Sweap: Reactive Synthesis for Infinite-State Integer Problems

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∞-state Synthesis: Sweap's Setting

Novel features are highlighted

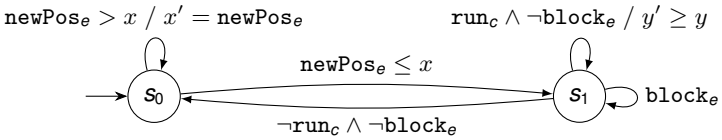
Arena: $A = \langle V, \mathbb{E}, \mathbb{C}, val_0, \delta \rangle$ Game: $\langle A, \varphi \rangle$

- V: state variables (integers)
- $\mathbb{E}$: inputs (Boolean or integers), $\mathbb{C}$: outputs (Boolean)
- val_0: initial valuation of state variables (optional)
- δ: transition relation (nondeterminism resolved by controller)
- $\varphi \in \mathrm{LTL}(\mathbb{E} \cup \mathbb{C} \cup \mathcal{P}r)$, $\mathcal{P}r =$ set of predicates over V
- E.g., $G\ ((x = 0) \Rightarrow F\ (x = 5))$

Realizability modulo arena

- Let environment $\mathcal{E}$ set the values of predicates.
- A trace is concretisable iff $\mathcal{E}$'s values for predicates agree with the valuation of V at every step.
- φ is realizable modulo A iff there is a strategy that preserves φ on every concretisable trace

Example: Infinite Race



$$V = \{x \overset{\text{init}}{=} 0, y \overset{\text{init}}{=} 0\}; \quad \mathbb{E} = \{\texttt{newPos}_e, \texttt{block}_e\}; \quad \mathbb{C} = \{\texttt{run}_c\}$$

Goal: $GF(s_1 \wedge \neg\texttt{block}) \implies GF(s_0 \wedge (y > x))$

Assumption

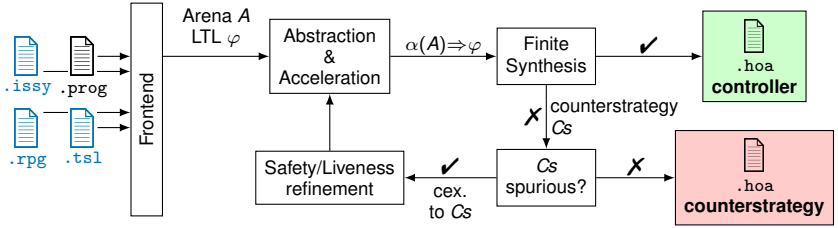
Environment cannot stay in s_0 forever, cannot block controller forever

Guarantee

Controller cannot stay in s_1 forever, must be ahead of the environment ∞ often

Sweap's CEGAR Approach

Novel features are highlighted

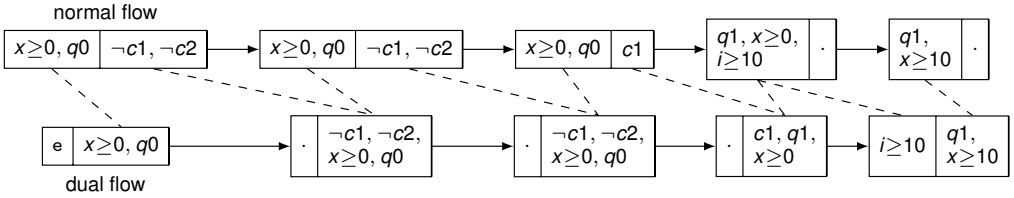


- Liveness refinement prunes unconcretisable infinite loops
- Acceleration: fairness assumptions on truth values of predicates
- Finite synthesis backends: Strix, SemML (new default)
- Main algorithmic contribution: dualization

Dualization

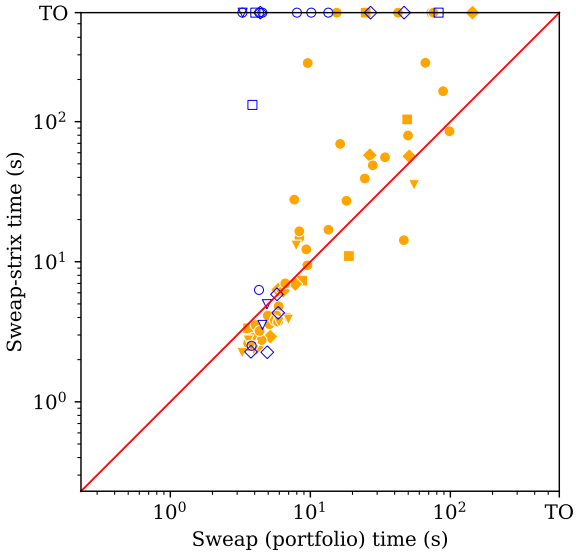
- Recall: we let $\mathcal{E}$ choose predicate values
- This approach does not terminate on some problems
- Specifically, those that do not admit finite counterstrategies

- Dualization flips control of the predicates to the controller
- However, this slightly breaks the order of play in the game
  $\Rightarrow$ We also turn φ into equirealisable φ^{dual}
  (add Xs, put additional constraints on $\mathcal{E}$)



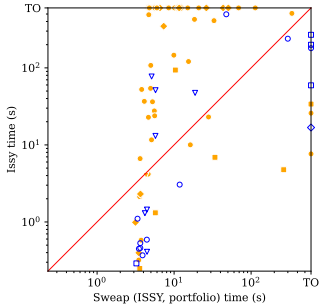
Evaluation of novel features

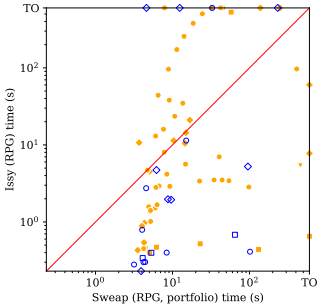
- `Sweap-strix`
  Uses Strix, no dualization
  (Roughly same as CAV'25 + bug fixes and optimisations)
- `Sweap (portfolio)`
  Uses SemML
  Best of normal + dual workflows
- 95 benchmarks (72 R, 23 U) in Sweap's native format
- 19 new verdicts (12 by dualization)
- Strix faster on smaller instances

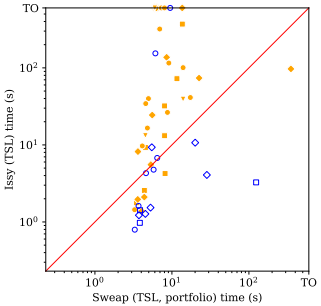


Evaluation vs Issy

Format	# Benchmarks	Tool	Realisable S	Realisable F	Realisable U	Unrealisable S	Unrealisable F	Unrealisable U
ISSY	115 (89 R, 26 U)	Issy	42	18	2	20	**14**	3
		Sweap	**70**	**53**	**40**	**21**	5	**4**
RPG	86 (66 R, 20 U)	Issy	52	**34**	2	16	**14**	0
		Sweap	**57**	25	**7**	**20**	6	**4**
TSL	65 (45 R, 20 U)	Issy	32	17	2	14	**10**	0
		Sweap	**38**	**21**	**8**	**17**	7	**3**







Conclusion

- CEGAR promising for ∞-state synthesis
- Dualization helps on unrealizable specifications
- Issy still (sometimes) faster, less memory hungry

Future work:

- Go beyond black-box finite synthesis
- Go beyond LIA
- Go beyond “monolithic” game arena

https://github.com/shaunazzopardi/sweap/

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