A Hot Method for Synthesising Cool Controllers

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Outline

1. Motivation
2. Discrete Controller Synthesis
3. Generic Search Techniques
4. Search-based Symbolic Discrete Controller Synthesis
5. Experimental Evaluations
6. Conclusion

Motivation: Solving Symbolic DCS Problems by using General Search Techniques

Symbolic Discrete Controller Synthesis (DCS) Problem

Given:
- System Model S with means of control
- Desired Objective Behaviours ω

Compute:
- Control Strategy *s.t* S controlled accordingly fulfils ω

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General Search Techniques

- Explore the space of all Candidate Solutions by performing Local Changes to candidates selected by means of a measure of their Fitness

  e.g., Genetic Programming and Simulated Annealing

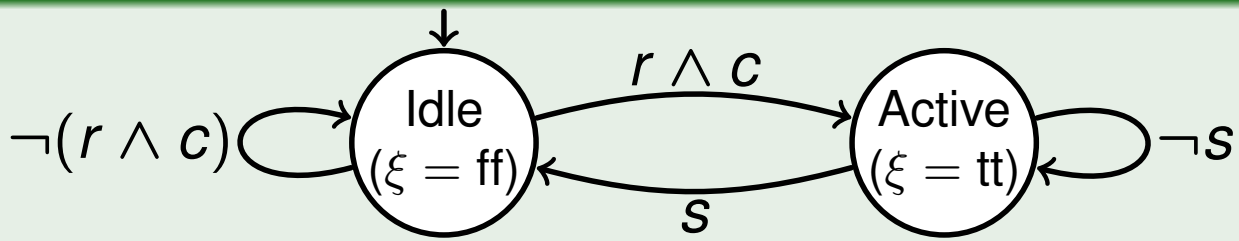
Related, Inspirational Works

- Genetic Programming already investigated for Program Synthesis [Clark and Jacob, 2001, Henderson et al., 2003, Johnson, 2007, Katz and Peled, 2008, 2009, 2011]
- Simulated Annealing performs better than Genetic Programming for Program Synthesis [Husien and Schewe, 2016]

⇝ What about for solving Symbolic DCS Problems?

DCS by Example: System, Objectives, & Strategies

Two-state Task



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- Controllable input variables: $\{c\}$
- State variables: $\{\xi\}$

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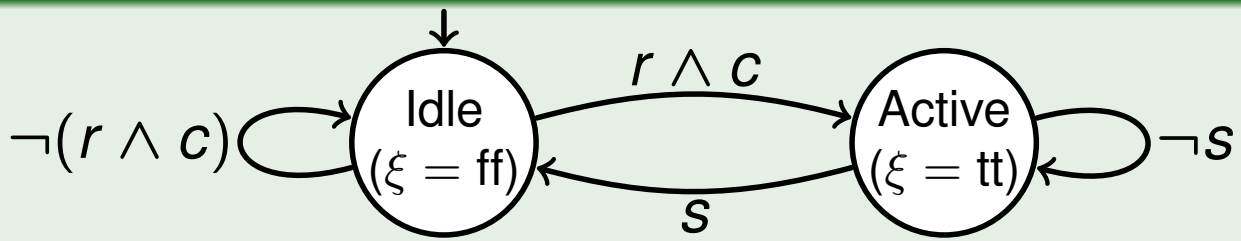

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- Never enter Active while s holds: $AG(s \Rightarrow AX\neg\xi)$

Symbolic Discrete Controller Synthesis Problem

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- Set of Objective CTL Formulae ω involving the variables of S

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Two Families of Symbolic Strategies

Non-deterministic Propositional Predicate involving variables of S

Deterministic Assignments to every Controllable input variable of S

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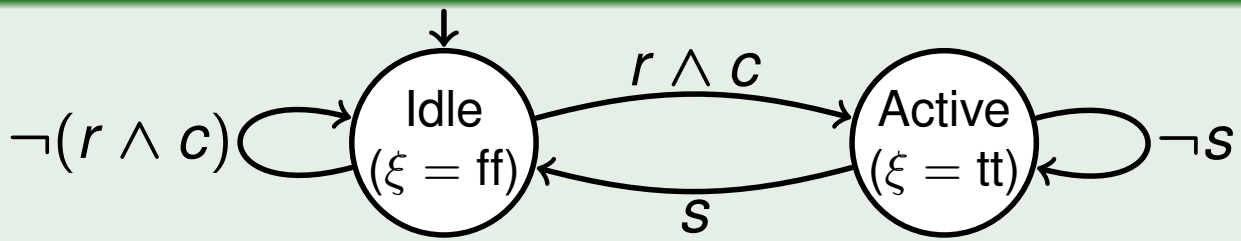

