Synthesis of asynchronous reactive programs from temporal specifications

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Hotel reservation

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Designing asynchronous systems is hard

Partial/Outdated information

Unpredictable delays

Specifying intent of a program is easier

Can we automatically generate an asynchronous program from its specification?

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Asynchronous synthesis

Can we automatically generate an asynchronous program from its specification written in LTL?

Asynchronous LTL synthesis

2EXPTIME-complete [Pnueli, Rosner; ICALP 1989]

But no tools!

Contributions

Towards building tools/techniques for asynchronous LTL synthesis

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Simpler theoretical analysis

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First tool for asynchronous synthesis for all of LTL

Existing tools restricted to specific LTL formula [Klein, Piterman, Pnueli; VMCAI 2012]

Direct translation to SAT causes blowup [Schewe, Finkbeiner; STTT 2013]

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Identify LTL subclasses with lower complexity

Asynchronous systems

[Pnueli, Rosner; ICALP 1989]

Asynchronous system (denoted by f)

- Reactive system
- Receives input sequence **I**, observes a sub-sequence **X** only
- Generates output sequence **O** based on **X** only
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Output (O)	-								

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Asynchronous LTL synthesis

[Pnueli, Rosner; ICALP 1989]

Given LTL specification **S,**

Generate asynch. system f s.t.

(I,O) satisfies **S** for all **I** and **X**

Challenge I: Partial information

Asych. system satisfies specification despite not reading all inputs

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Example: Always (i → Eventually o)

✗ f returns the last observed value

Input (I)	T	T	F	T	F	F	T	…
Output (O)	-	-	-	F	F	F	F	…

Challenge I: Partial information

Asych. system satisfies specification despite not reading all inputs

Example: Always (i → Eventually o)

✗ f returns the last observed value

✓ f always returns True

Input (I)	T	T	F	T	F	F	T	…
Output (O)	-	-	-	T	T	T	T	…

Challenge II: Non-deterministic delays

Between observing input and generating output

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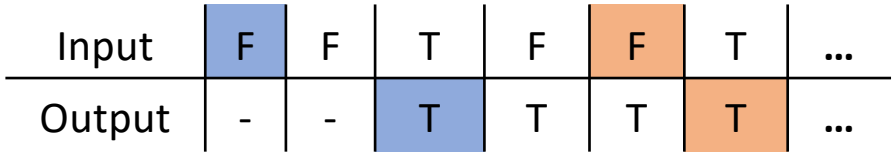

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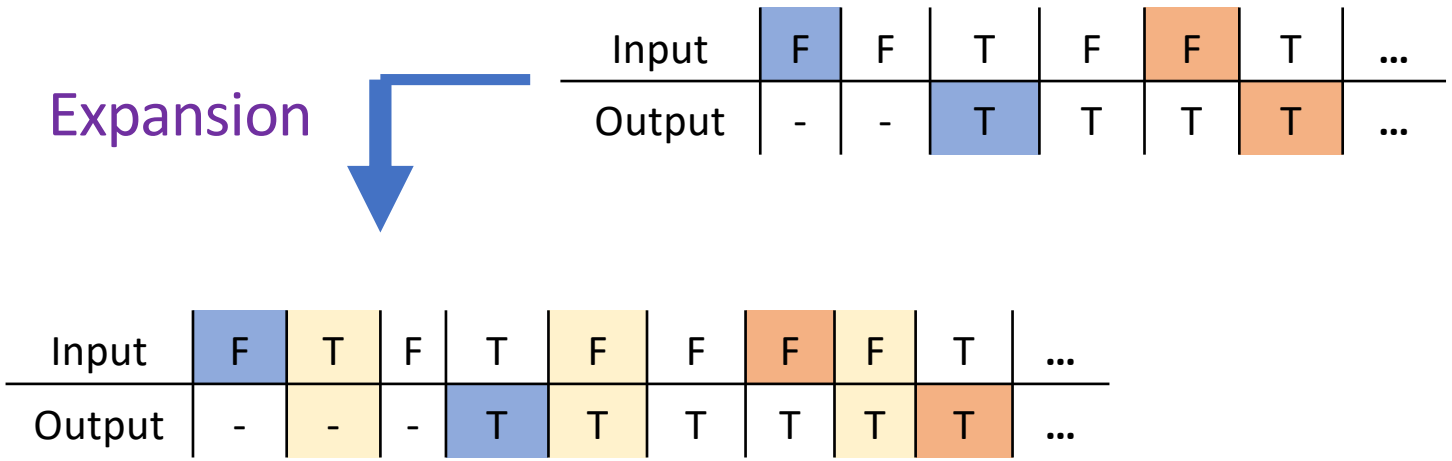

