Synthesizing safe coalition strategies

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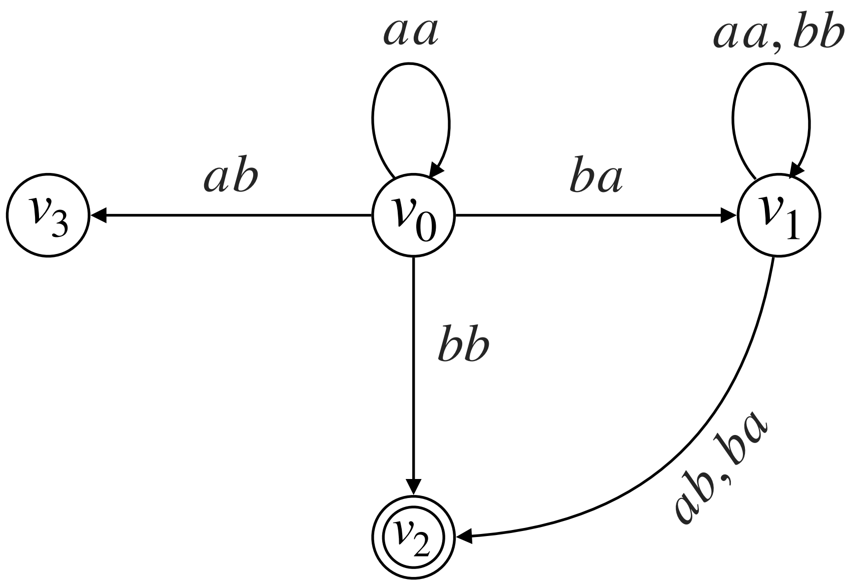
FSTTCS 2020

2-player Concurrent games on graphs



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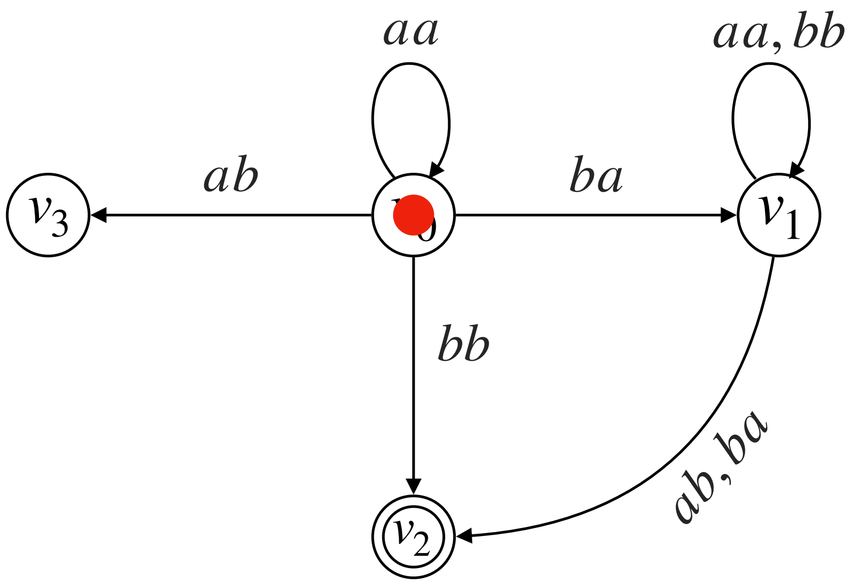

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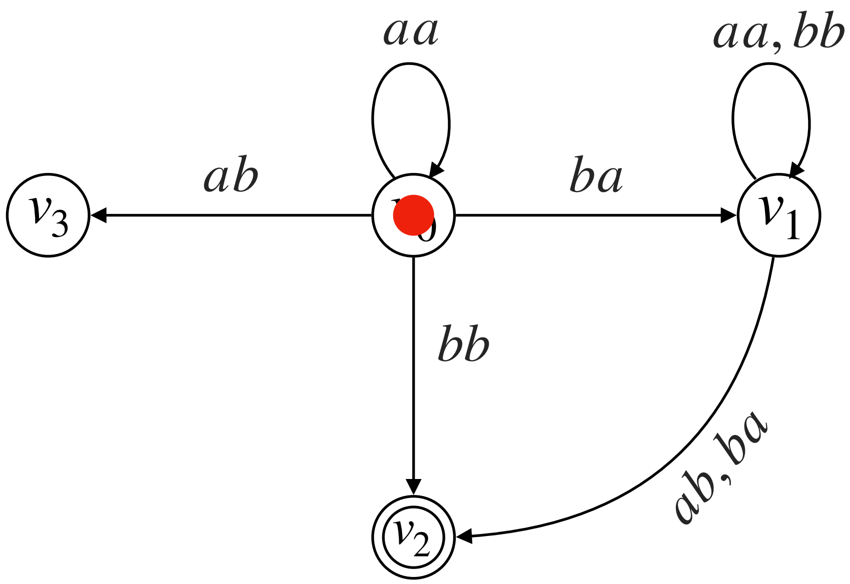

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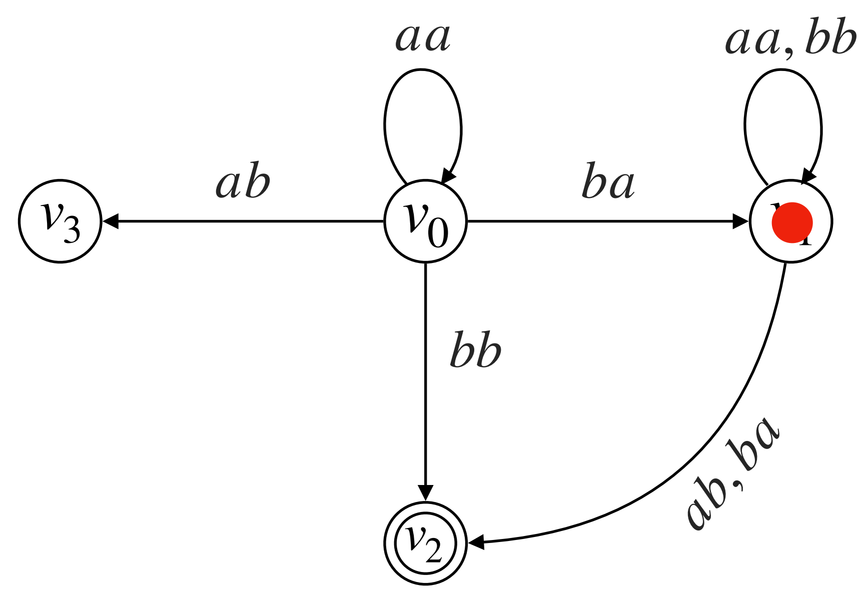