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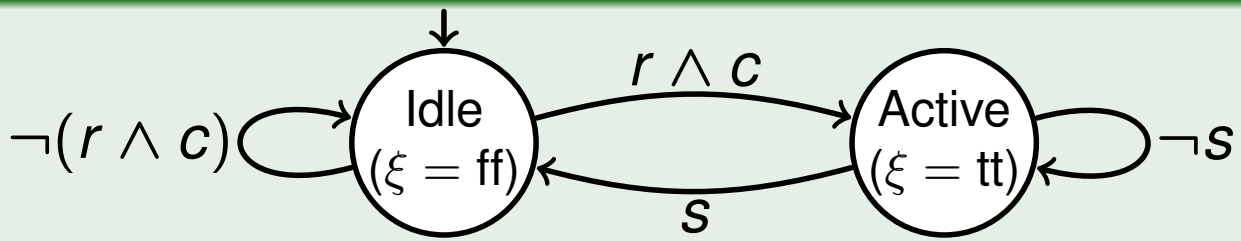

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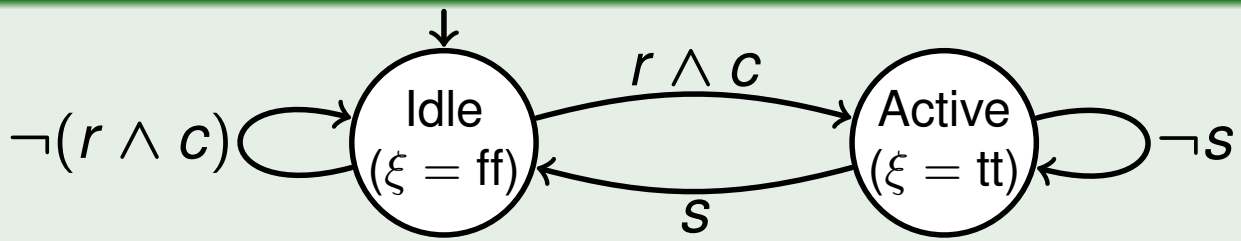

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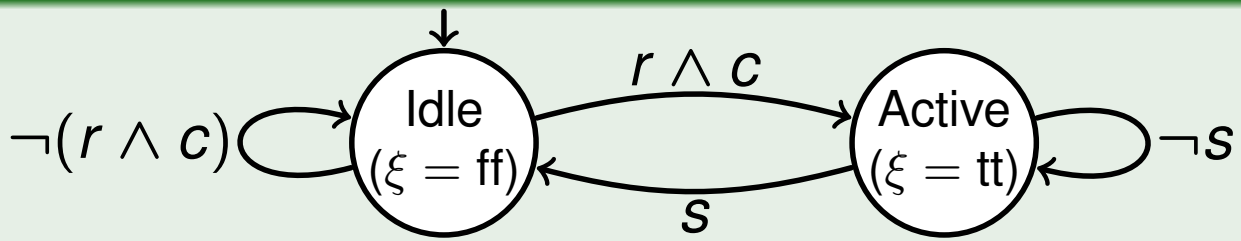

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Generic Search Techniques

Genetic Programming

- Maintain a Population P of λ Candidates
- Until a candidate solution is found in P:
  Select $\mu \ll \lambda$ candidates based on their Fitness;
  Generate new candidates by means of Mutations (and Crossovers)

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Simulated Annealing

- Temperature θ decreasing over time ("Cooling schedule")
- Unless the Candidate x is a solution:
  Mutate x to obtain x';
  Repeat with x' instead of x if $\mathrm{Fitness}(x') \geqslant \mathrm{Fitness}(x)$,
  or with a probability increasing with temperature (*i.e.,* decreasing with time) and decreasing with their fitness gap

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Search-based Symbolic Discrete Controller Synthesis

Issues

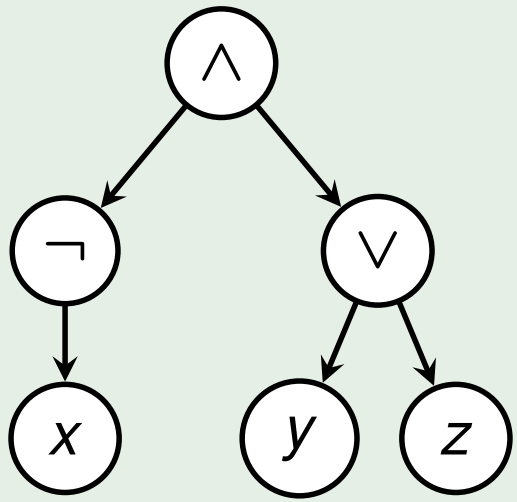
- How to Represent Candidate Strategies?
- How to Mutate Candidates?
- How to Measure the Fitness of a Candidate?
- How to Explore the Search Space Efficiently?