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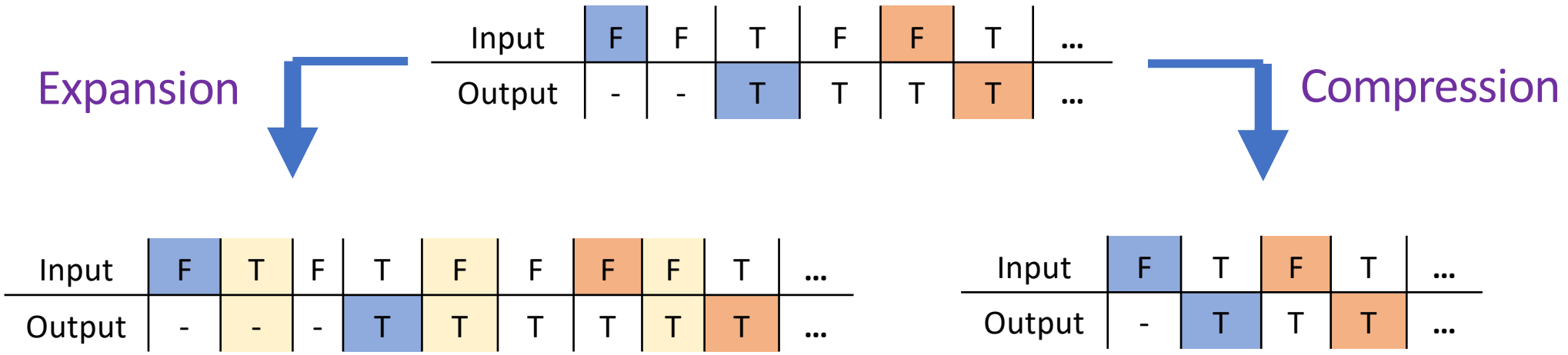

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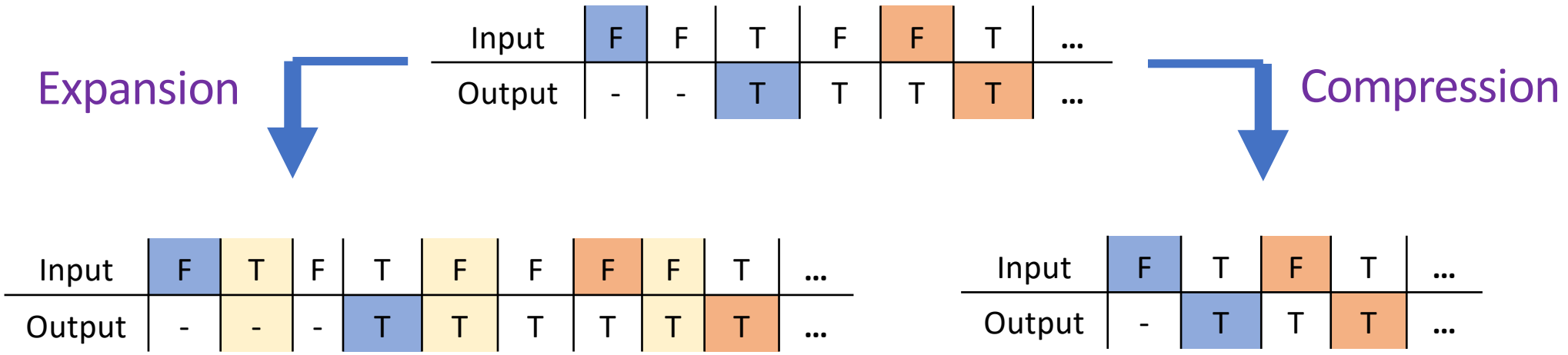

(I,O) satisfies **S** iff all expansions and compressions of (I,O) satisfy **S**

Previous work [Pnueli, Rosner; ICALP 1989]

A trace satisfies **TS** iff all expansion and compression of the trace satisfy **S**

Asynch. synthesis of **S** $\equiv$ Synch. synthesis of transformed specification **TS**