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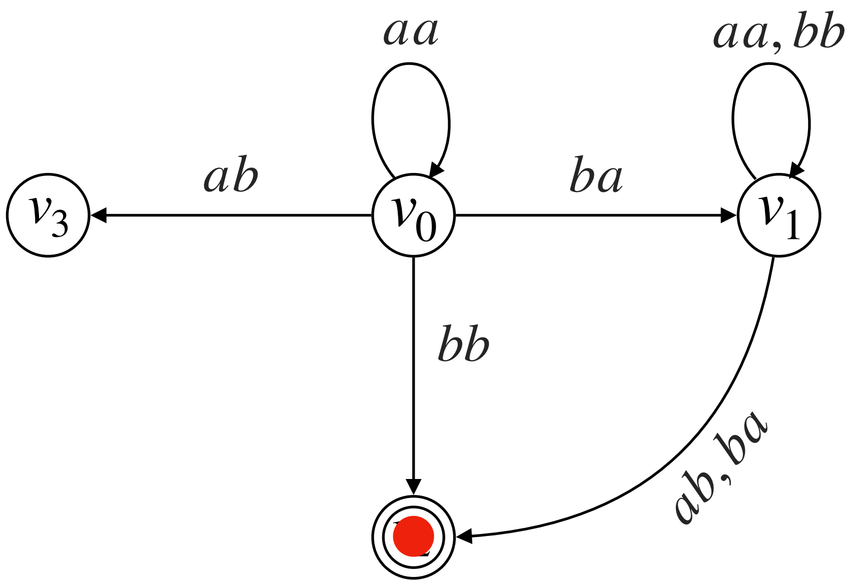

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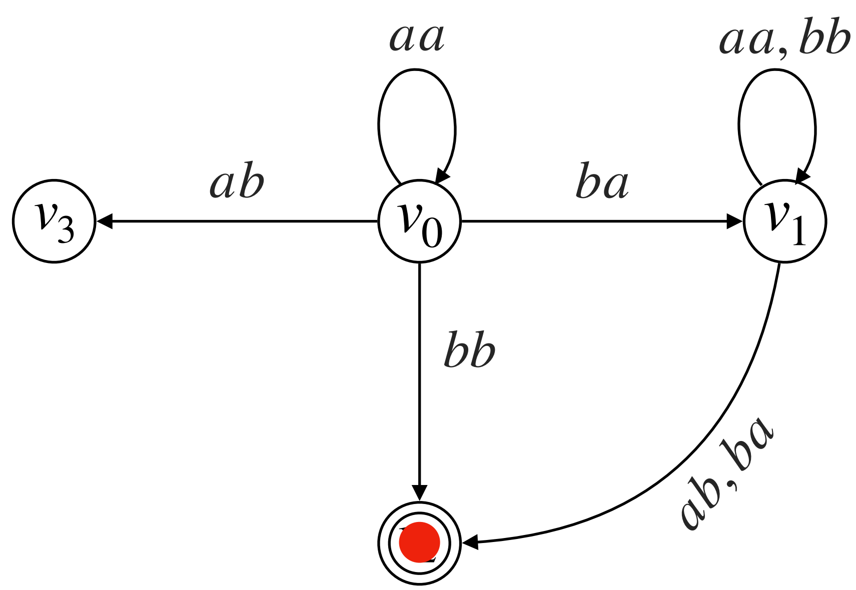

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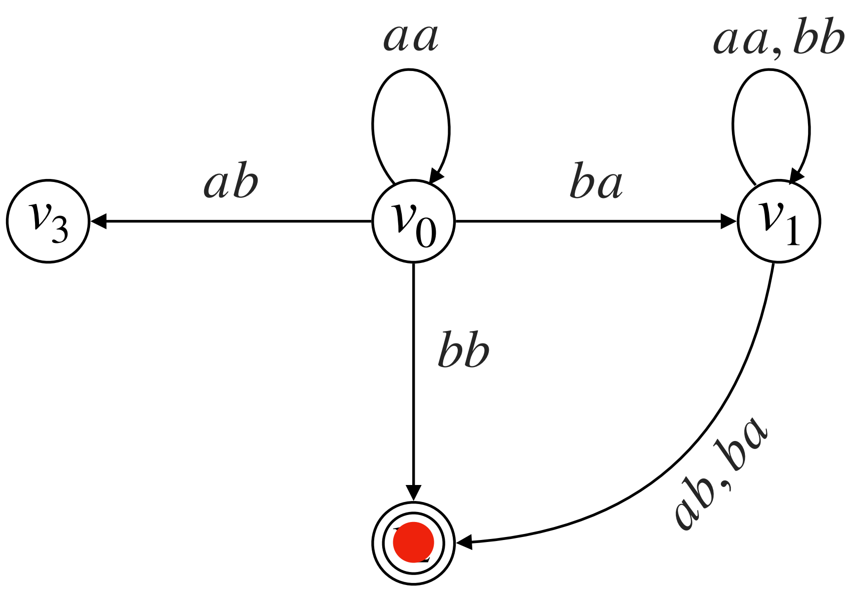