Representing Candidates

Trees built according to the Grammar of Propositional Predicates

- **Leaves** Labelled with either a variable, or a constant in (tt, ff);
- **Nodes** Labelled with $\neg$, $\vee$, or $\wedge$

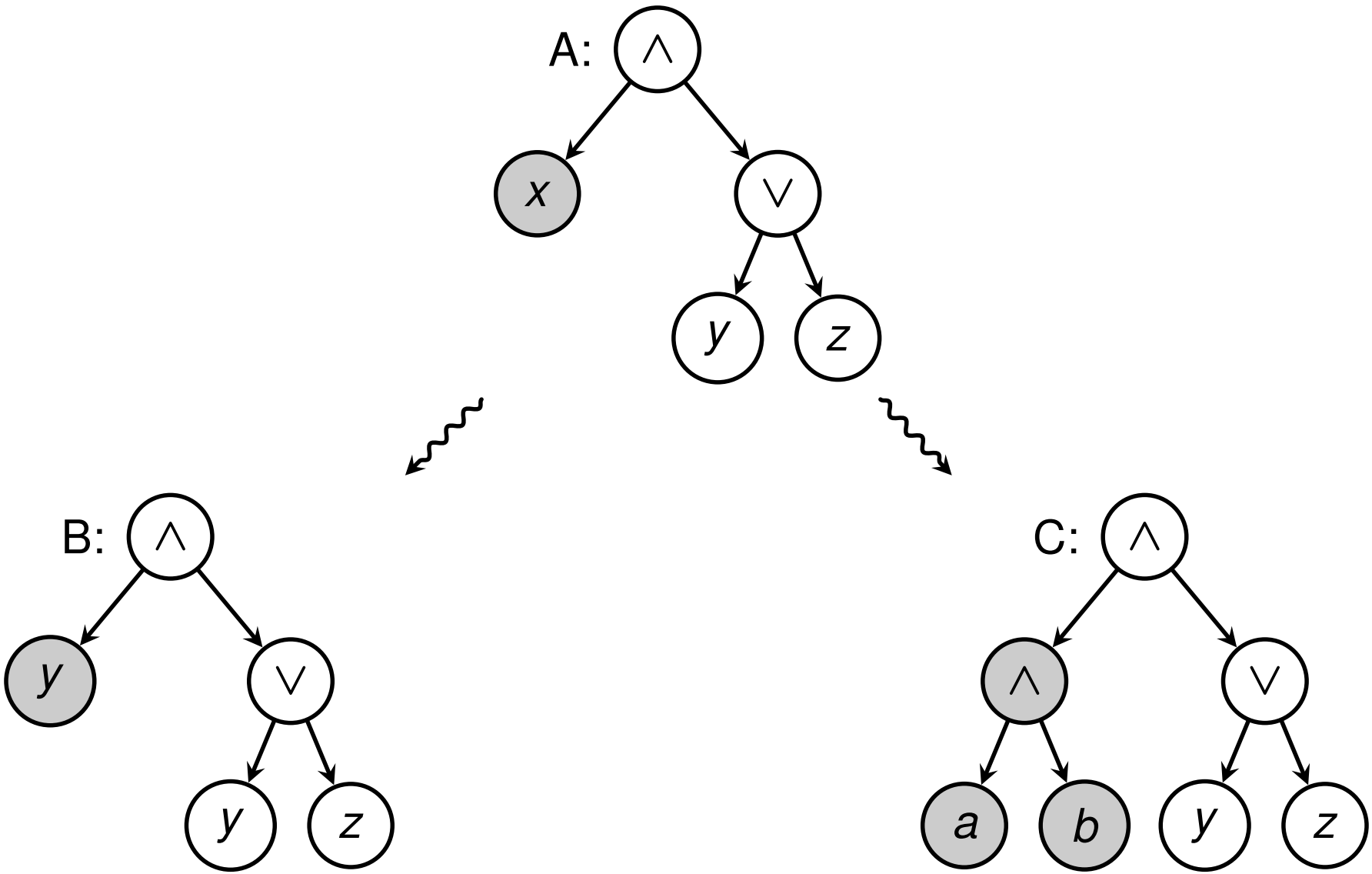
e.g., $\neg x \wedge (y \vee z)$



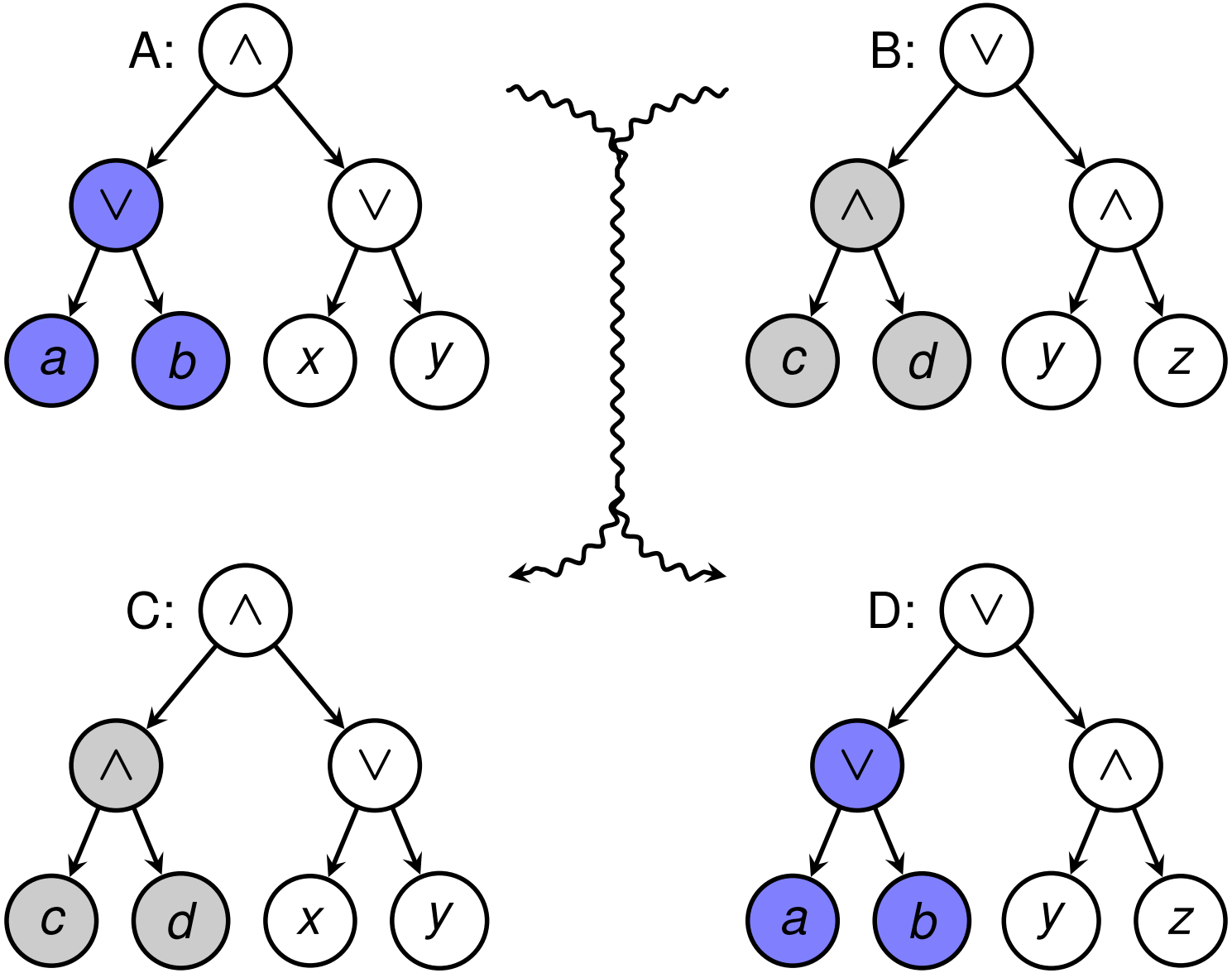
Contrary to Classical Symbolic DCS Algorithms, we directly seek Deterministic Strategies (*i.e.,* Assignments to controllable variables)

$\rightsquigarrow$ One candidate strategy $\equiv$ One tree per controllable variable

How to Make Changes? Example Mutations



How to Make Changes? Example Crossover



Model Checking as a Fitness Function

Deriving Partial Objectives from Target Objectives ω

- ω' Obtained by Substituting one Universal Path Quantifier occurring Positively of Objectives of ω, if any, by an Existential one: $A\psi \rightsquigarrow E\psi$
- ω" Ditto with Objectives of ω'

