On the Extraordinary Effectiveness of Logic in Strategic Reasoning

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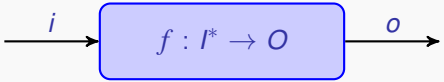
Vardi Fest
Haifa, Israel, July 31, 2022

SAPIENZA
UNIVERSITÀ DI ROMA

Process



Function f sends outputs according to the history of inputs.

Abadi, Lamport, Wolper - Realizable and Unrealizable Specifications of Reactive Systems. - ICALP'89

Finding processes via Synthesis

- Self-programming mechanism.
- Specifying a problem is usually simpler than solving it.
- Aim: correct-by-construction.

Specification Language

Linear-Time Temporal Logic

$$\varphi := p \mid \neg\varphi \mid \varphi \vee \varphi \mid \varphi \wedge \varphi \mid \mathtt{X}\varphi \mid \varphi \mathtt{U} \varphi \mid \mathtt{F}\varphi \mid \mathtt{G}\varphi$$

Pnueli - The Temporal Logic of Programs. - FOCS'77

LTL Synthesis

There exists a function f such that, for all possible stream of inputs g, the combined behaviour $\pi(f, g)$ satisfies the LTL specification φ. $(\exists f)(\forall g)\pi(f, g) \models \varphi$

Pnueli and Rosner - On the Synthesis of a Reactive Module. - POPL'89

Embedding strategic reasoning into logic

Alternating-Time Temporal Logic

$$\varphi := \langle\langle A \rangle\rangle \varphi \mid [\![A]\!] \varphi \mid \text{LTL}$$

Alur, Henzinger, Kupferman. - Alternating-Time Temporal Logic. - J.ACM 2002

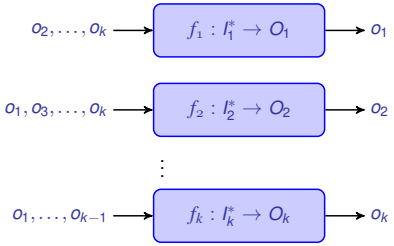
Expressing LTL synthesis

$$\langle\langle \text{controller} \rangle\rangle \psi_{\text{LTL}}$$

LTL Synthesis $\rightsquigarrow$ ATL* model-checking

Adding rationality to the environment

Multiple agents each with their own specifications and interacting in a shared framework.



Wooldridge, Gutierrez, Harrenstein, Marchioni, **P.**, Toumi - Rational Verification: From Model Checking to Equilibrium Checking. - AAAI'16

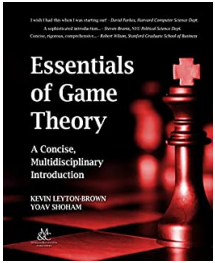
Kupferman, **P.**, Vardi - Synthesis with Rational Environments. - AMAI'16

EQUILIBRIUM CHECKING:
Check that a given configuration of strategies is in Equilibrium

EQUILIBRIUM EMPTINESS:
Find a configuration of strategies that are in Equilibrium

WEAK RATIONAL SYNTHESIS:
Find a system strategy and an equilibrium configuration satisfying a system specification

STRONG RATIONAL SYNTHESIS:
Find a system strategy that makes all equilibrium configurations satisfy the specification



Note: ATL* is not capable of representing (and solving) these problems.

Strategy Logic

$$\varphi ::= \text{LTL} \mid \langle\langle x \rangle\rangle \varphi \mid [\![x]\!] \varphi \mid (a, x)\varphi$$

- $\langle\langle x \rangle\rangle \varphi$: *"there exists a strategy x for which φ holds"*
- $[\![x]\!] \varphi$: *"for all strategies x, it holds that φ holds"*
- $(a, x)\varphi$: *"φ holds, when the agent a uses the strategy x"*

$$\varphi_{NASH} = \langle\langle x_1 \rangle\rangle \cdots \langle\langle x_n \rangle\rangle \bigwedge_{i=1}^{n} ([\![x_i]\!] \psi_i) \rightarrow \psi_i$$


Mogavero, Murano, **P.**, Vardi - Reasoning about Strategies: on the Model Checking Problem. - TOCL'14


P. - Logics for Multi-Agent Systems Verification. - PhD Thesis 2015

Impact

Research Community

- Widely used in Synthesis and Strategic Reasoning $\sim$ 400 citations (and counting!)
- Widely disseminated
  - Research Projects MSCA-IF, Royal Academy, JP Morgan
  - PhD courses and Summer/Winter Schools ESSLLI
  - Invited Talks and Meetings Dagsthul

Variations and extensions


Berthon, Maubert, Murano, Rubin, Vardi - Strategy Logic with Imperfect Information. - TOCL'21


Aminof, Kwiatkowska, Maubert, Murano, Rubin - Probabilistic Strategy Logic. - IJCAI'19


Bouyer, Kupferman, Markey, Maubert, Murano, **P.** - Reasoning about Quality and Fuzziness of Strategic Behaviours. - IJCAI'19

A nice memory

Interior night: lecturers and students are hanging out in the hall after a day of classes

Moshe[approaching Giuseppe]: Have you already planned to visit some research center abroad for your PhD?
Giuseppe[visibly speechless]: Erm, no?
M.: Then you should come visit me!

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Interior day: 31st March 2014, Duncan Hall (Rice University)

Moshe: You came as a boy. You leave as a man!