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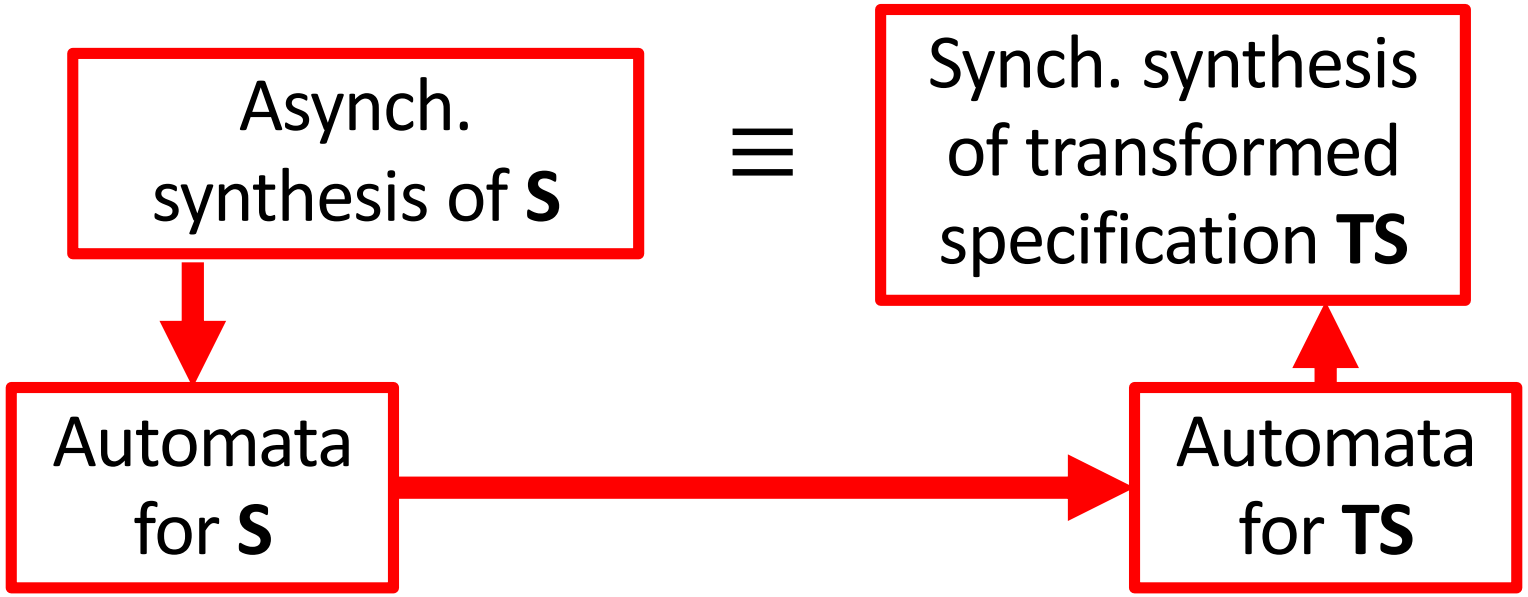

