Improving Translation of Live Sequence Charts to Temporal Logic

Rahul Kumar Eric Mercer Annette Bunker

AVOCS 2007

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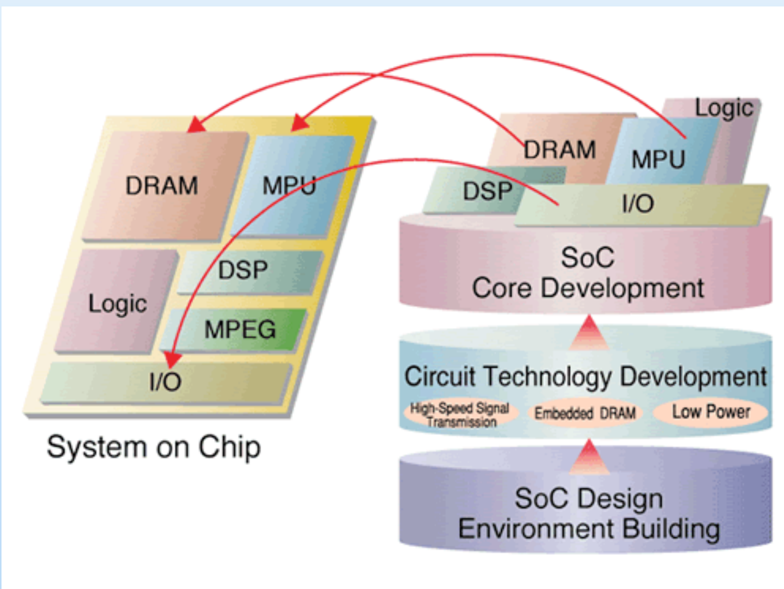
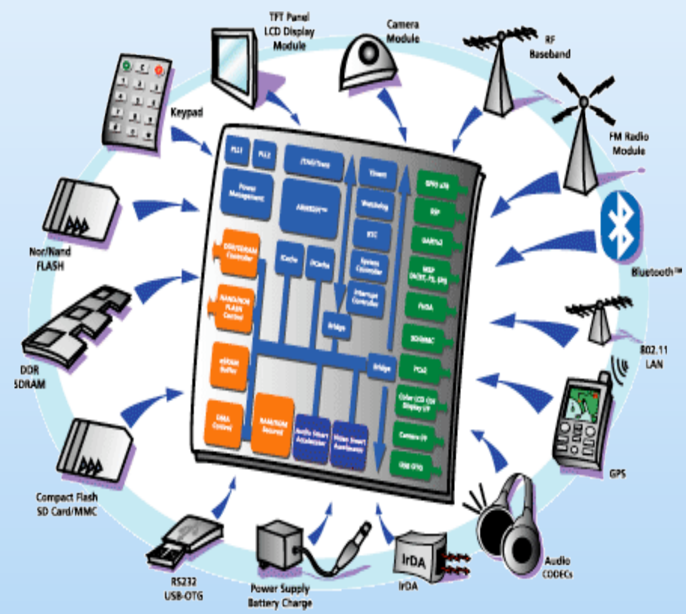
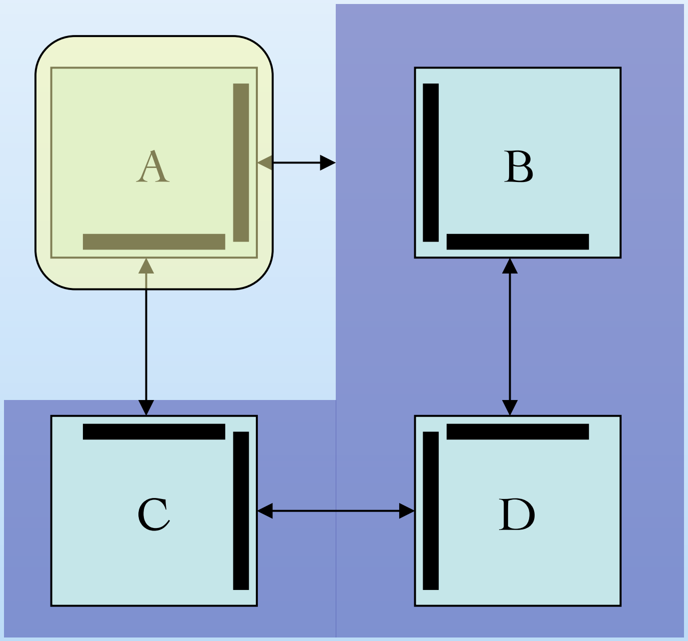
Trends: SoC, Multi-agent Systems





Traditional Testing



Abstracted Environment

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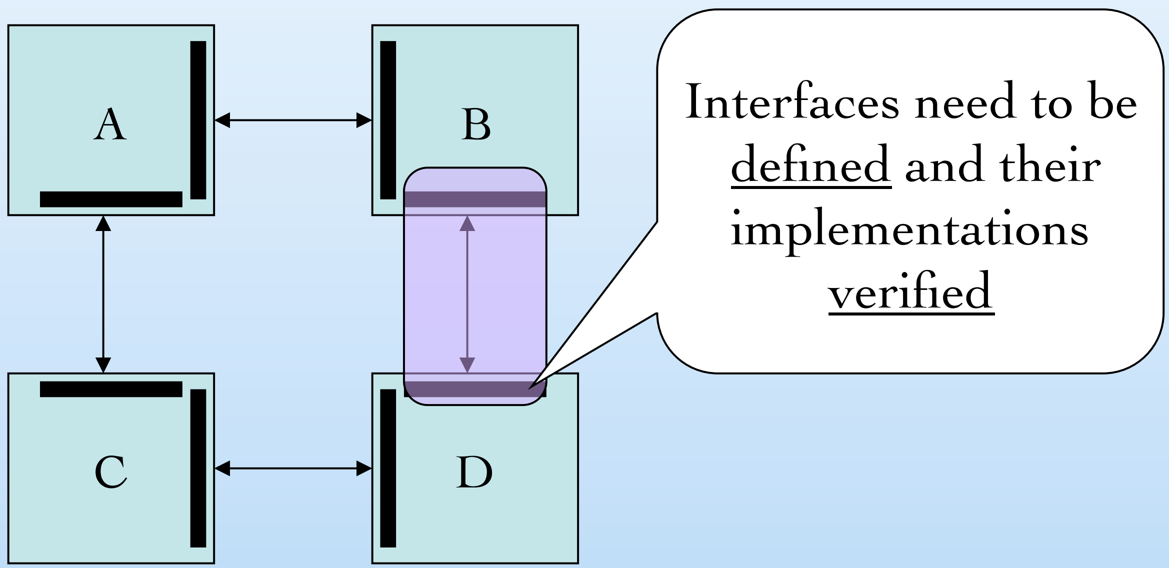
What do IP Core vendors and consumers need?



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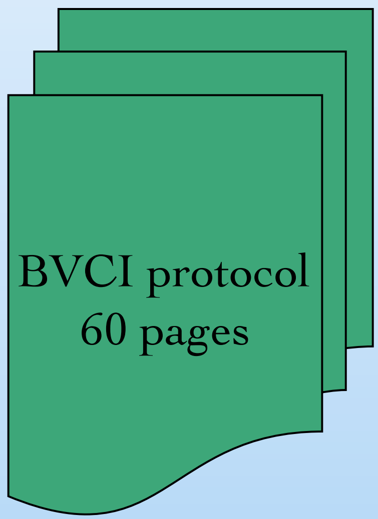
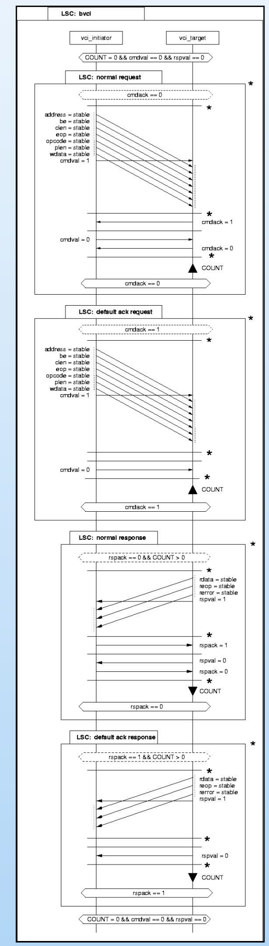
Scenario Based Specifications

- R.Z. ITU-T 120: Message Sequence Charts
- Damm *et. al.*: Live Sequence Charts
- Bunker *et. al.*: Protocol Live Sequence Charts





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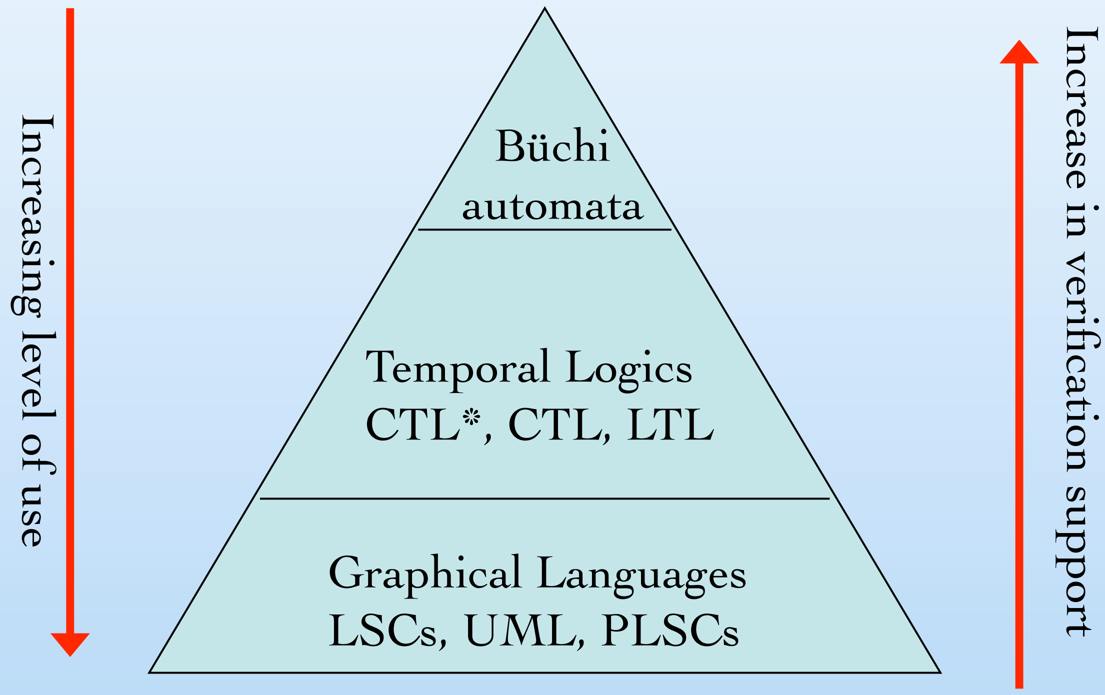
What do we have so far?