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Example Derived Partial Objective Formulae

Given $\omega = \{AG(s \Rightarrow AX\neg\xi)\}$:

$$\omega' = \{EG(s \Rightarrow AX\neg\xi), AG(s \Rightarrow EX\neg\xi)\}$$
$$\omega'' = \{EG(s \Rightarrow EX\neg\xi)\}$$

Model Checking as a Fitness Function (Cont'd)

Measuring the Fitness of a Candidate Strategy Γ

- Build System S' controlled according to Γ
- Model-check S' against objectives of ω, ω', and ω''
- Add m points per satisfied objective of ω
- Add m' ($< m$) points per satisfied objective of ω'
- Add m'' ($< m'$) points per satisfied objective of ω''

Six Search Algorithms for Solving DCS Problems

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Rigid SA Considers all objective properties to determine fitness

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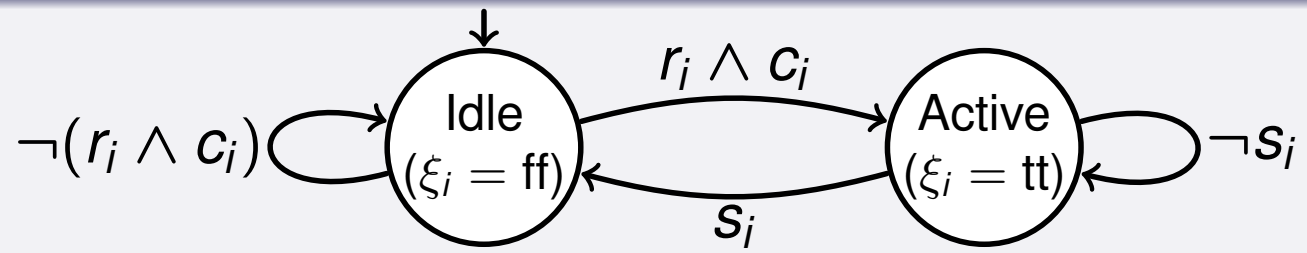
Genetic Programming

		Crossovers?	
		no	yes
Safety-first?	no	GP	GP w. CO
	yes	Safety-first GP	Safety-first GPw. CO

Scalable Benchmarks

N–Tasks



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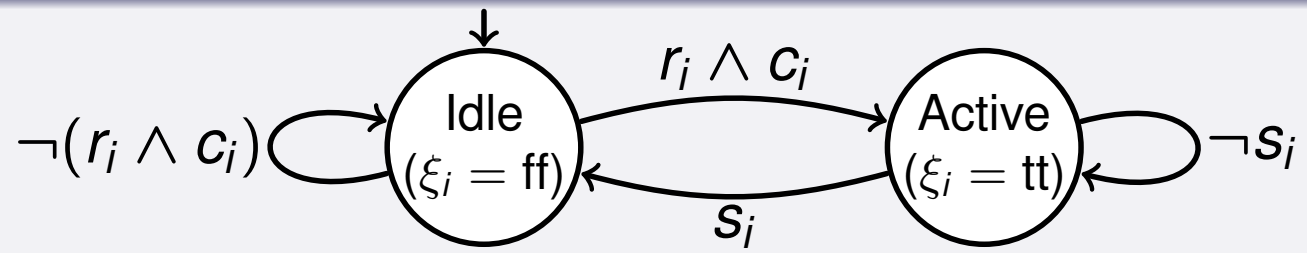

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Safety Objective: *Mutual Exclusion* between Active tasks

$$\left\{ AG\left(\bigwedge\nolimits_{(i,j)\in\{1,\ldots,N\}^2, i\neq j} \neg\left(\xi_i \wedge \xi_j\right)\right)\right\}$$

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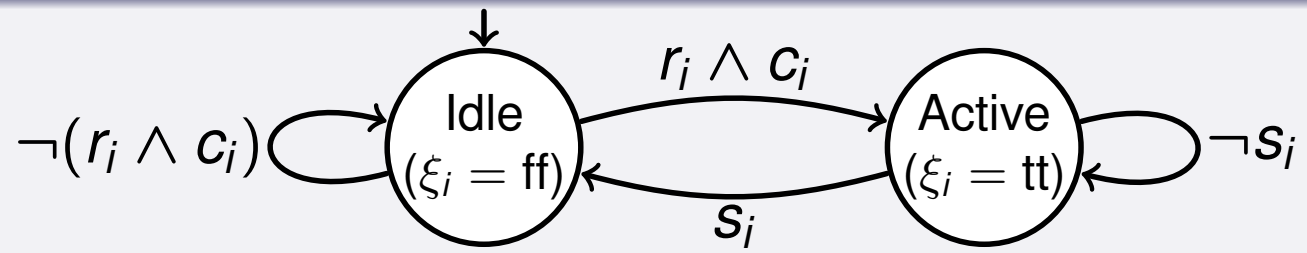