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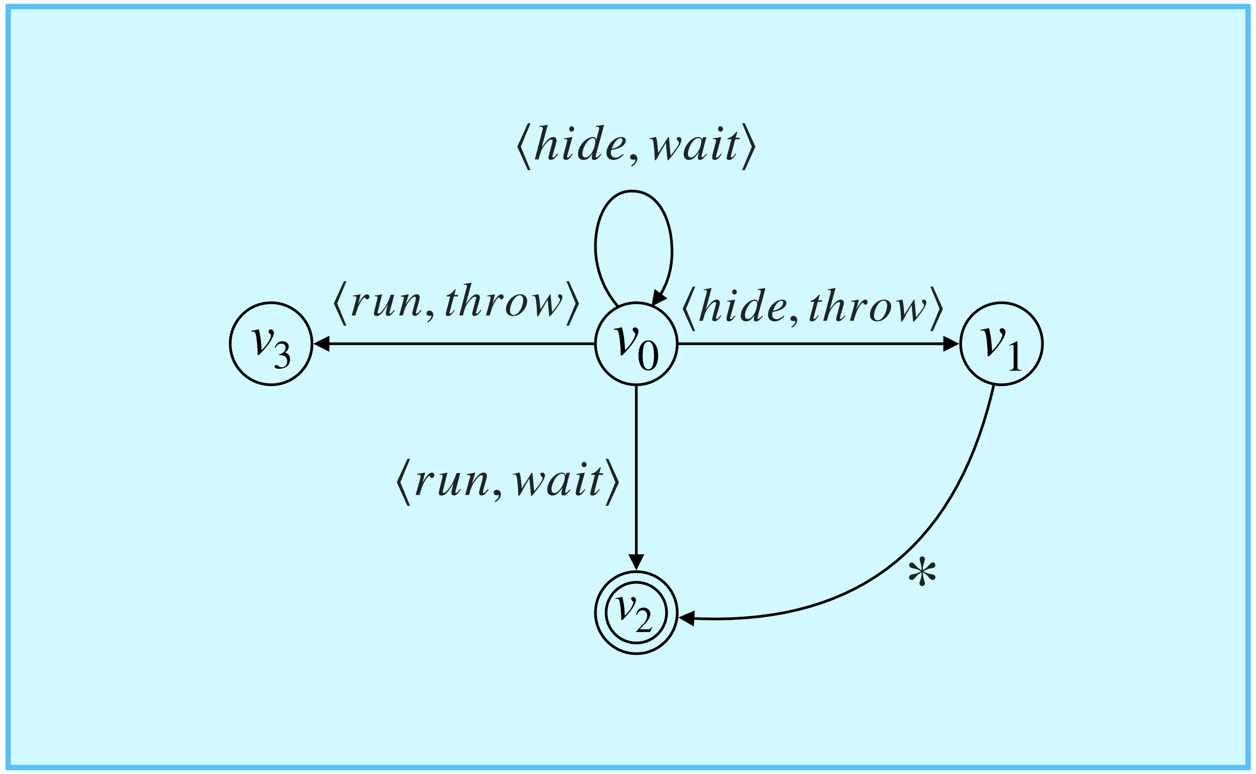
- Examples of winning objectives: Reachability, Safety…

Example

[Alfaro, Henzinger, Kupferman '07]

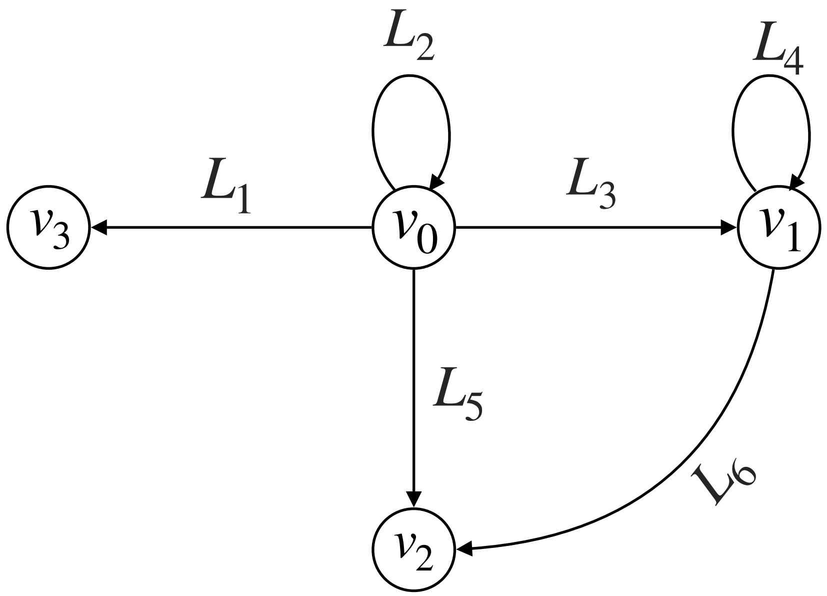
Hide-or-run example

- Player 1 wants to reach home safely when Player 2 wants to throw a snowball at him.



- No player has a winning strategy.

Parameterized concurrent game arena



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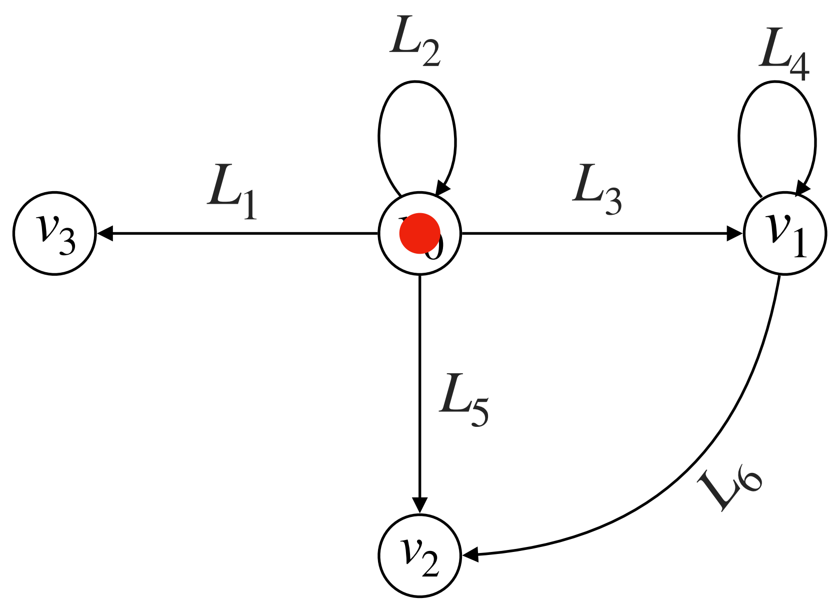

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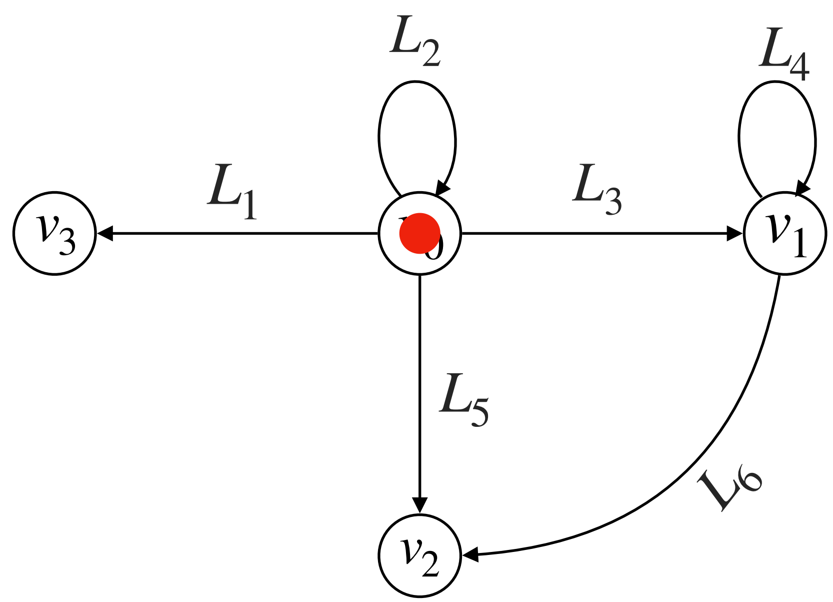

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  - Next vertex is such that $w \in L_i$ (non-determinism is resolved by adversary).