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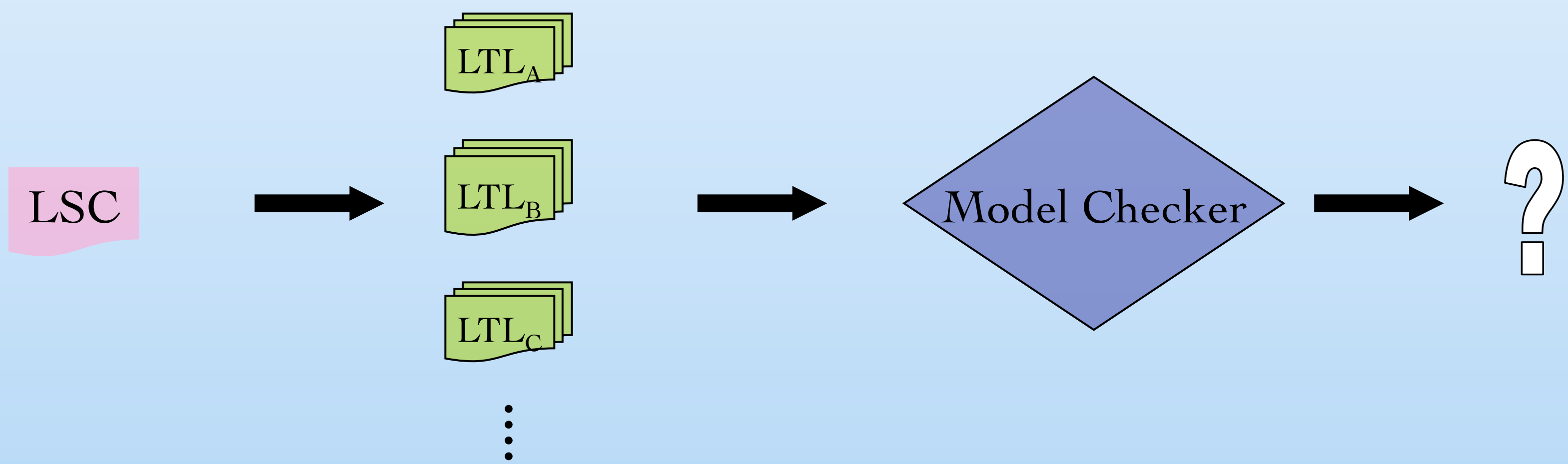
Verification Using Scenarios

Theoretically correct
Difficult to use

Easy to use
Formally incomplete

Bunker *et. al.*
2002



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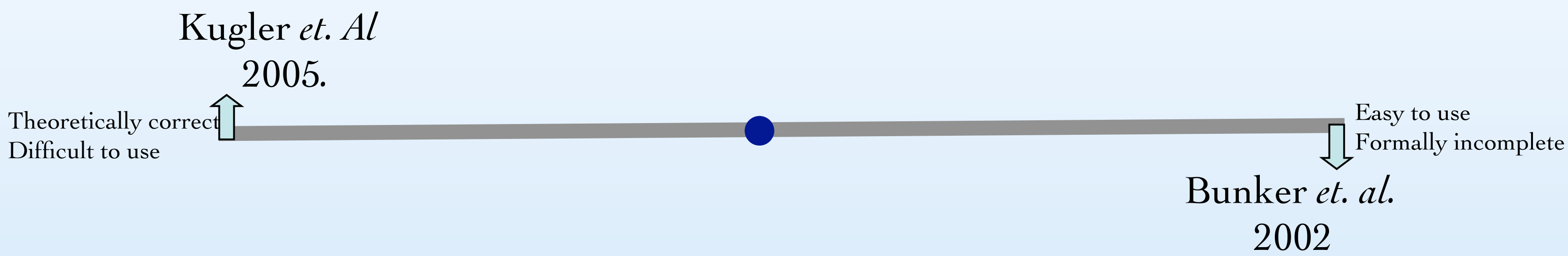
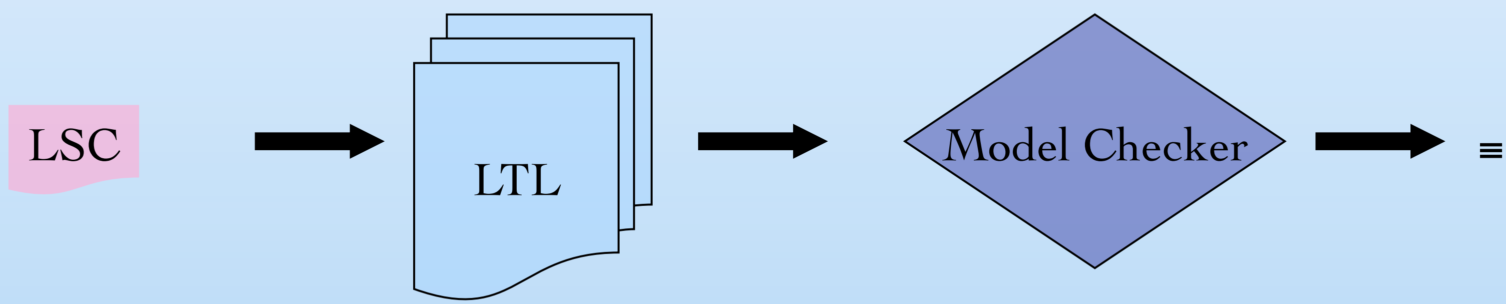
Verification Using Scenarios





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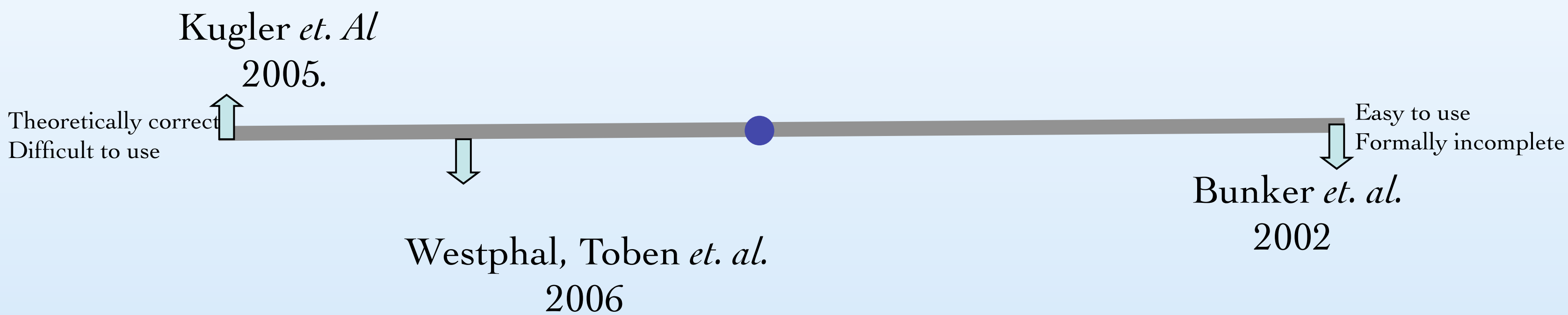
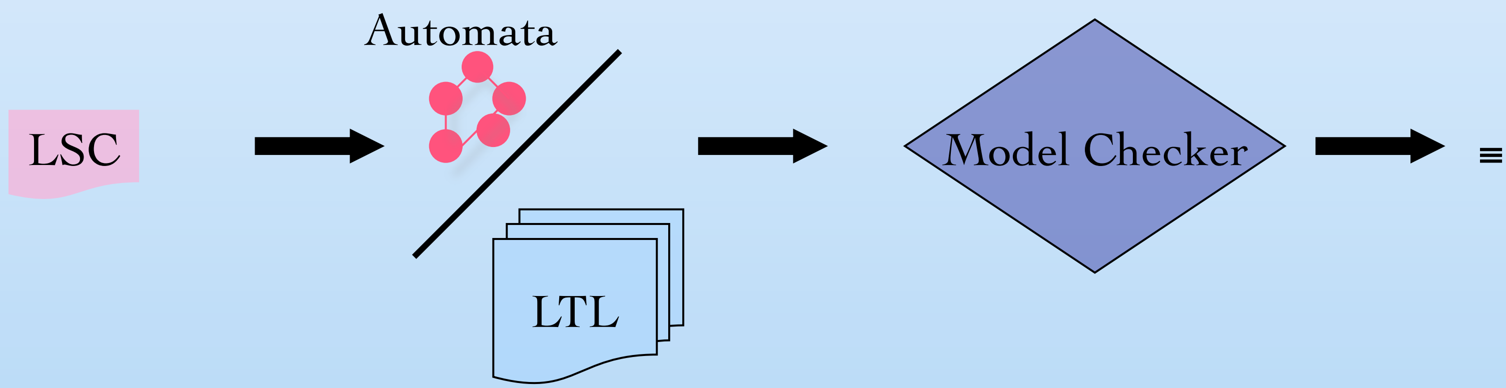
Verification Using Scenarios





