: Motivation

- Many structures in computer science are infinite but with some easy structure
  - Temporal unravelling of state transition systems
  - Constraint Databases
- Want to handle algorithmic problems also on classes K of those infinite structures $A \in K$
- Minimal requirements
  - Every $A \in K$ should be representable in a finite way.
  - Effective semantics (for a logic L such as FOL): Given formula $\psi(\vec{x})$ of L and (a presentation of) a structure $A \in K$, one can effectively produce a presentation of the set $\{ \vec{a} \mid A \models \psi(\vec{a})\}$

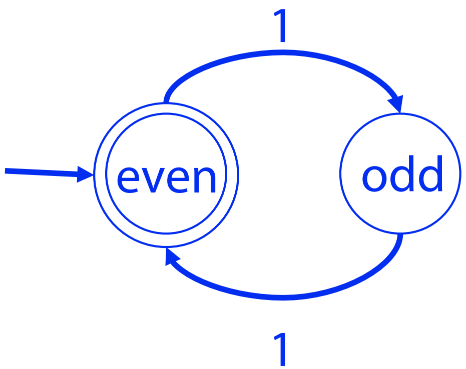
Automatic structure = defined by automaton

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

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



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

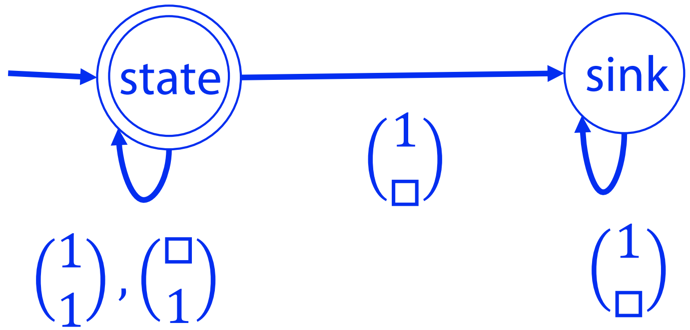


- $\mathcal{A}_{\leq}$

Automatic structure = defined by automaton

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

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



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)	Controller	Many players (Maubert et al 2019)
Public announcements	NP-c	PSPACE-c	PSPACE-c
Public actions	PSPACE-c	EXPTIME-c	EXPTIME-c
Boolean pre/post	Decidable	decidable	undecidable
all	Undecidable	undecidable	Undecidable (Peterson/Reif 79)

Types of planning

- Centralized player:
    - Agents by themselves do nothing than following the update of the environment;
    - plan, if it exists, is found by centralized planner
- Controller:
    - two players: controller and a perturbing environment;
    - action chosen in turn;
    - controller seeks strategy: history (of odd length)-> action;
    - uniformity NOT required (hence
- Multi-Player: Agents have to find strategies under imperfect information and uniformity condition (not knowing about others' strategies)

Perspectives: DEL and Formal Language Theory

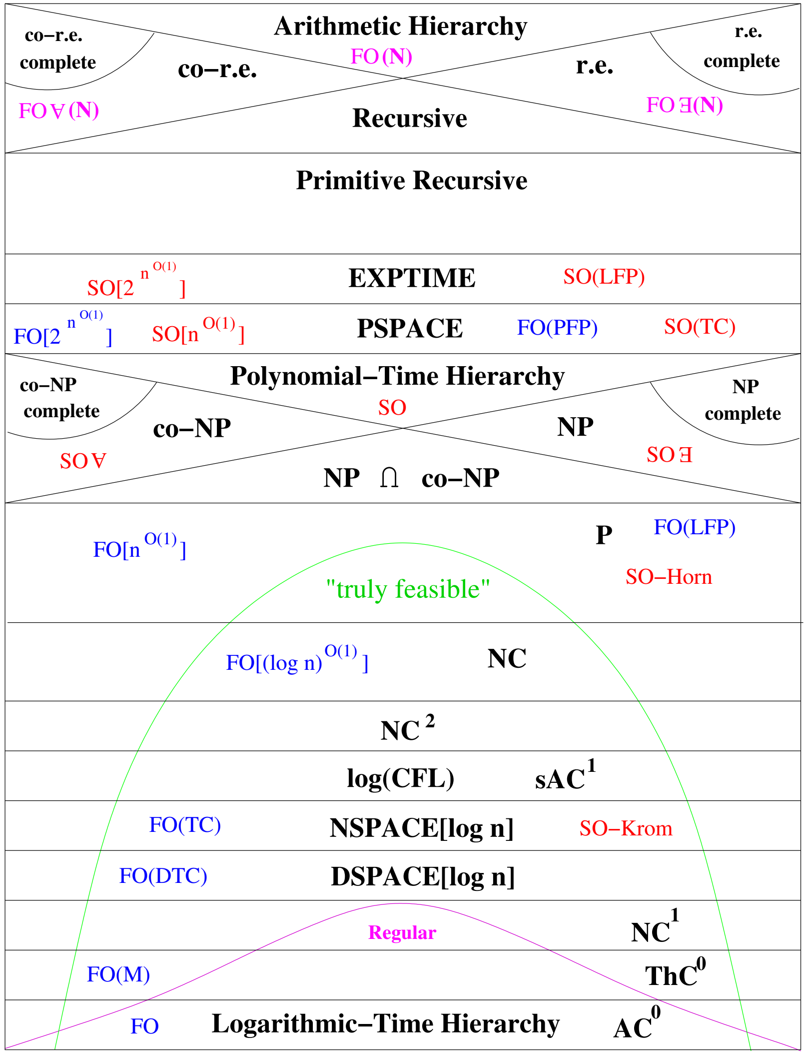
Question: Is epistemic planning one agent (pre: md 1, no post) decidable?

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

Descriptive Complexity



The Descriptive World

Uhhh, a lecture with a hopefully useful

APPENDIX

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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