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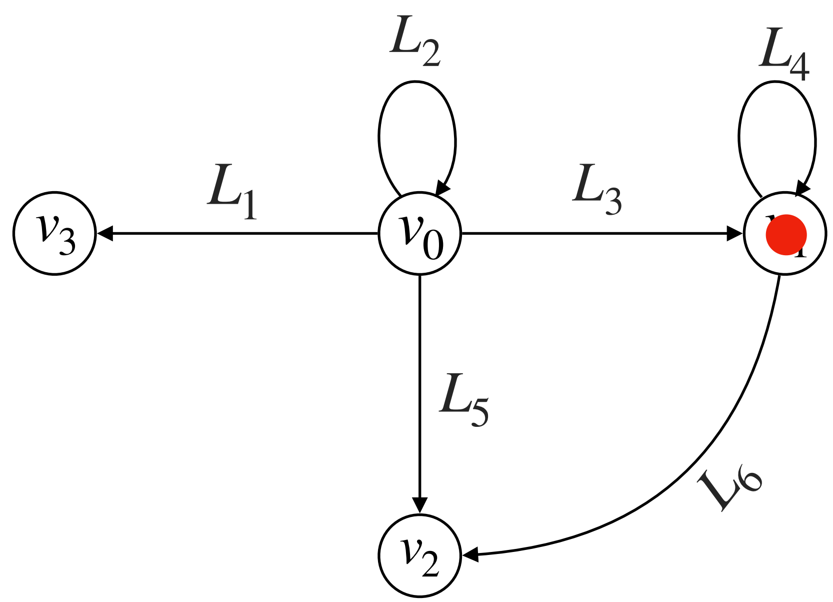

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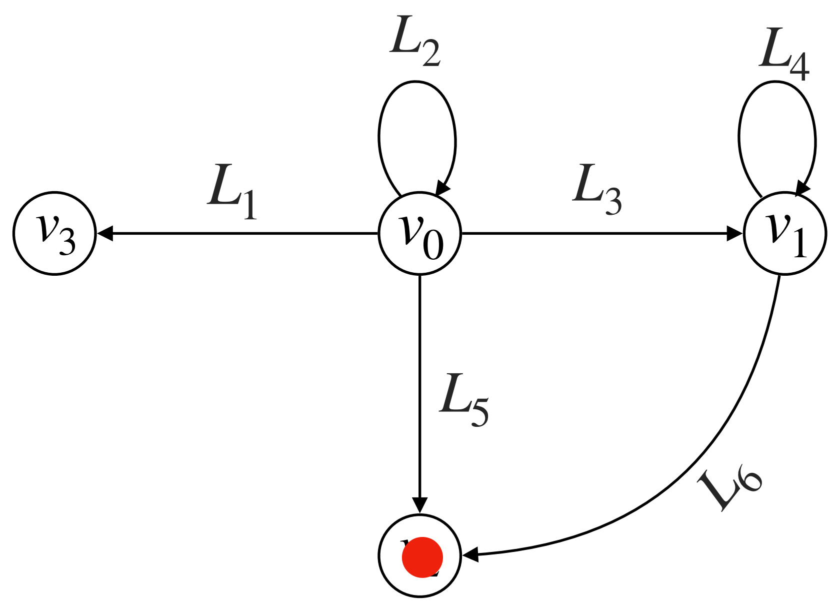

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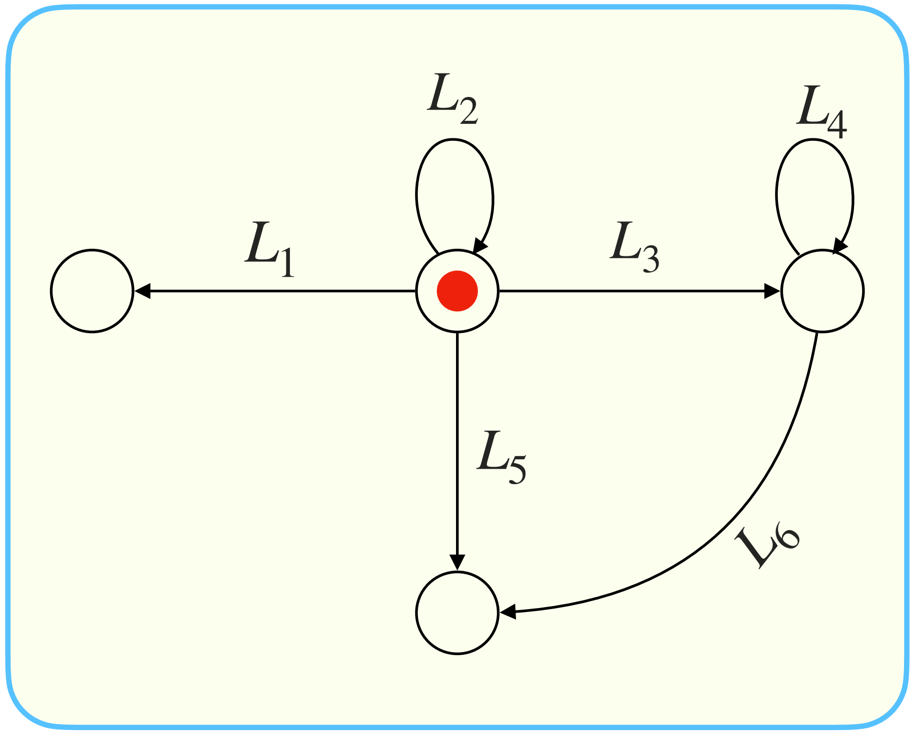

A distinguished player trying to achieve a goal against arbitrary number of opponents.