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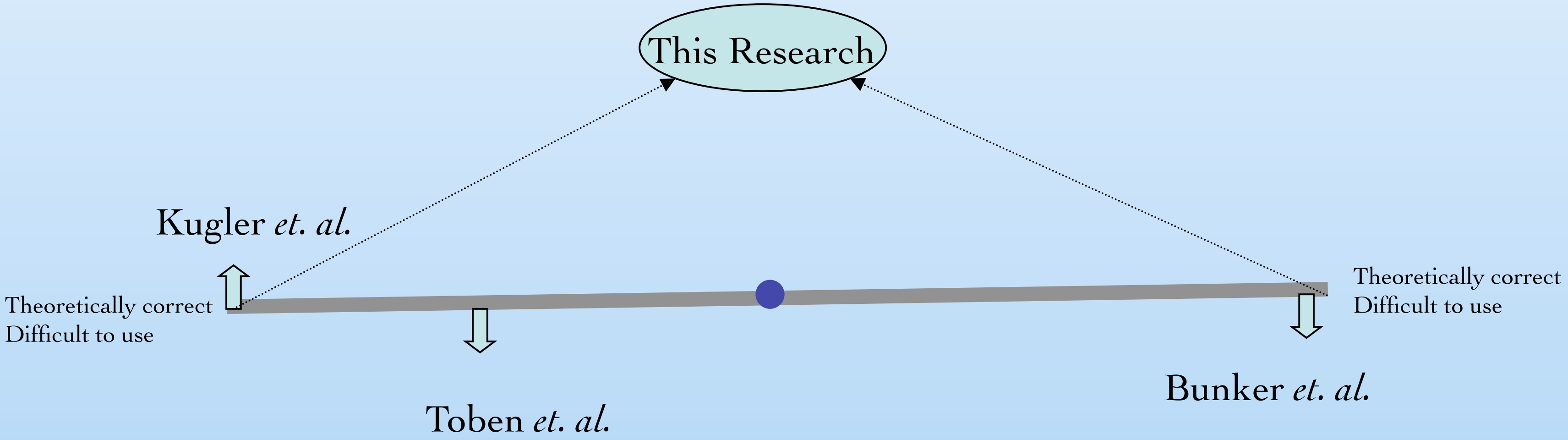
Problems & Solutions

Bridge the gap between graphical specifications and verification methodologies



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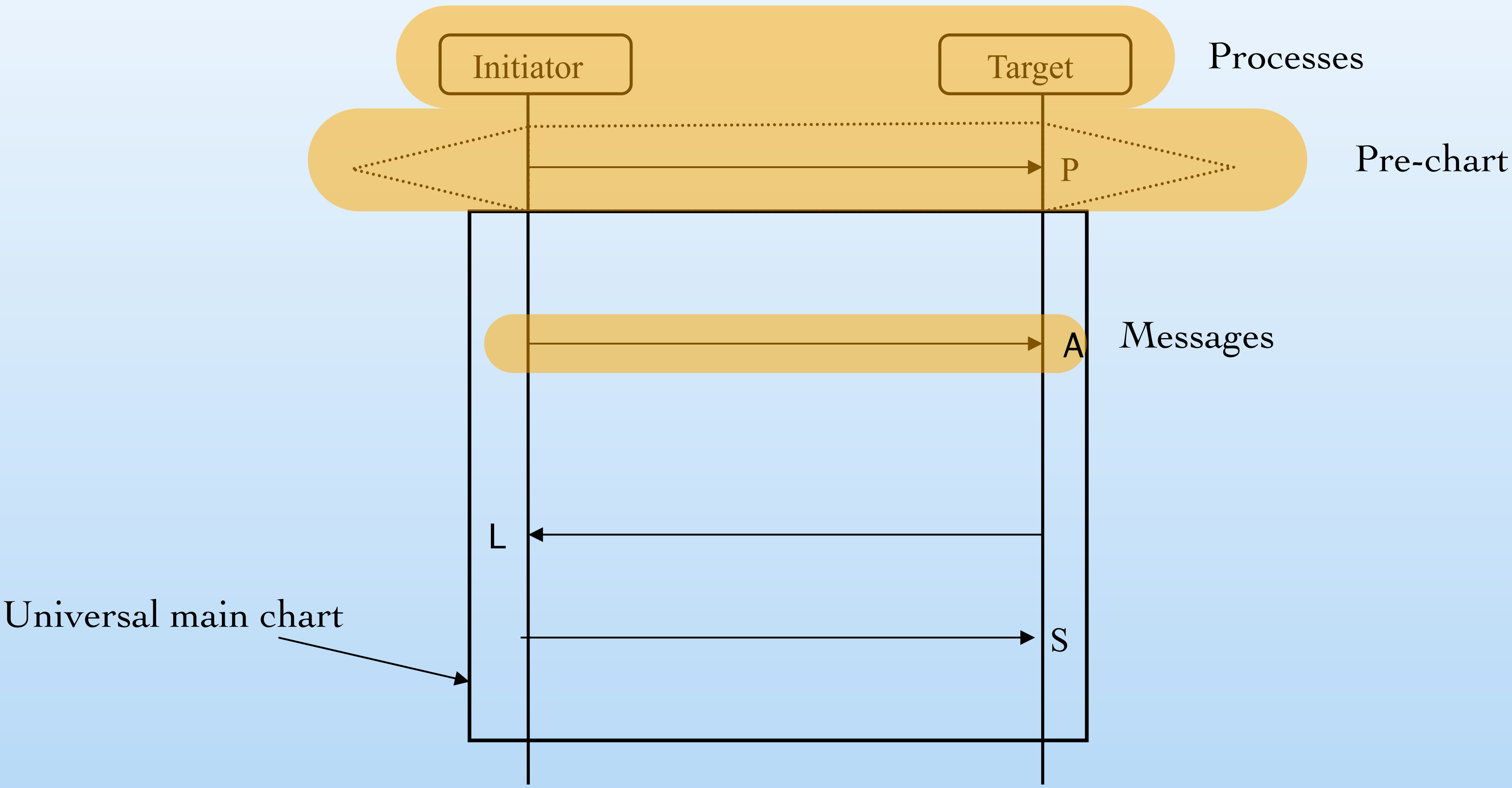
Live Sequence Charts



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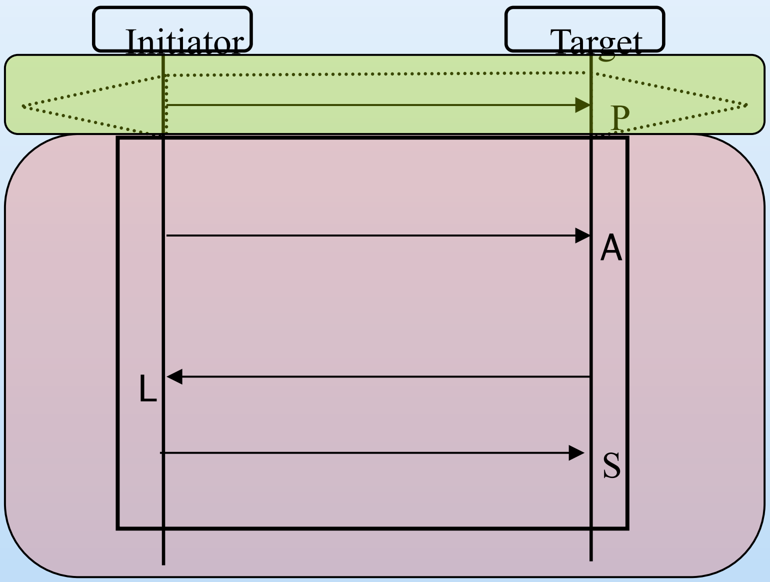
Kugler's Approach



$$G(\ \Theta_{pre} \Rightarrow \Theta_{main}\ )$$

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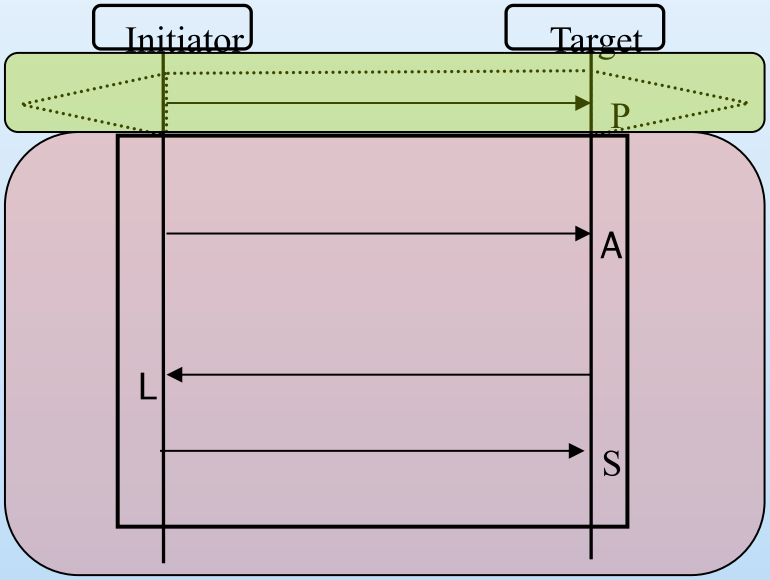
Kugler's Approach



$$G(\ P \Rightarrow \Theta_{main}\ )$$

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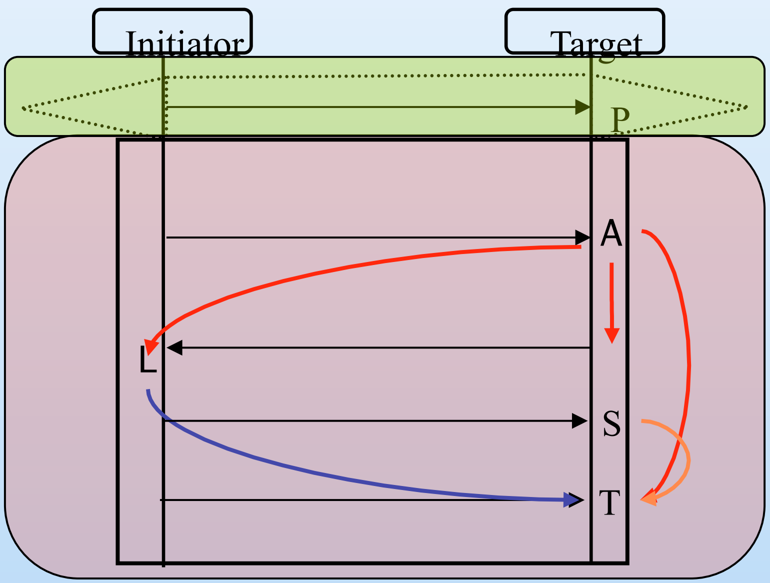
Kugler's Approach - Ordering



$$
\begin{aligned}
G(\ P \Rightarrow\ & (\neg L\ \mathcal{U}\ A) \wedge \\
& (\neg S\ \mathcal{U}\ A) \wedge \\
& (\neg T\ \mathcal{U}\ A) \wedge \\
& (\neg S\ \mathcal{U}\ L) \wedge \\
& (\neg T\ \mathcal{U}\ L) \wedge \\
& (\neg T\ \mathcal{U}\ S) \wedge \\
& (\mathcal{F}\ T))
\end{aligned}
$$