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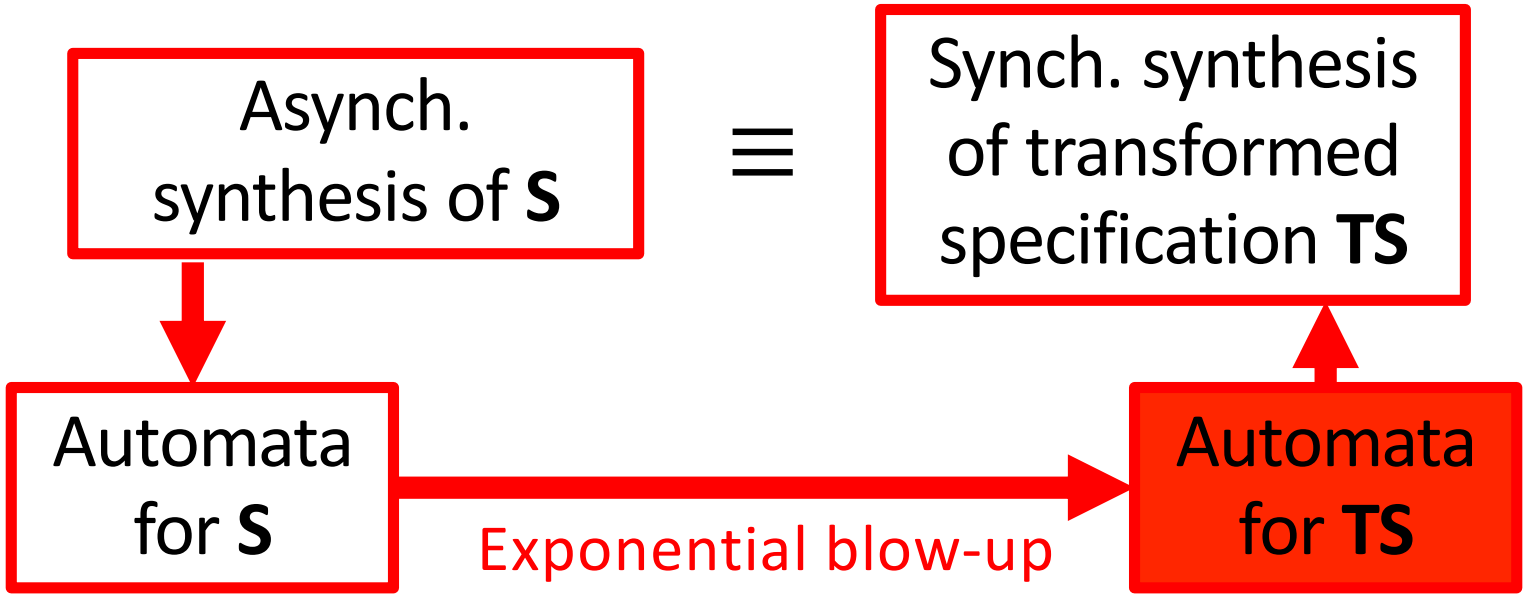
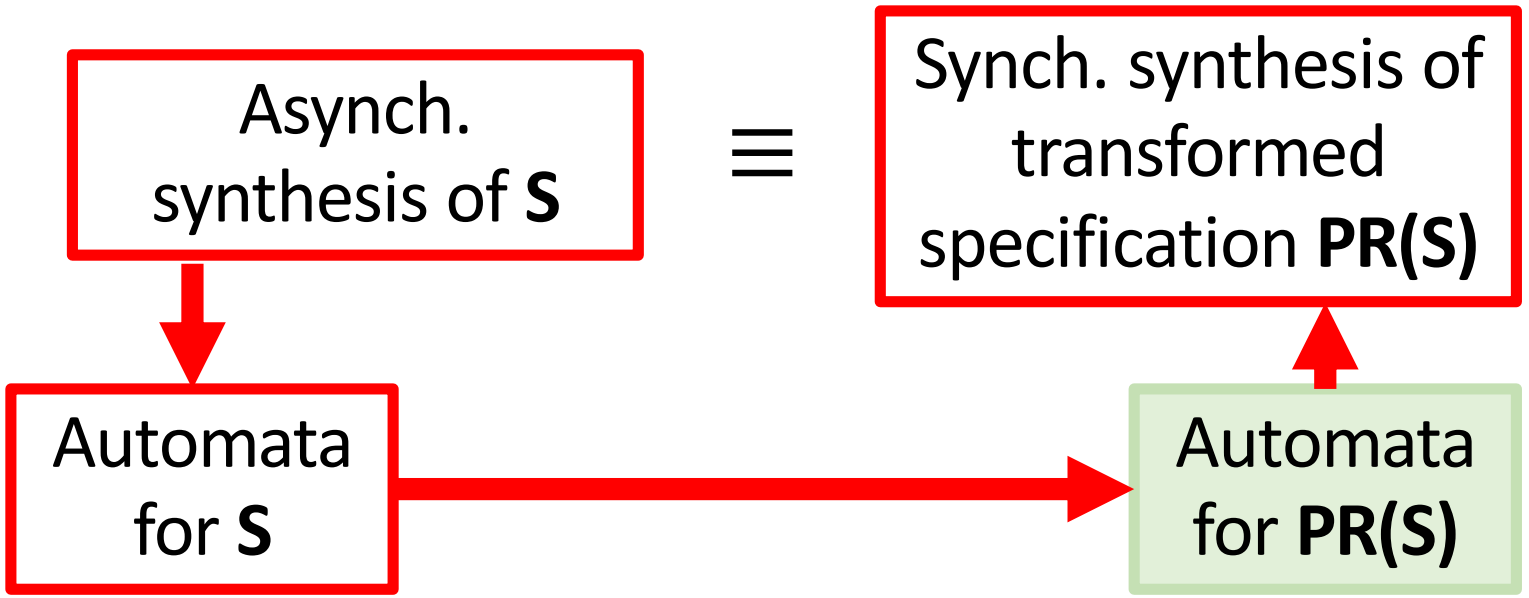