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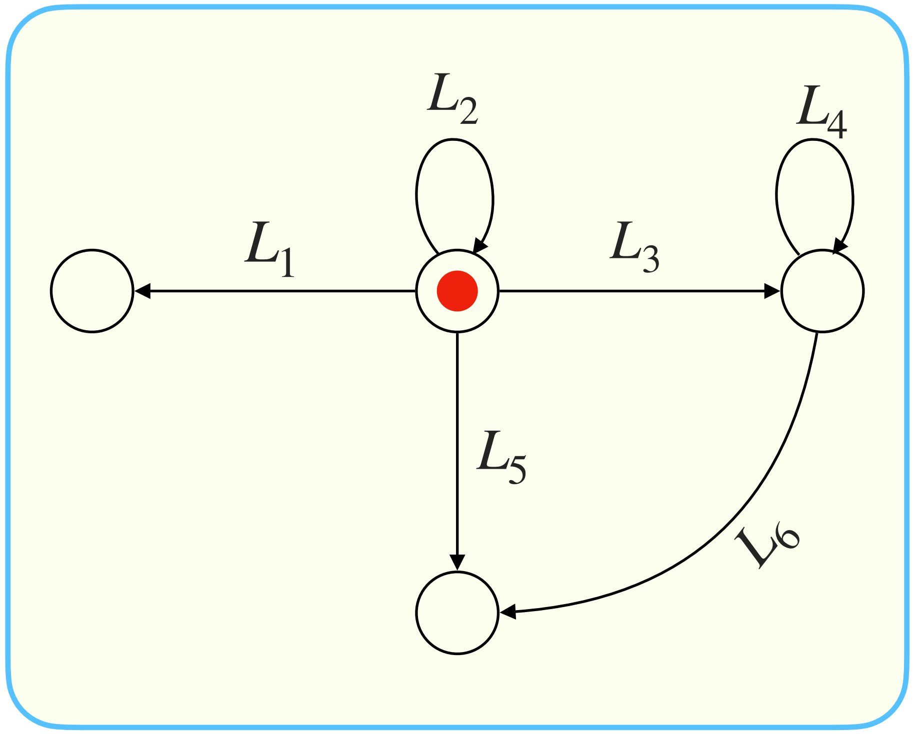

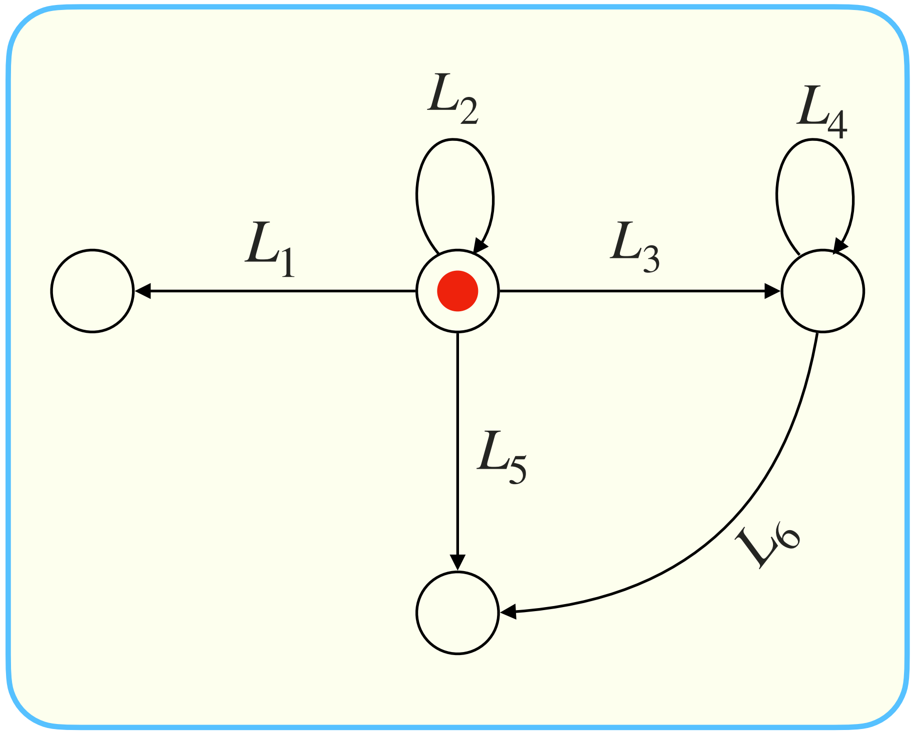

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Arbitrary number of players trying to achieve a common goal.

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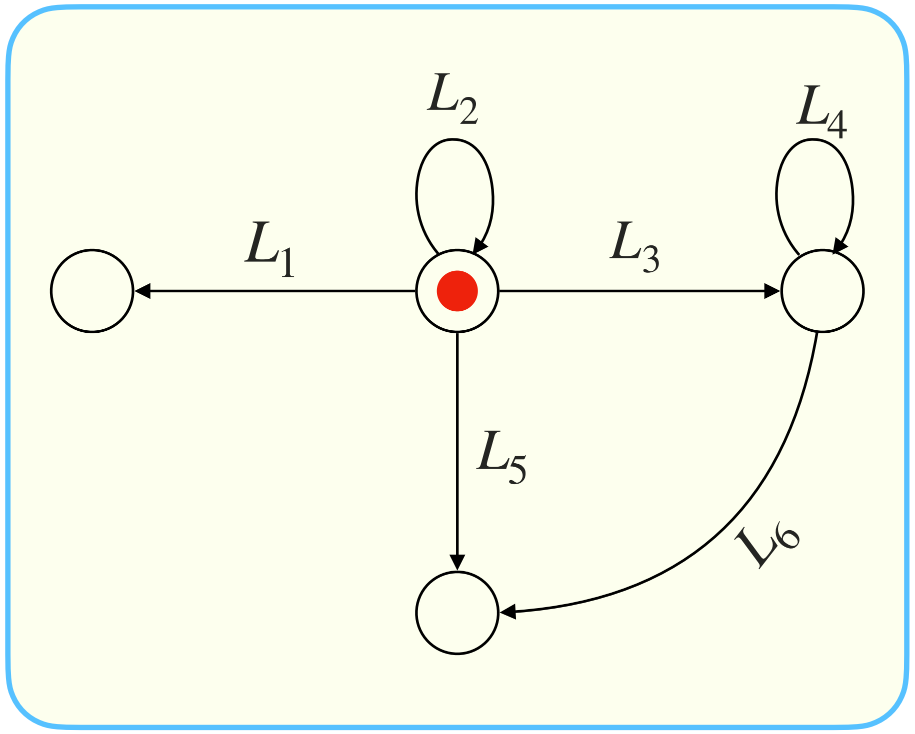