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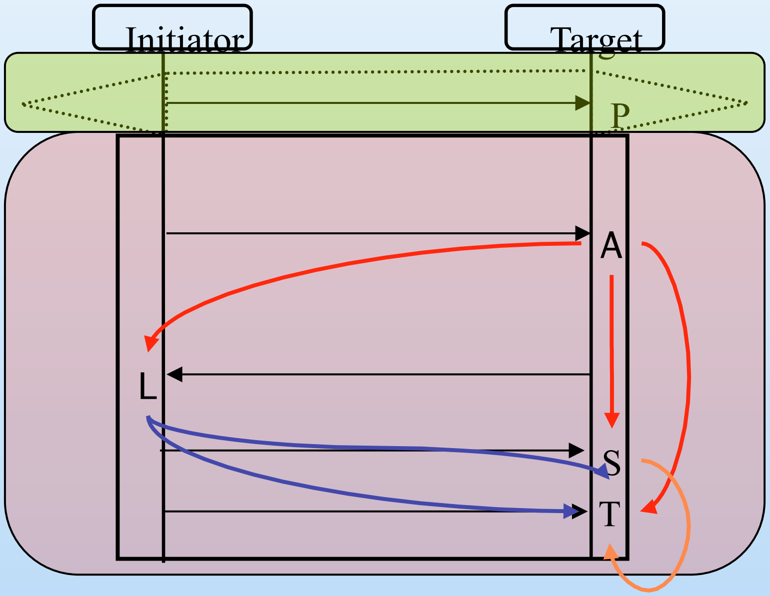
Kugler's Approach - Uniqueness



$$G(\ P \Rightarrow \neg\chi_{A,L} \wedge \neg\chi_{A,S} \wedge \neg\chi_{A,T} \wedge$$
$$\neg\chi_{L,S} \wedge \neg\chi_{L,T} \wedge$$
$$\neg\chi_{S,T}\ )$$

$\neg\chi_{a,b}$: $(\neg b \wedge \neg a)\ U\ (a \wedge X((\neg b \wedge \neg a)\ U\ a))$

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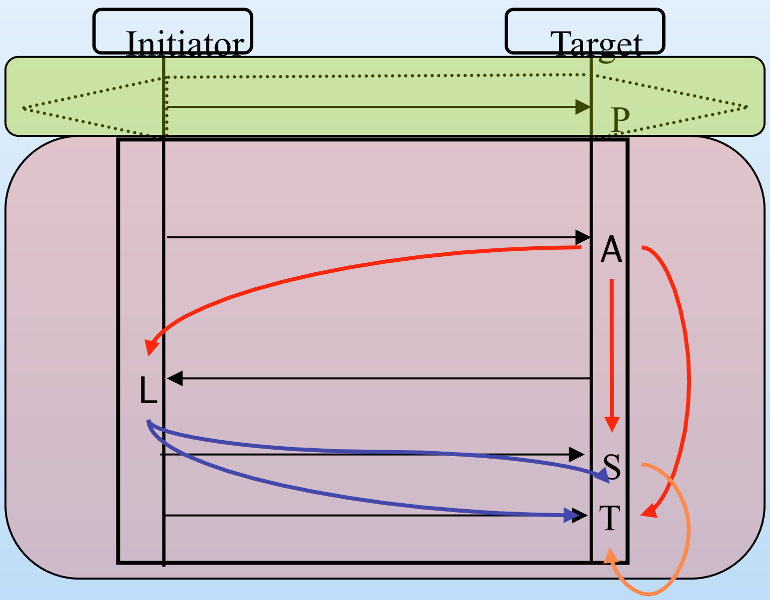
Kugler's Approach - Total



$G(\ P \Rightarrow (\neg L\ \boldsymbol{U}\ A) \wedge \neg\chi_{A,L} \wedge \neg\chi_{A,S} \wedge \neg\chi_{A,T} \wedge$

$(\neg S\ \boldsymbol{U}\ A) \wedge \neg\chi_{L,S} \wedge \neg\chi_{L,T} \wedge$

$(\neg T\ \boldsymbol{U}\ A) \wedge \neg\chi_{S,T} \wedge$

$(\neg S\ \boldsymbol{U}\ L) \wedge$

$(\neg T\ \boldsymbol{U}\ L) \wedge$

$(\neg T\ \boldsymbol{U}\ S) \wedge$

$(\boldsymbol{F}\ T))$

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Kugler's Approach - Drawbacks

- Very large formulas for small charts
- LTL to automata fails for large charts
- Verification fails for larger charts/models
- Limited set of LSC constructs translated

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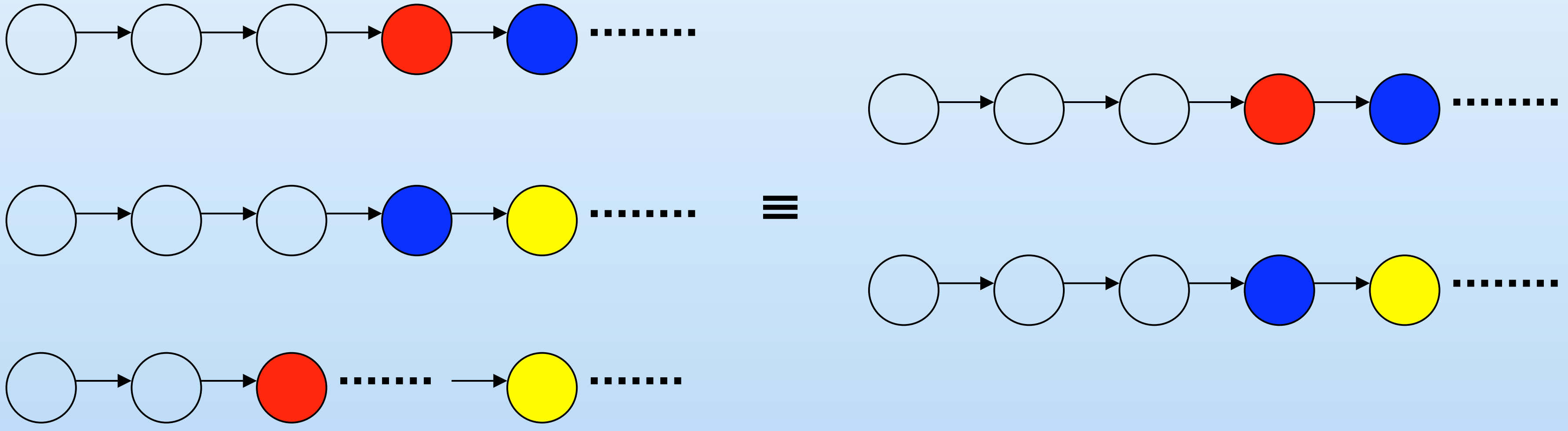
Reductions: Until Transitivity



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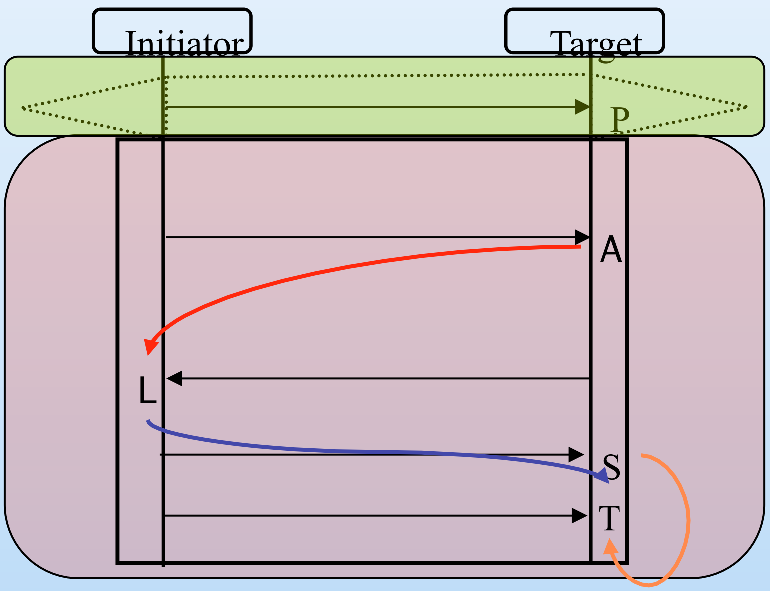
Reductions: Using Until Reduction