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Liveness Objectives: Every Idle task *Eventually* becomes Active

$$\bigcup\nolimits_{i\in\{1,\ldots,N\}} \{AG((\neg\xi_i \wedge r_i) \Rightarrow AF\xi_i)\}$$

Experimental Setup

Fitness Measure: Points

- $m = 100$ for satisfied Target Objectives (ω)
- $m' = 80$ and $m'' = 10$ for Satisfied Partial Objectives (ω' and ω'')

Parameters for Simulated Annealing

- Initial temperature of 20,000; Decreasing by 0.8 at each iteration

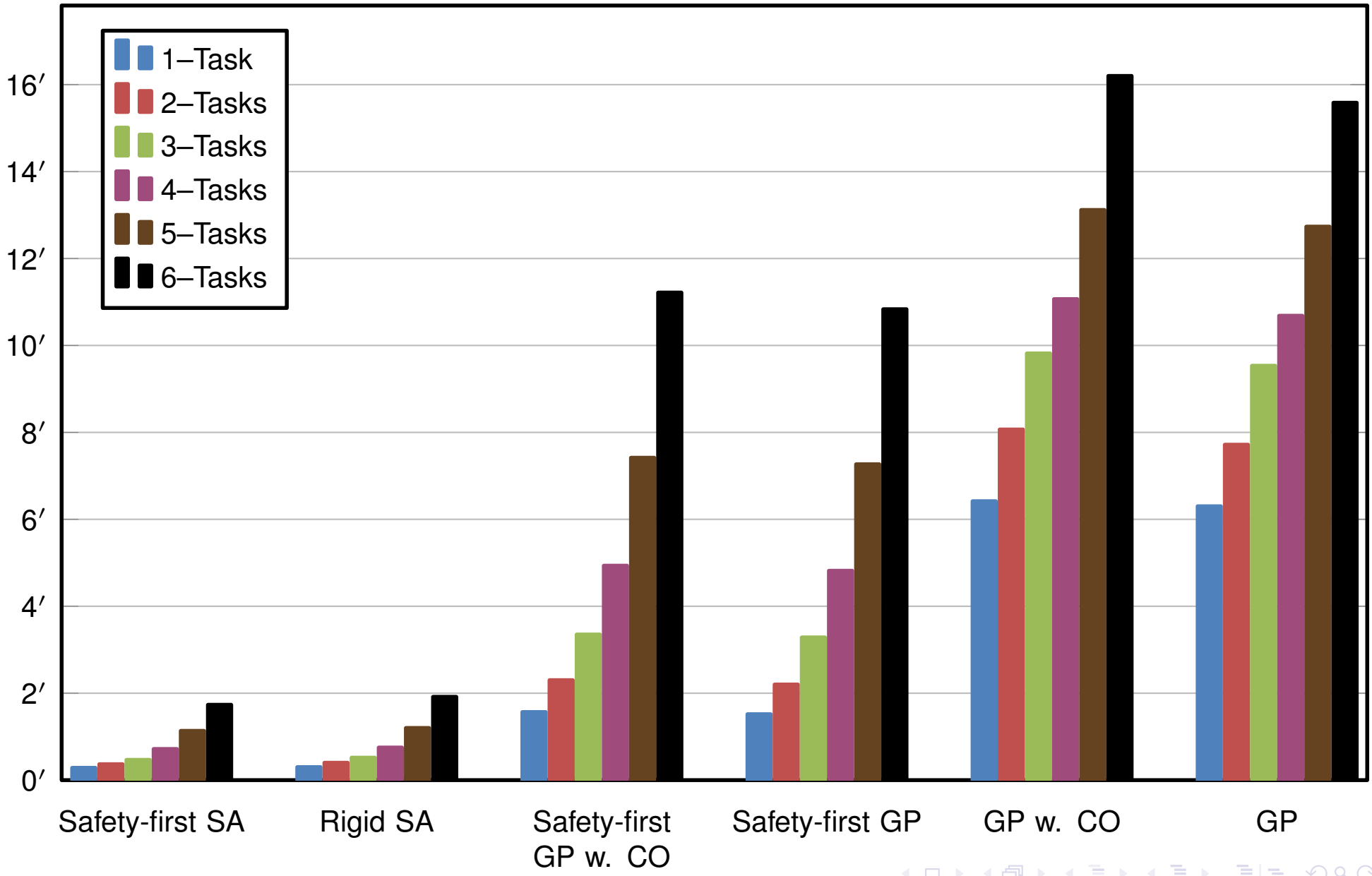
$\rightsquigarrow$ Search ends after 25,000 iterations