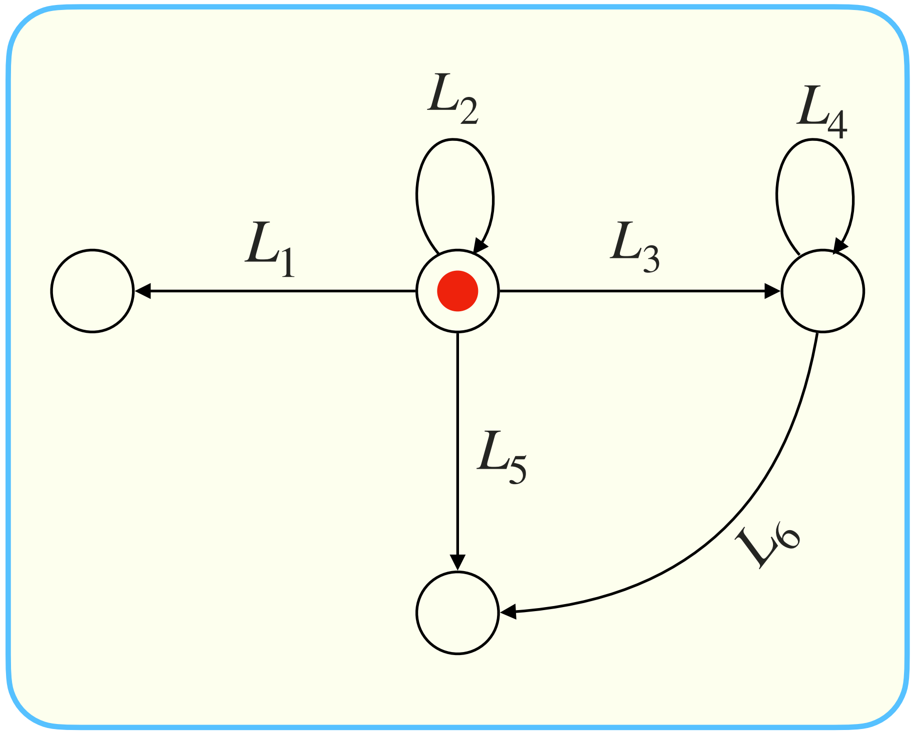

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[FSTTCS 2019]

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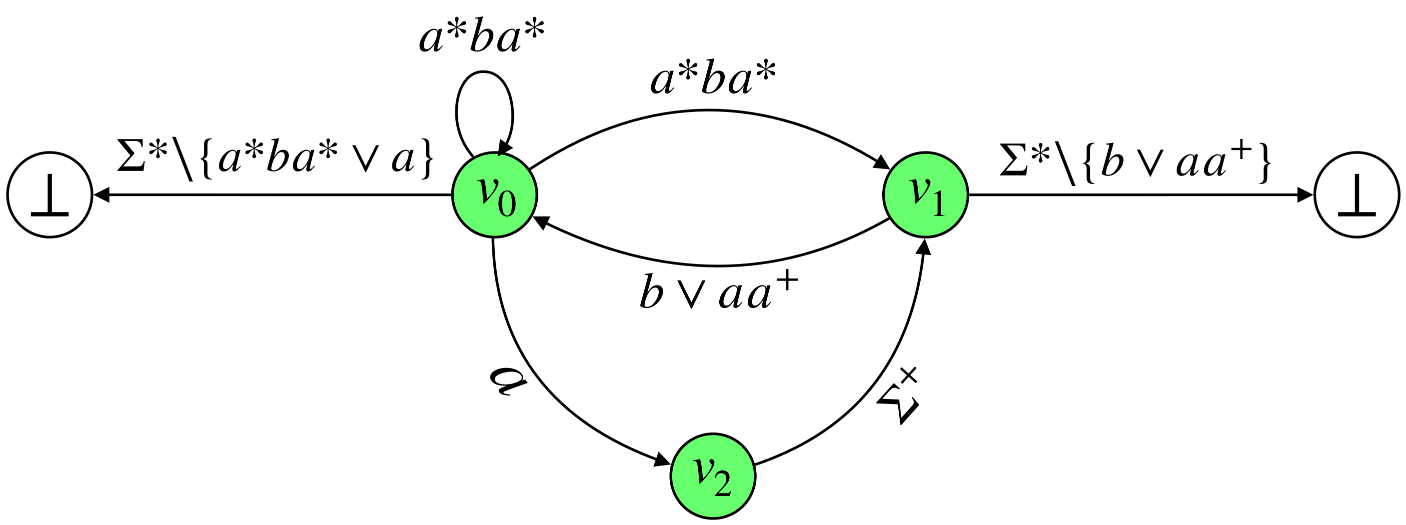
[This work]

Safe coalition problem



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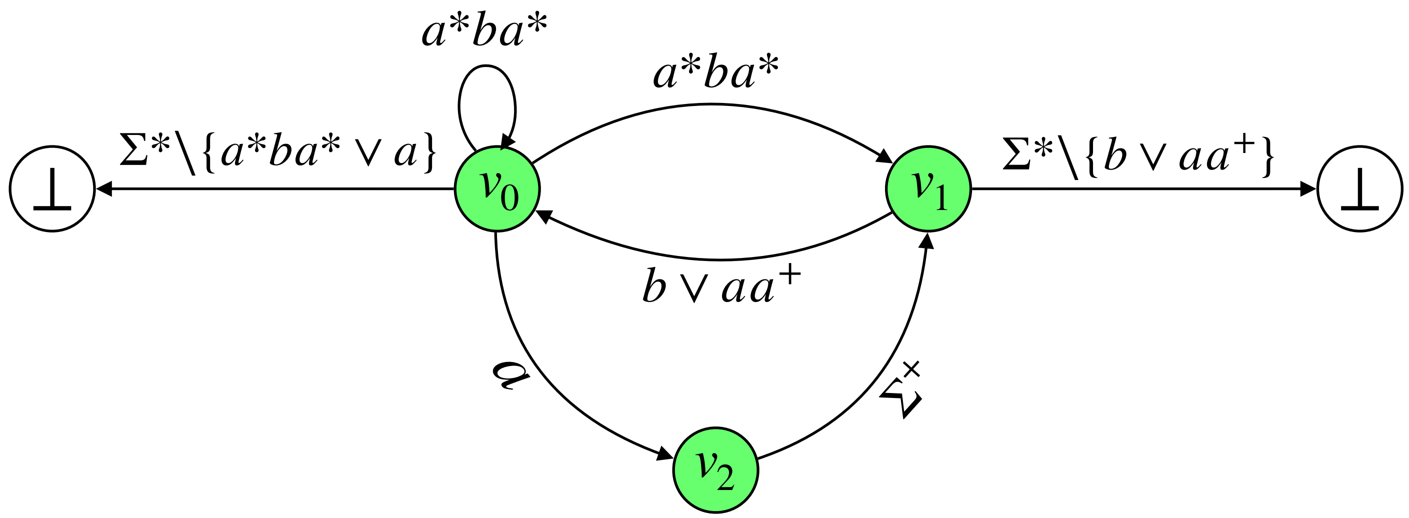