$G($ pre $\Rightarrow (\neg L\ \mathcal{U}\ A) \wedge$

~~$(\neg S\ \mathcal{U}\ A) \wedge$~~

~~$(\neg T\ \mathcal{U}\ A) \wedge$~~

$(\neg S\ \mathcal{U}\ L) \wedge$

~~$(\neg T\ \mathcal{U}\ L) \wedge$~~

$(\neg T\ \mathcal{U}\ S) \wedge$

$(\mathcal{F}\ T))$

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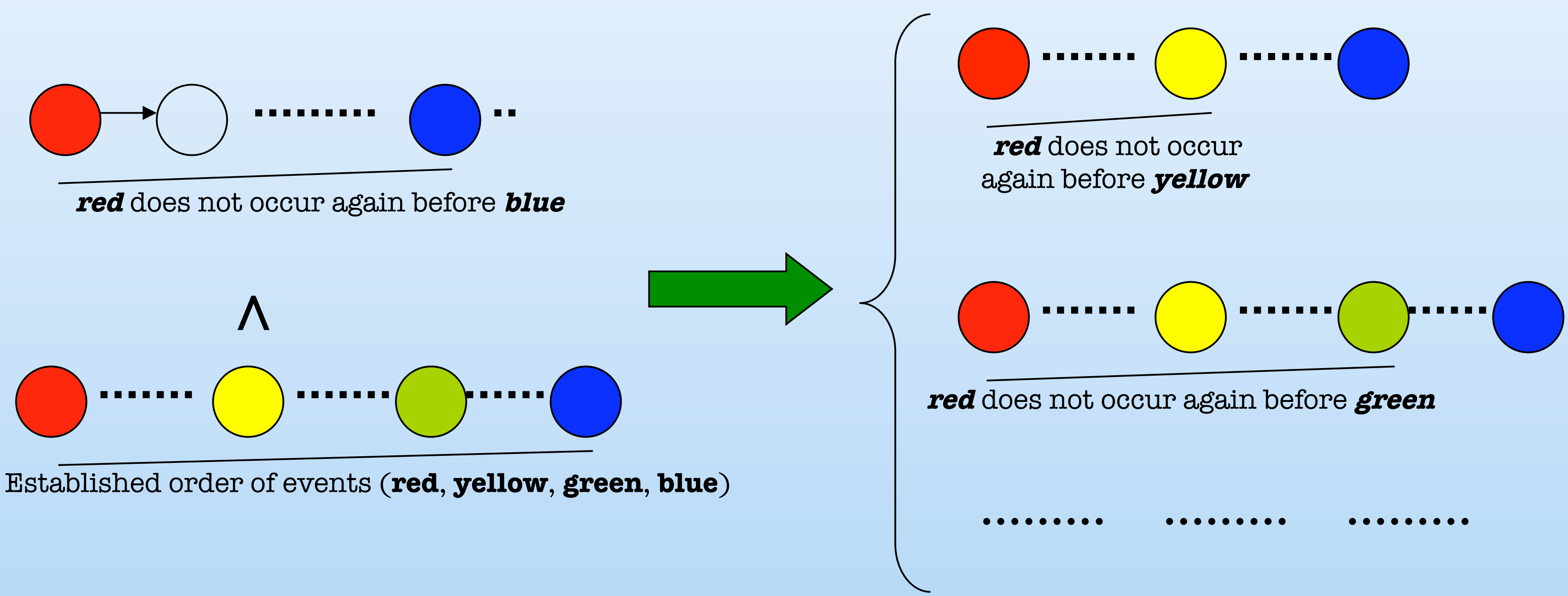
Reductions: Uniqueness

Using Coverage to Specify Uniqueness



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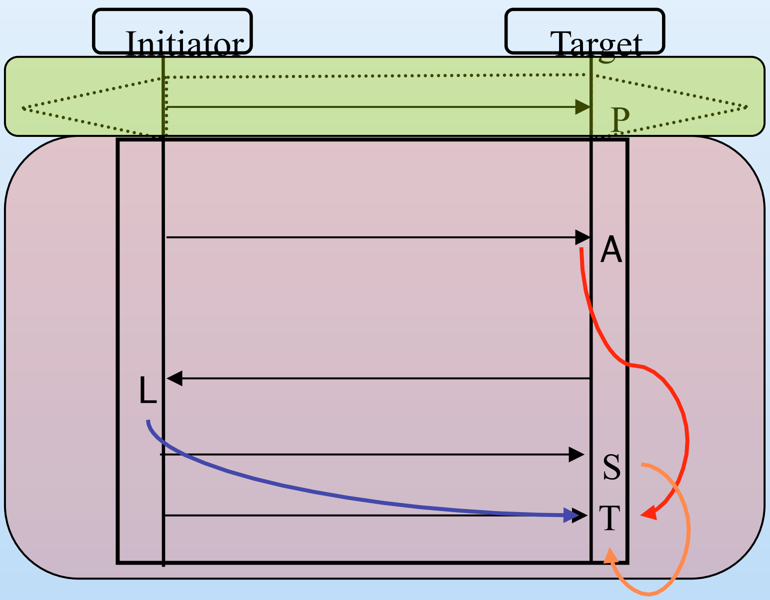
Using Uniqueness Reduction



$$G(\ pre \Rightarrow \neg\chi_{A,L} \wedge \neg\chi_{A,S} \wedge \neg\chi_{A,T} \wedge \neg\chi_{L,S} \wedge \neg\chi_{L,T} \wedge \neg\chi_{S,T}\ )$$

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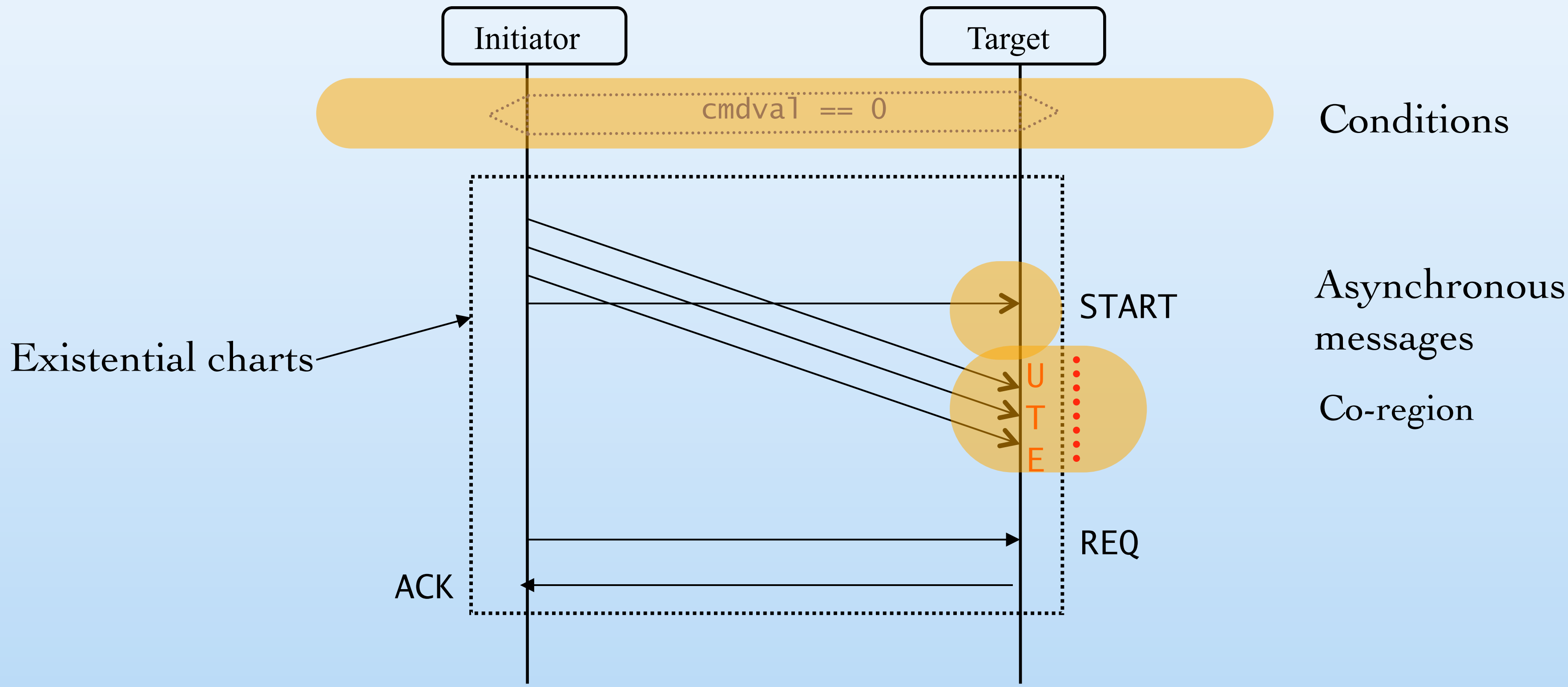
Additional Constructs



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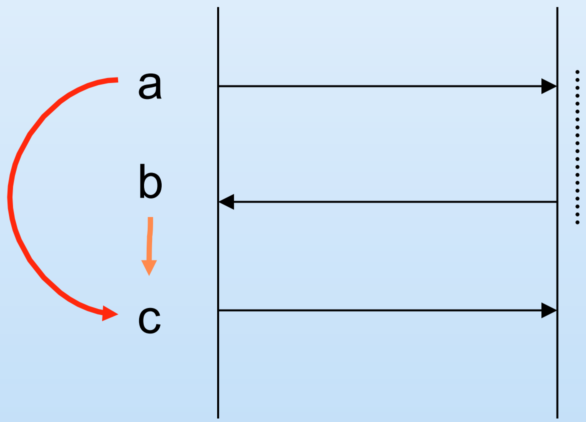
Co-regions



$(\neg c\ \boldsymbol{U}\ a) \wedge$
$(\neg c\ \boldsymbol{U}\ b) \wedge \boldsymbol{F}\ c$