Caused by compression

Our reduction: Pnueli-Rosner (PR) closure

A trace satisfies **PR(S)** iff all expansions ~~and compressions~~ of the trace satisfy **S**



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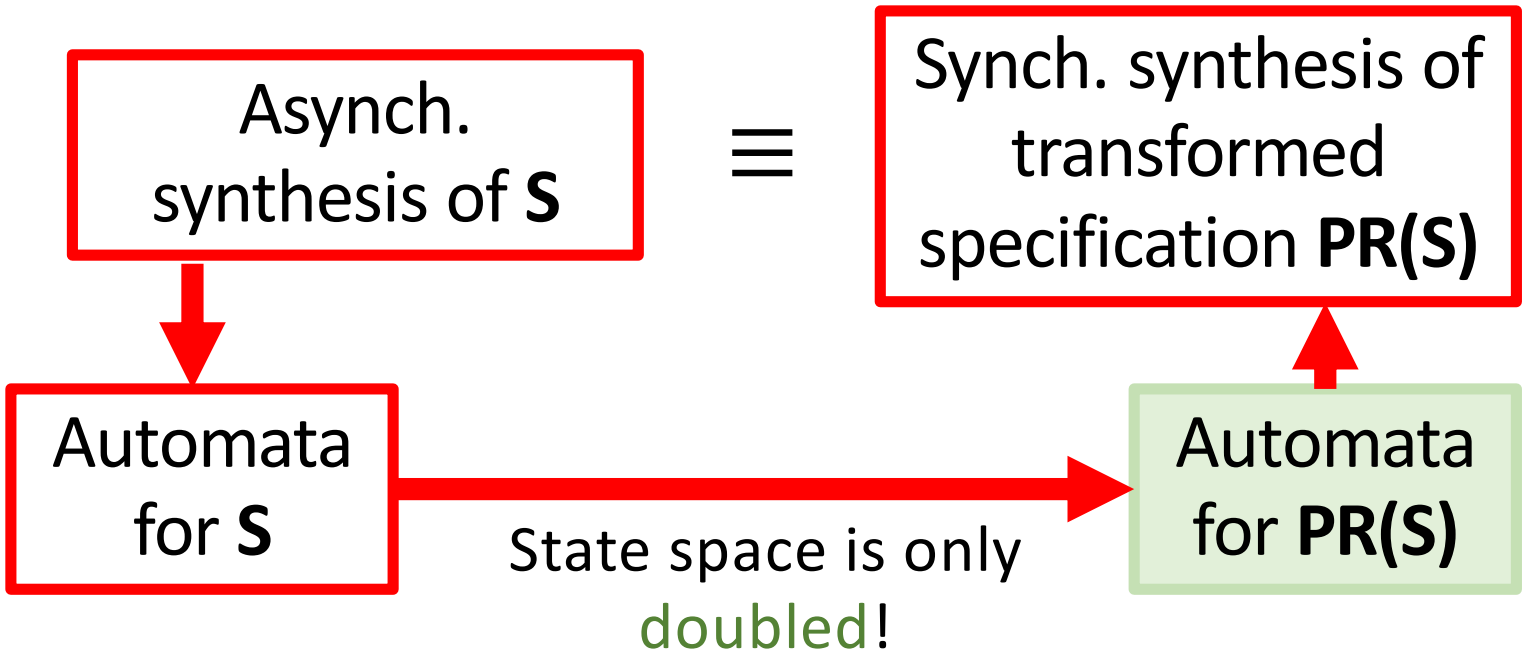