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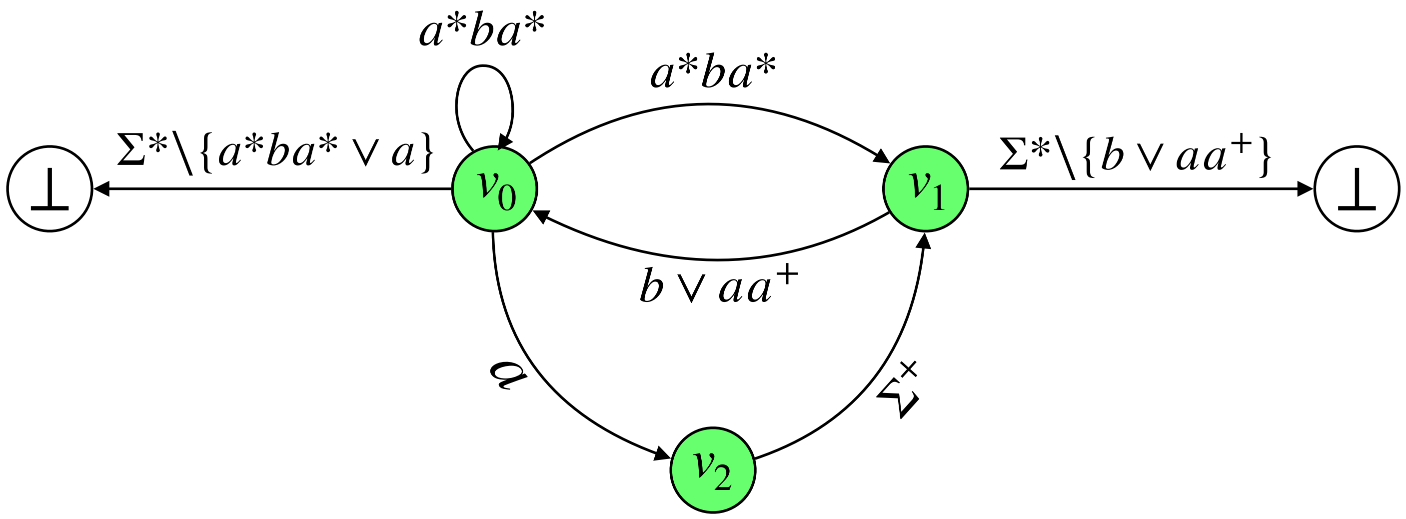

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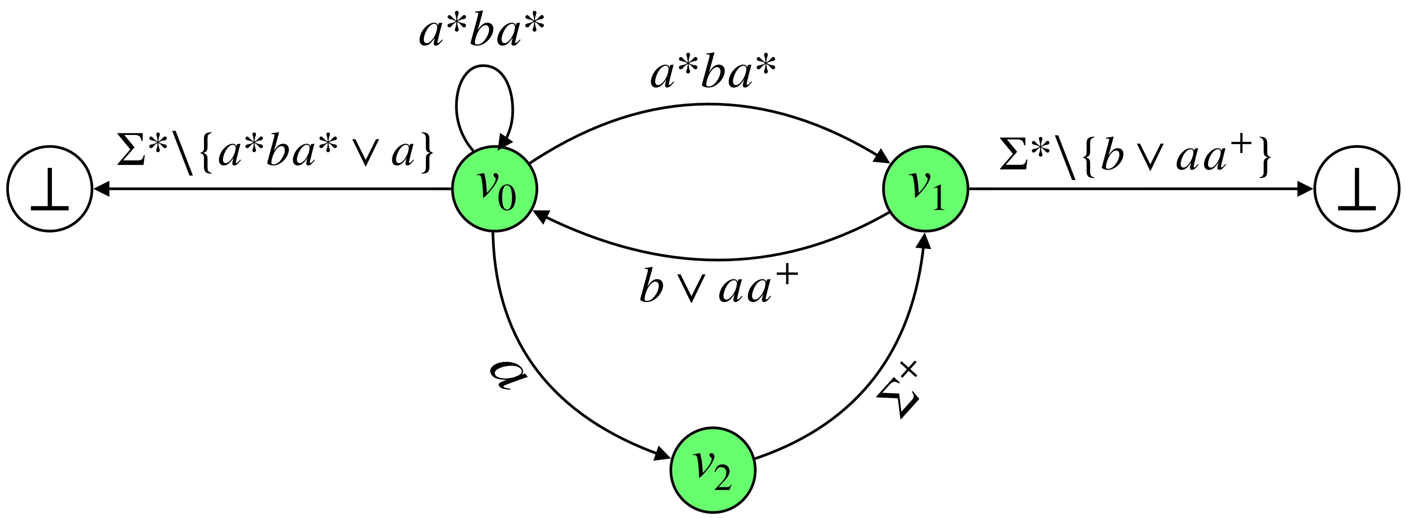

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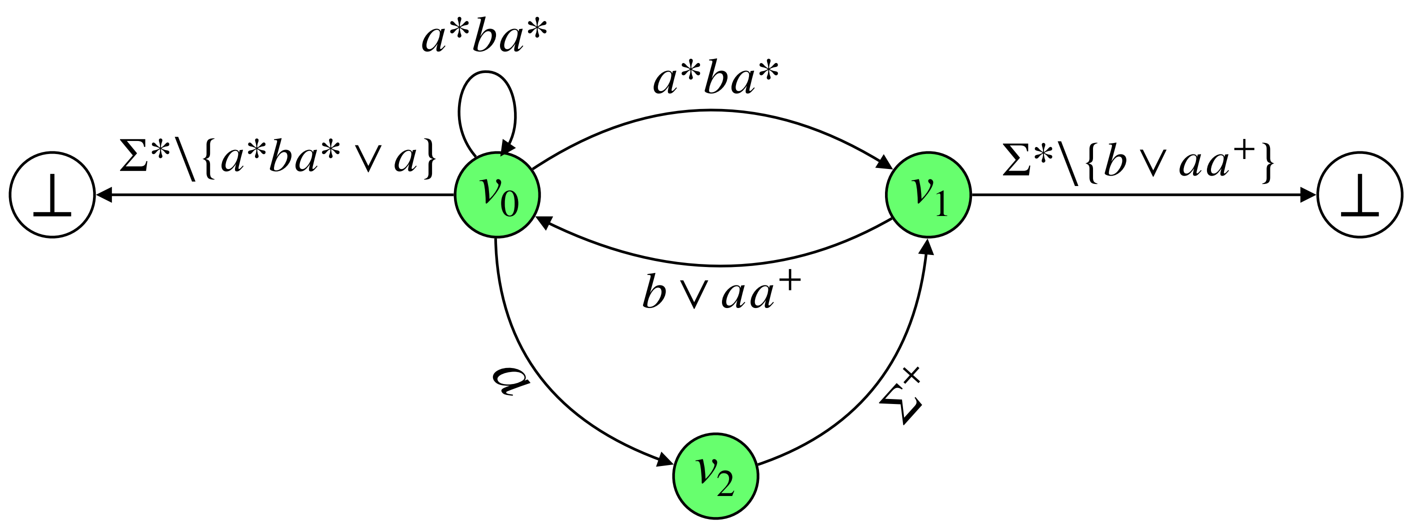