Force a,b to occur but in any order

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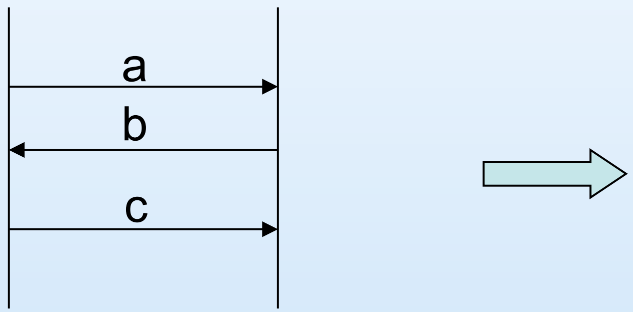
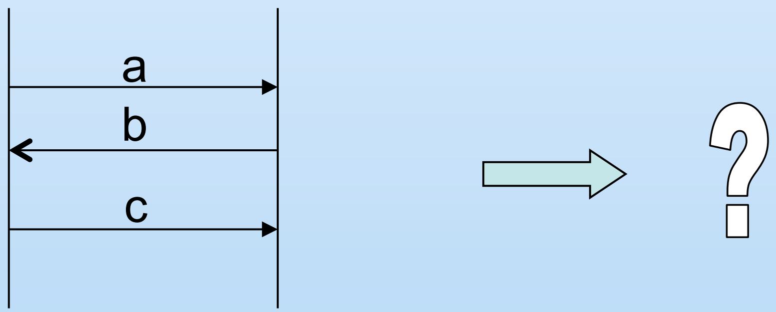
Asynchronous Messages



Single letter per message



Describe send and receive events

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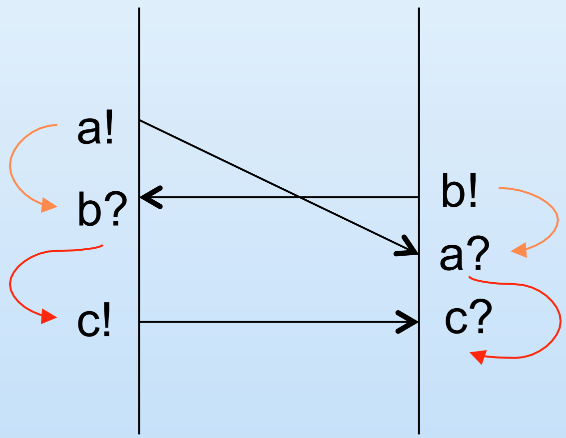
Asynchronous Messages



$(\neg b?\ \boldsymbol{U}\ b!) \wedge (\neg a?\ \boldsymbol{U}\ a!) \wedge (\text{assumption})$

$(\neg b?\ \boldsymbol{U}\ a!) \wedge (\neg a?\ \boldsymbol{U}\ b!) \wedge$

$(\neg c?\ \boldsymbol{U}\ a?) \wedge (\neg c!\ \boldsymbol{U}\ b?) \wedge$

$\boldsymbol{F}\ c? \wedge \boldsymbol{F}\ c!$

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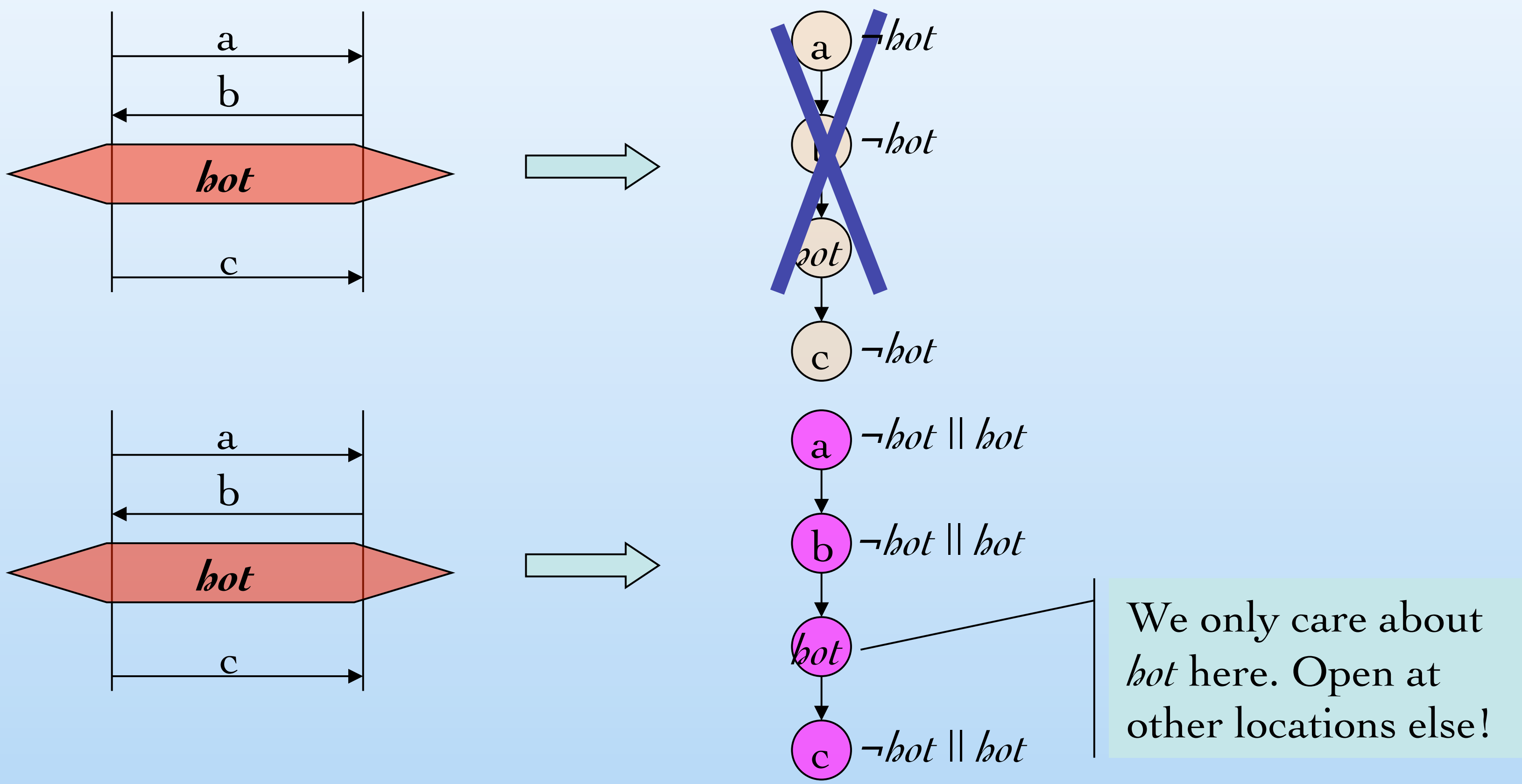
Conditions



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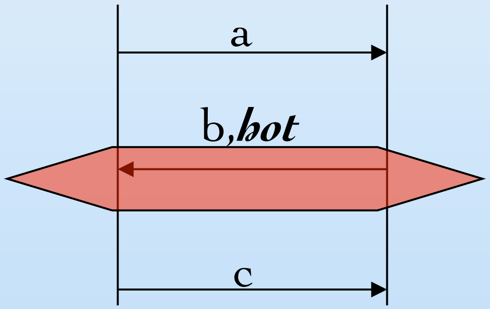
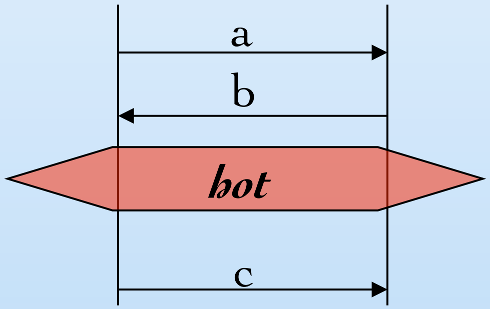
Conditions

Bonded Conditions



Non-bonded Conditions



Translation undecided

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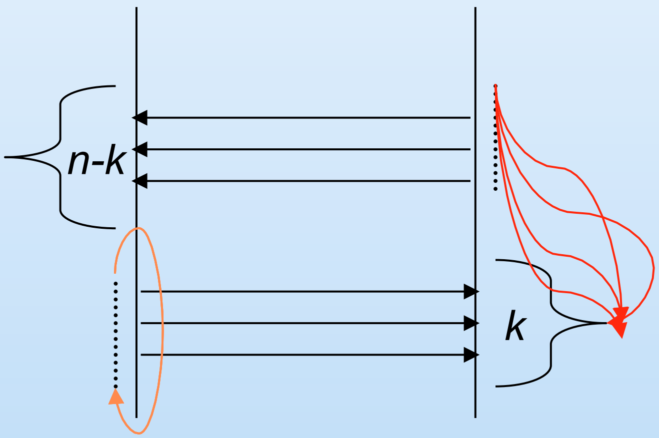
Analysis



Worst case chart

Ordering

n-k properties to order first n messages before *k* messages
k properties for enforcing occurrence of final k messages

n

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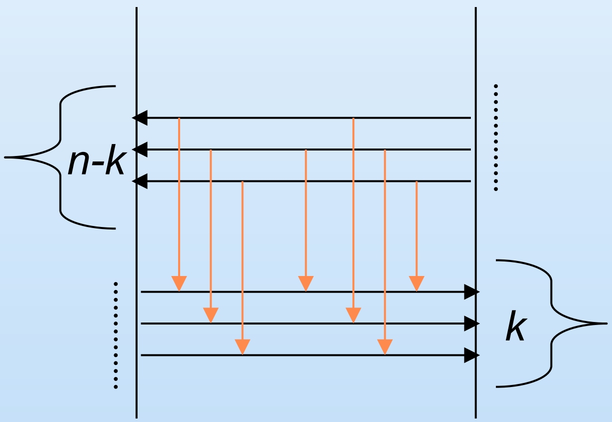
Analysis



Worst case chart

<u>Uniqueness</u>

k properties for each of the n messages
(k-1) properties for each of the k messages

$$n*k$$

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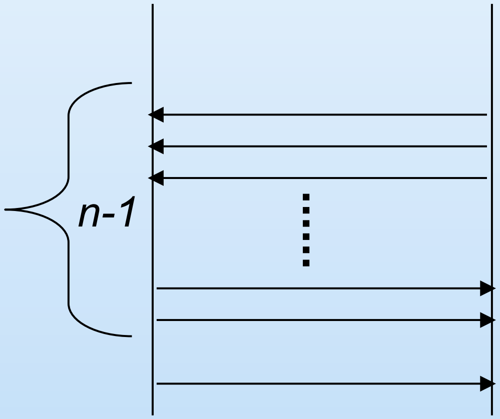
Analysis