Parameters for Genetic Programming

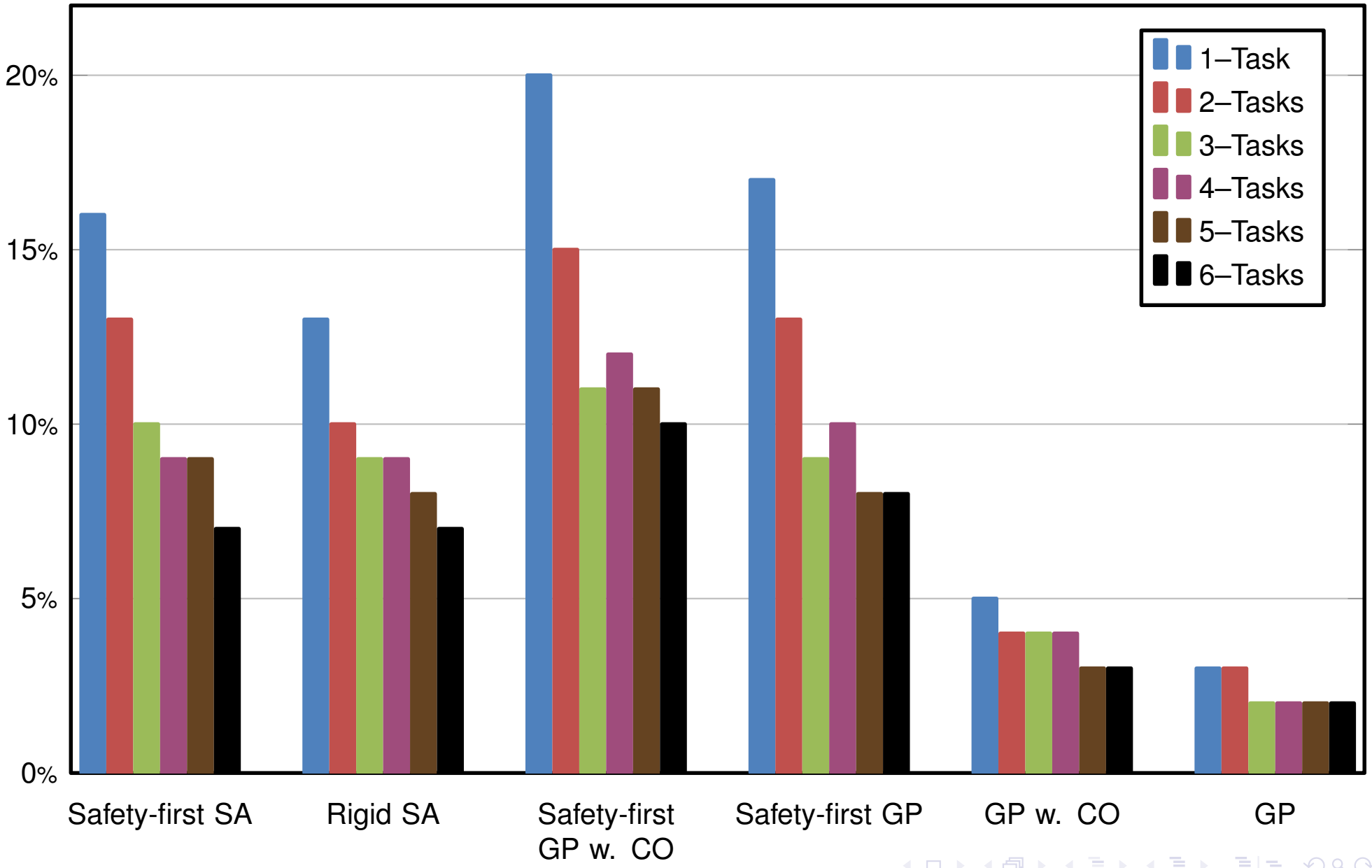
- Population of 150 candidates; Keep 5 at each iteration
- Abort after 2,000 iterations

- Using NuSMV Model-checker
- Running on Intel core i7 3.40 GHz CPU with 16GB RAM