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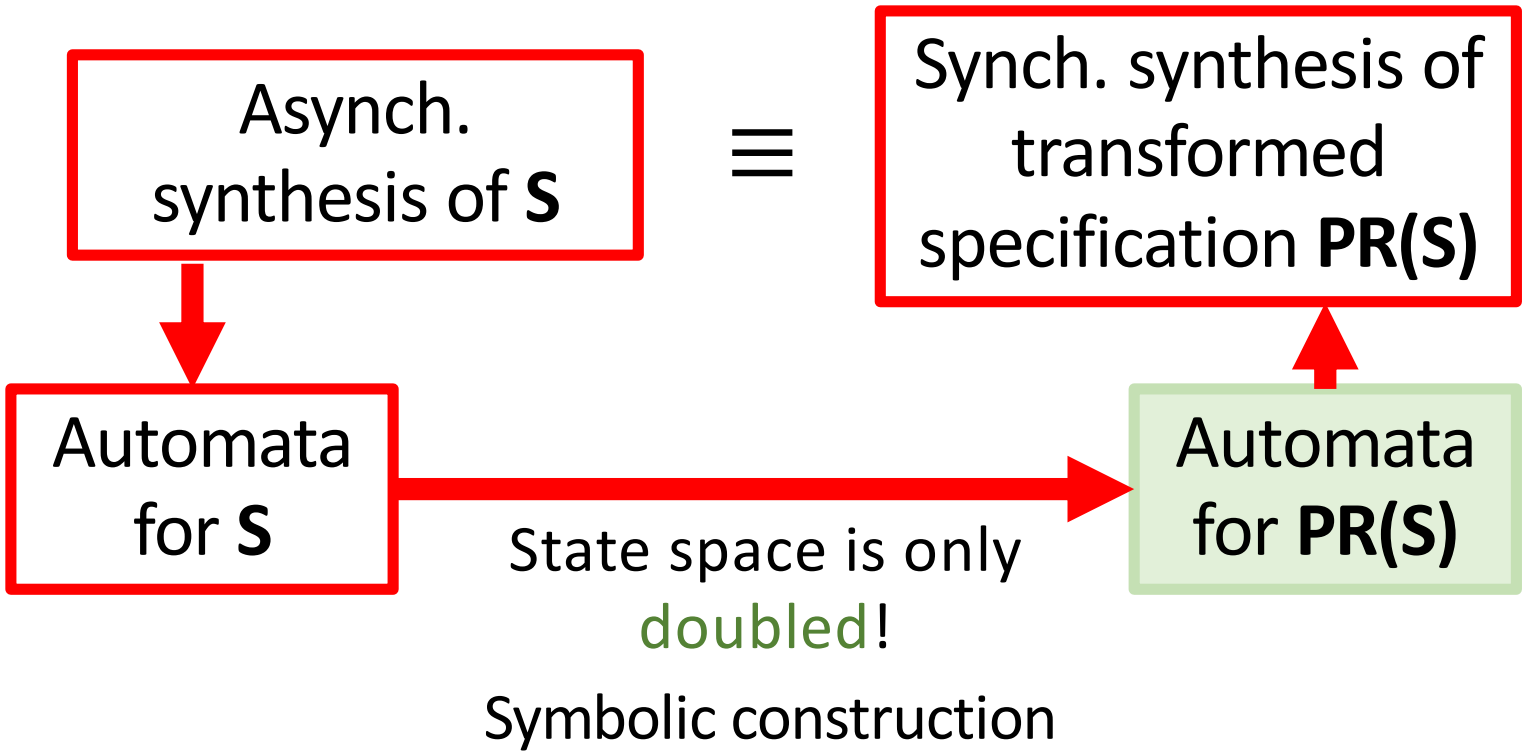

Implementation and Experiments

- Prototype tool BAS (**B**ounded **A**synchronous **S**ynthesis)
  - BDD-based symbolic construction of **PR(S)** from **S**
  - Bounded synch. synthesis tool
    - BoSy [Faymonville, Finkbeiner, Tentrup; CAV 2017]
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- Evaluate performance on ~15 formulae
  - Number of propositions in range of 2-16
  - Length of LTL-specification ranges from 5-80
  - Almost all formulae solved in less than 2 second
  - PR(φ) construction takes ~2% of total time

Asynchronous LTL synthesis, in a nutshell

- Efficient reduction of asynch. LTL synthesis to synch. synthesis
  - Modified spec. PR closure is *exponentially smaller* than previous reduction
  - Prototype implementation BAS

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- Low-complexity subclasses of GR(1) spec.
  - Reduction to single-alternation QBF satisfiability
  - Much lower complexity than the general 2EXPTIME