For chart of size *n* & 1 maximal message:

Ordering: *n* properties

Uniqueness: *n* properties



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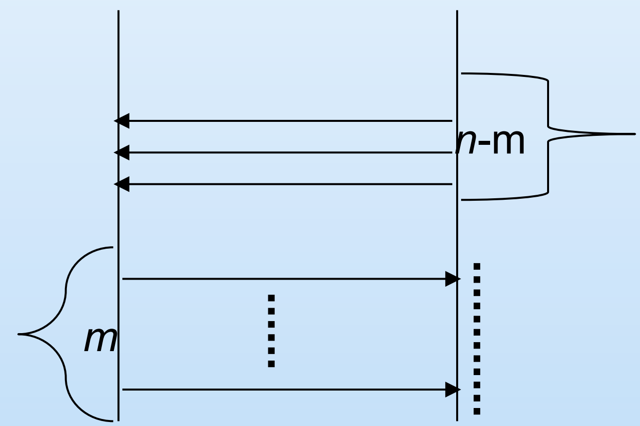
Analysis

Multiple maximal messages *(m)*:
Ordering: n
Uniqueness: $n*m$

As $m \rightarrow n$, formula becomes quadratic



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Theoretical Results

- Ordering in linear properties
- Uniqueness in sub-quadratic properties
- Translation at *most* as opposed to at *least* quadratic
- Additional constructs
  - Existential charts
  - Co-regions
  - Asynchronous messages
  - Invariants and bonded conditions

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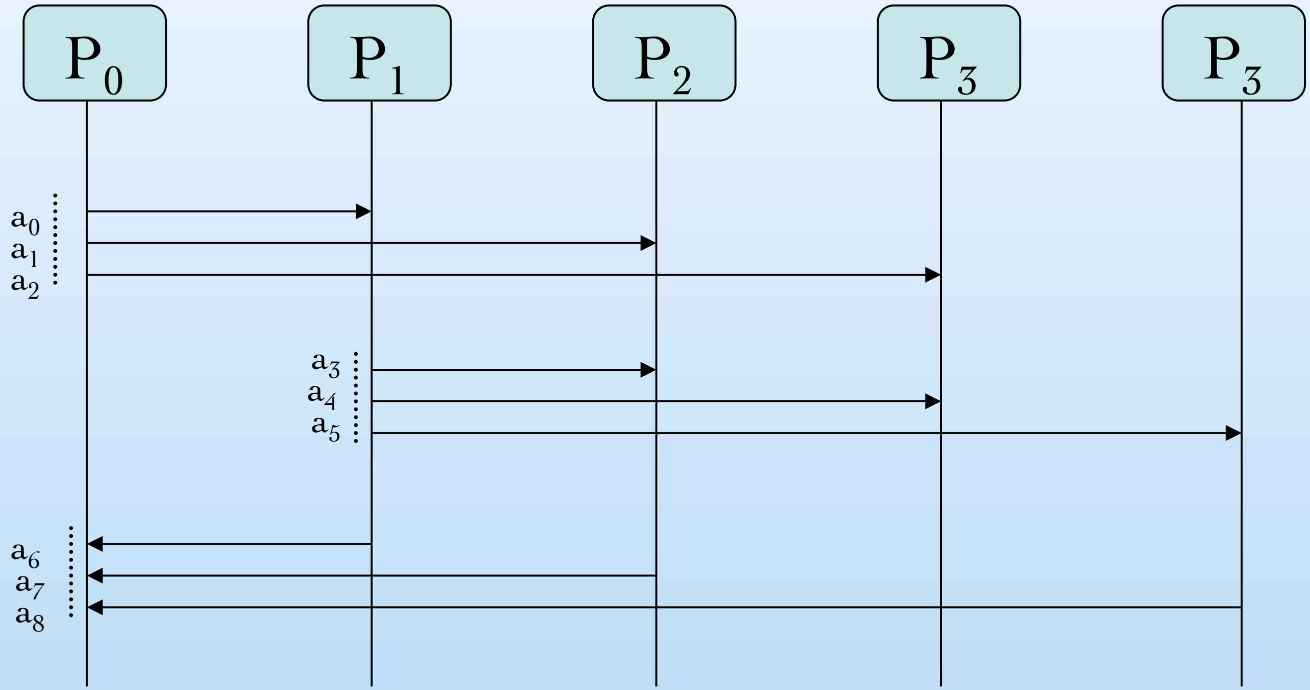
Experiments - Specifications

<u>A3 specification</u>



Other specifications with 5-7 messages

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Experiments - Models and Verifiers

- Models
  - Promela models with simple message passing
  - Puzzle models followed by messages
  - "**_e**" models contain errors in main chart
- SPIN and NuSMV for model checking
- LTL2BA: explicit state automata generation

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Empirical Results - LTL2BA

Specification	**Messages**		**Kugler's Translation**		**Improved Translation**	
	Total Messages	Maximal Messages	Size	Time (s)	Size	Time (s)
SpecA	5	1	209	59	109	1
SpecB	5	2	175	428	142	2
SpecC	**7**	**2**	**LTL2BA DNF**		**139**	**2**

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Empirical Results - SPIN

Specification	Model	Kugler'sTranslation		Improved Translation	
		States	Time (s)	States	Time (s)
SpecB	SysA	2612	0.02	2158	0.02
	SysA_e	2446	0.07	1965	0.06
SpecC	SysB	-		4175	0.03
	SysB_e	-		4589	0.12
A2	**Soko**	**3847560**	**104**	**1557700**	**36**
	Soko_e	**1479320**	**32**	**620902**	**12**
A3	Soko	-		2840220	69
	Soko_e	-		1031970	22

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Empirical Results - NuSMV

Specification	Model	States	Kugler's Time (s)	Improved Time (s)
A2	bridge	76992	14	5
	Abp4	2236420	30	11
	Bridge_e	76992	29	13
	Abp4_e	2236420	76	27
A3	bridge	76992	22	8
	abp4	2236420	59	20
	Bridge_e	76992	56	20
	Abp4_e	2236420	146	50
A4	**bridge**	**76992**	**49**	**11**
	abp4	2236420	174	29
	Bridge_e	76992	132	26
	Abp4_e	**2236420**	**337**	**67**
A5	bridge	76992	175	26
	abp4	2236420	555	73
	Bridge_e	76992	509	56
	Abp4_e	**2236420**	**1271**	**131**

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Conclusions

- Reductions produce vast improvement
- Scalability still limited in explicit state
- Translating constructs can be difficult
- Is this translation minimal?
- What about LSC to automata?

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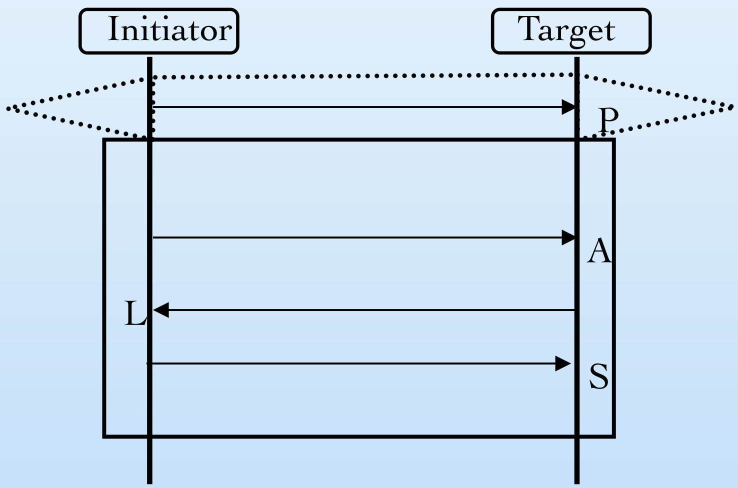
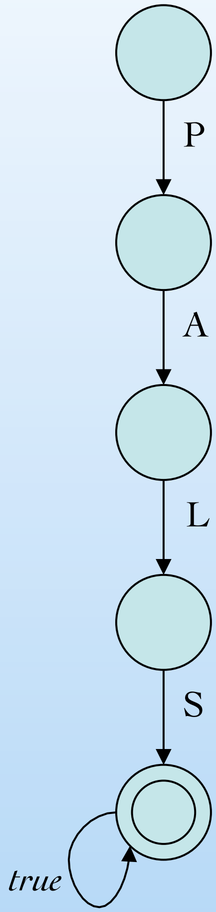
LSC To Automata: Traditional Method