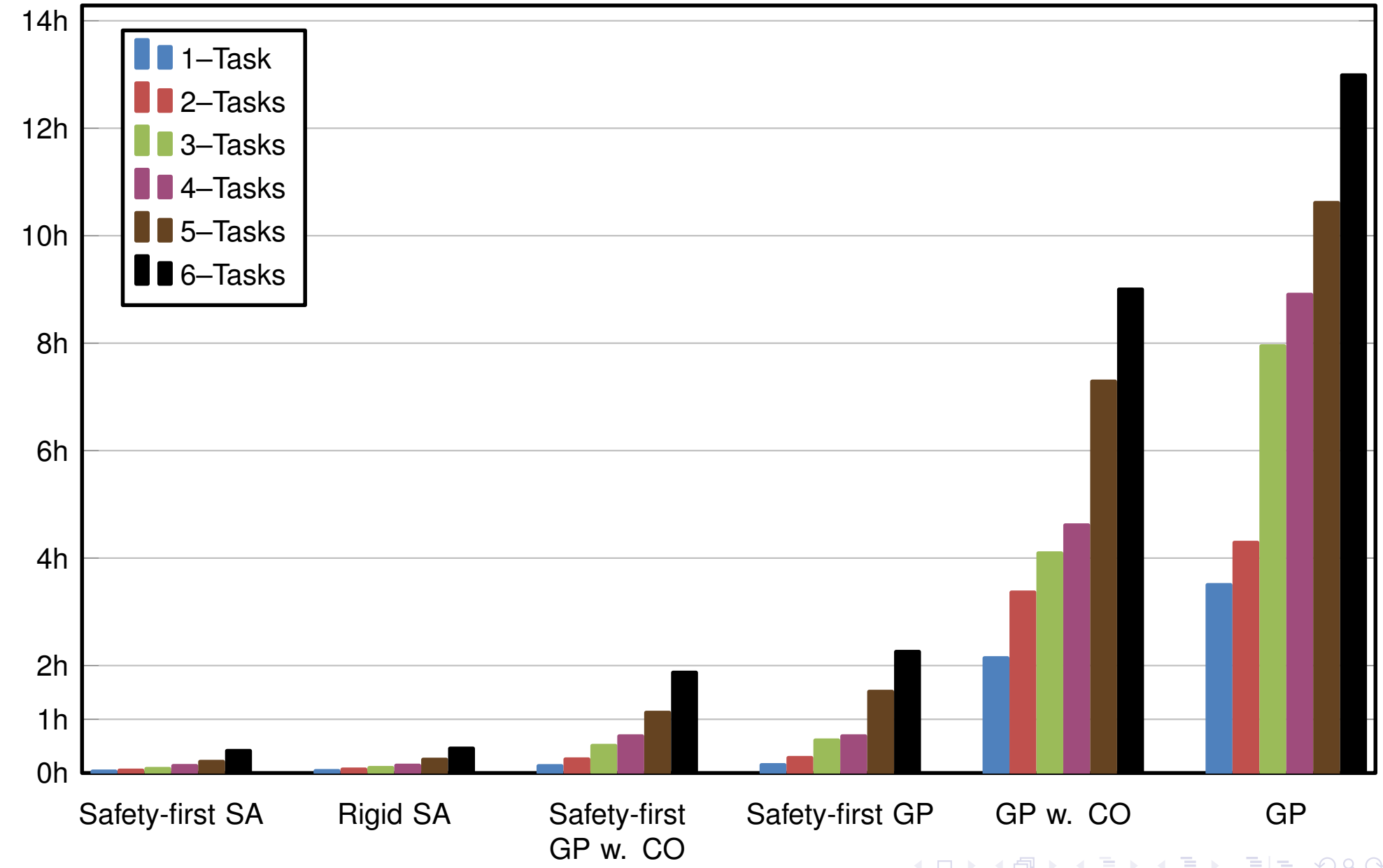
Experimental Results: Individual Execution Time



Experimental Results: Success Rate



Experimental Results: Overall Expected Runtime



Conclusion & Further Works

Summary

- Solving a Class of DCS Problems where Deterministic Strategies are sought with General Search Techniques
- Experimental Evaluation using a Scalable DCS Problem
- Relative Performances of the Algorithms match our previous results for Program Synthesis
- Runtime Performances of Classical Symbolic Techniques are several orders of magnitude better [Marchand et al., 2000, Berthier and Marchand, 2014]

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Trails for Improvements & Further Investigations

- Parameter tuning: Good cooling schedule? Population size?
- Integration in a Model-checker

Thanks!

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