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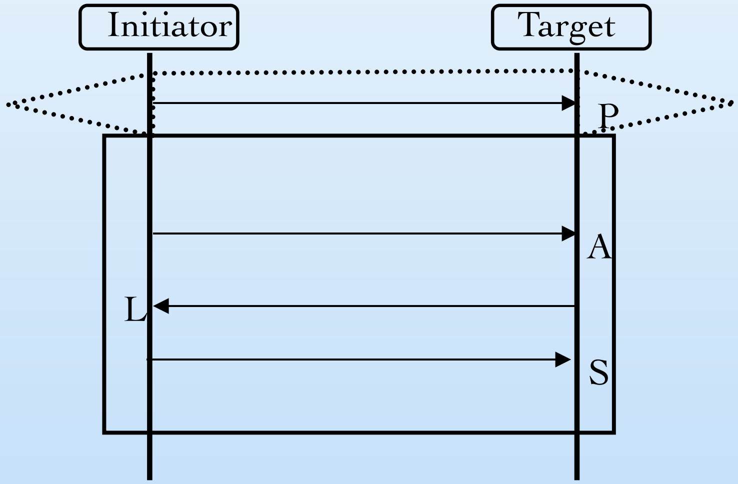
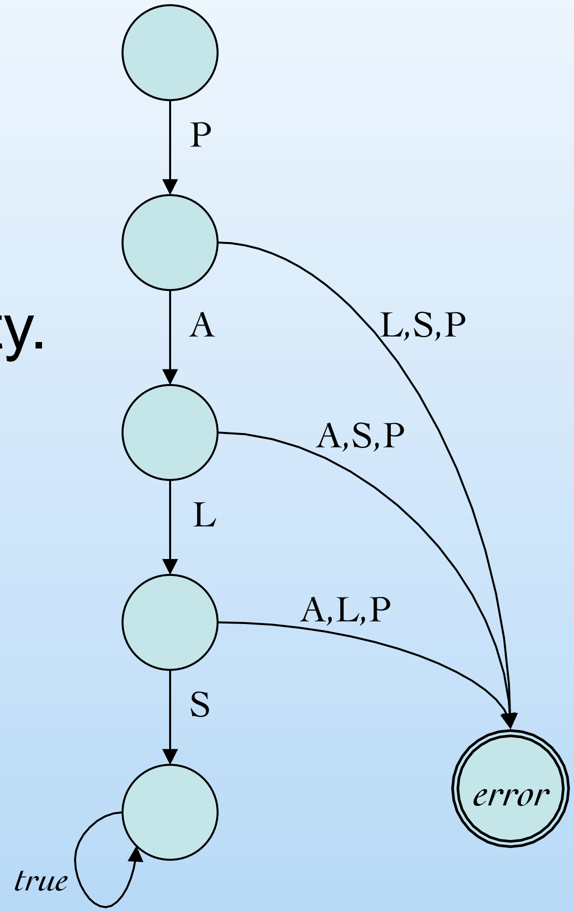
LSC To Automata: Reachability



Verify safety.



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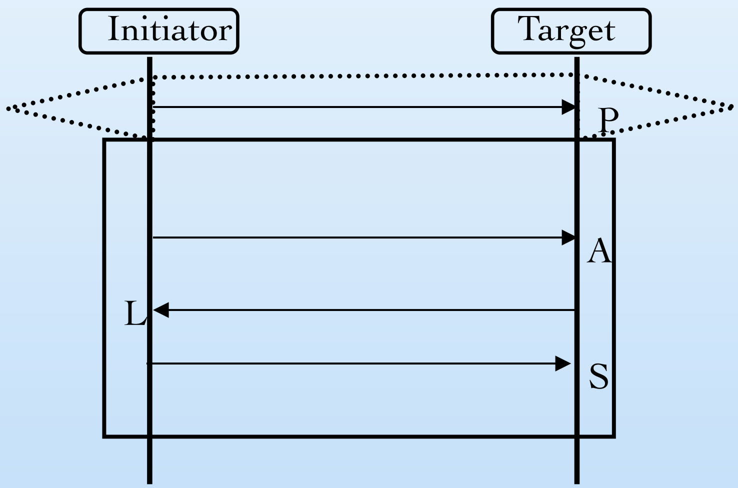
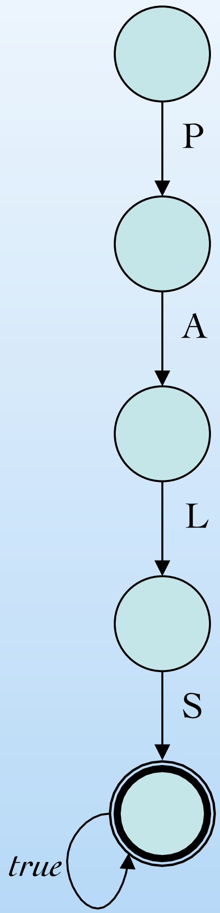
LSC To Automata: Liveness



Verify *AGAF(fair)* to enforce progress



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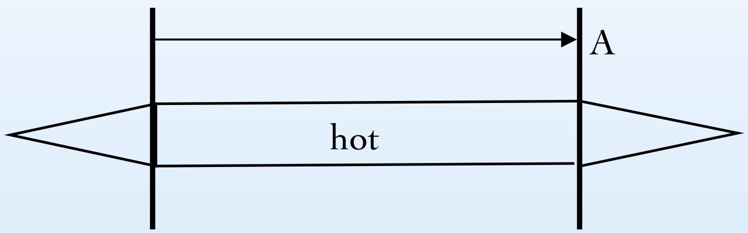
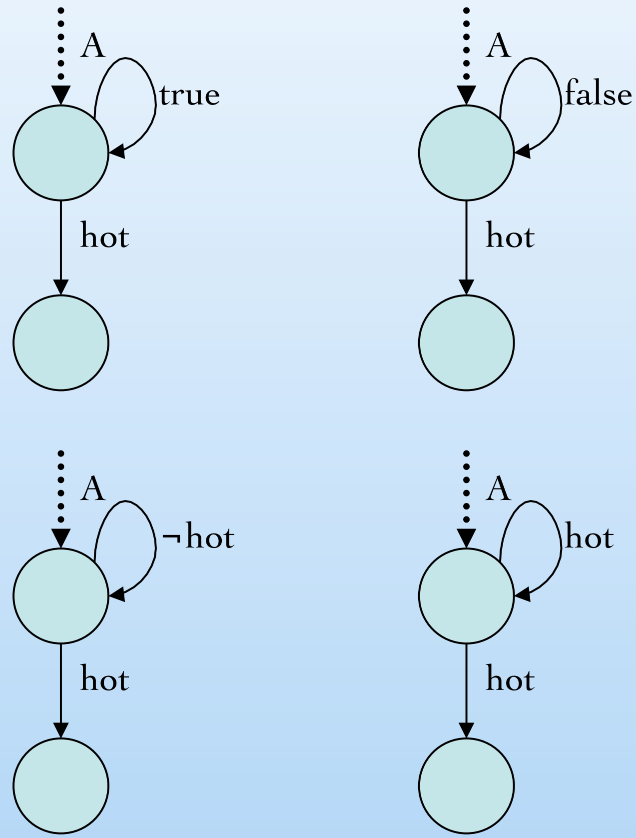
LSC to Automata: Conditions





How do you detect errors without introducing non-determinism?

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Drawbacks

- Safety and progress checking performed in two separate runs
- Non-determinism because of conditions
- Undecided semantics of conditions

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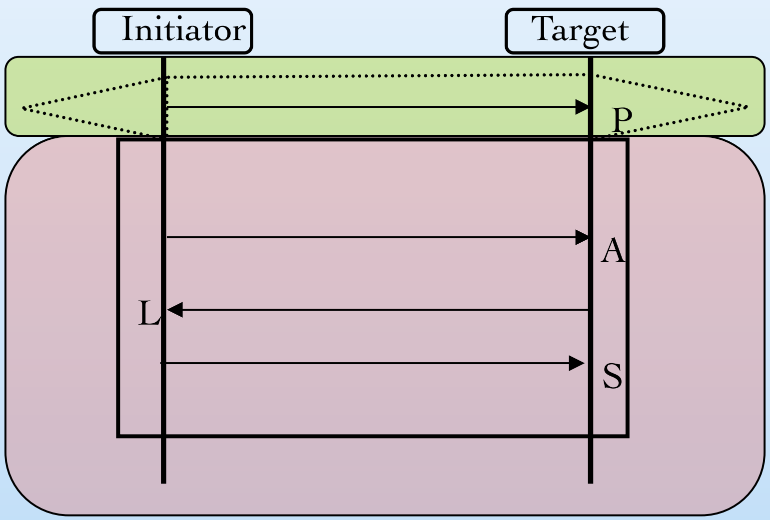
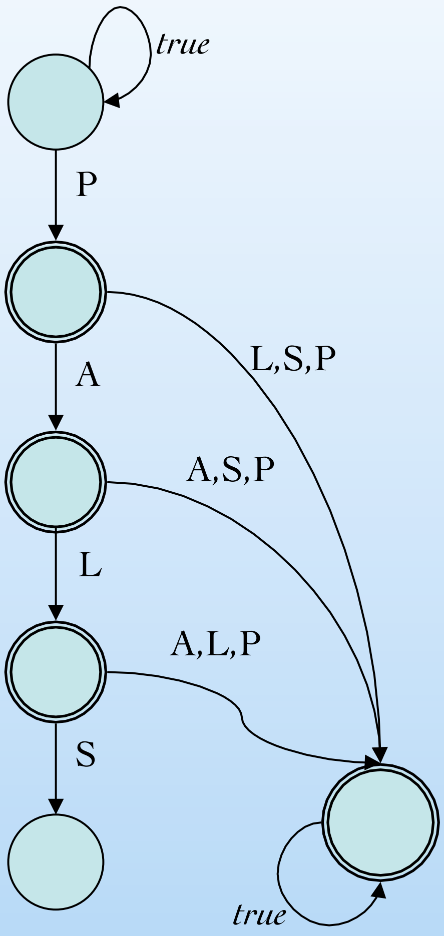
New Solution



Safety and Liveness in one run by verifying $EGEF(error)$



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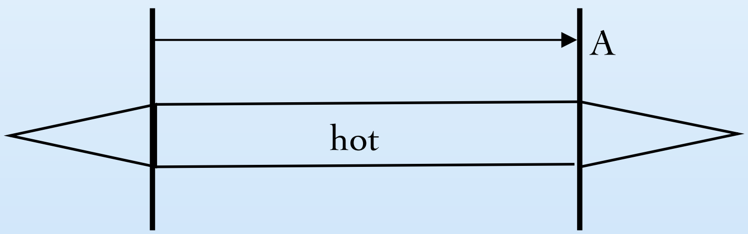
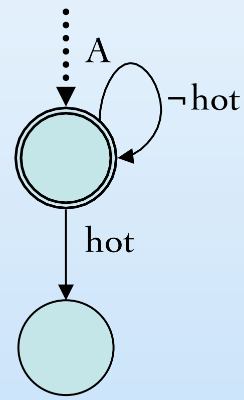
Conditions in New Solution





Placement of error state fixes the problem of non-determinism as well as detecting errors!

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Advantages

- One shot verification using LSCs
- All constructs supported
- No non-determinism
- More error states means faster detection of errors in system
- Simple unwinding algorithm

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