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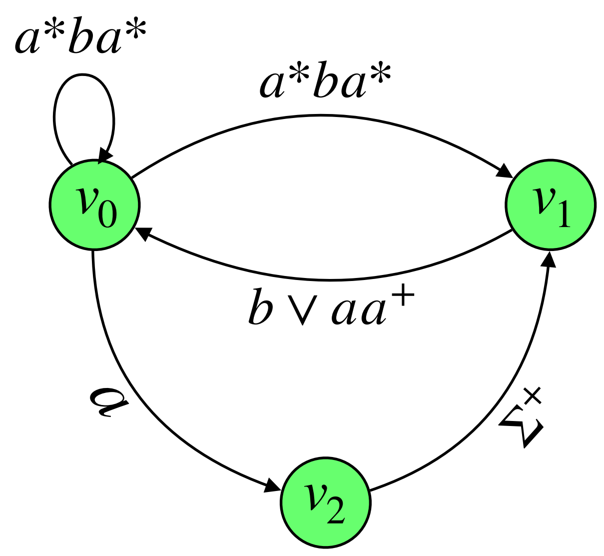
Input: Arena $\mathscr{A}$, initial vertex $v_0 \in V$ and set of safe vertices S.

Output: Yes iff $\exists \widetilde{\sigma} \,.\, \forall k \,.\, Out^k(v_0, \widetilde{\sigma}) \subseteq S^\omega$.

Example



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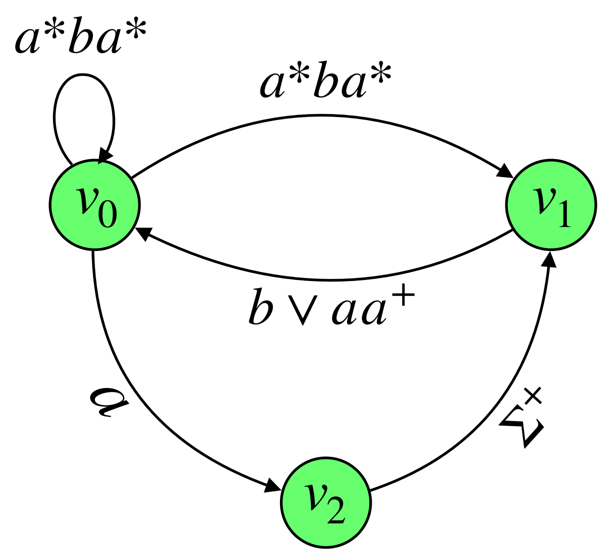

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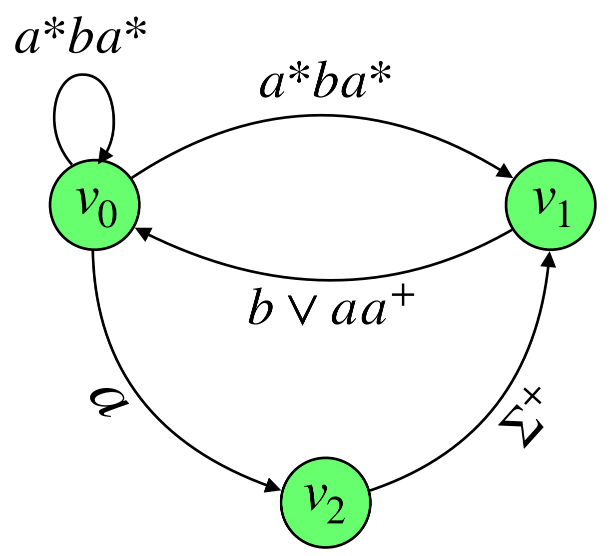

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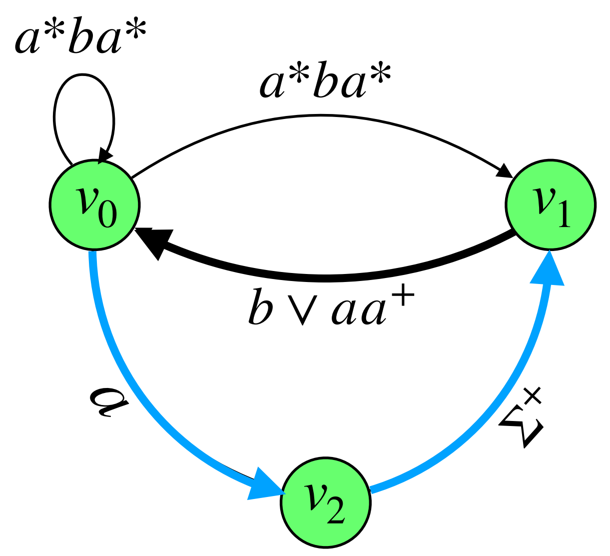

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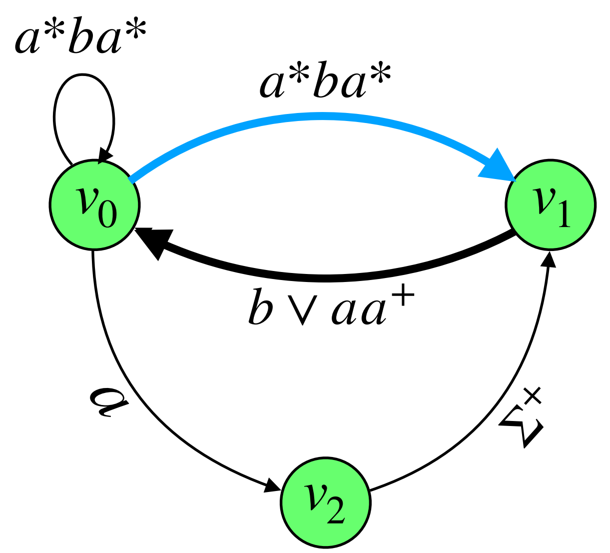

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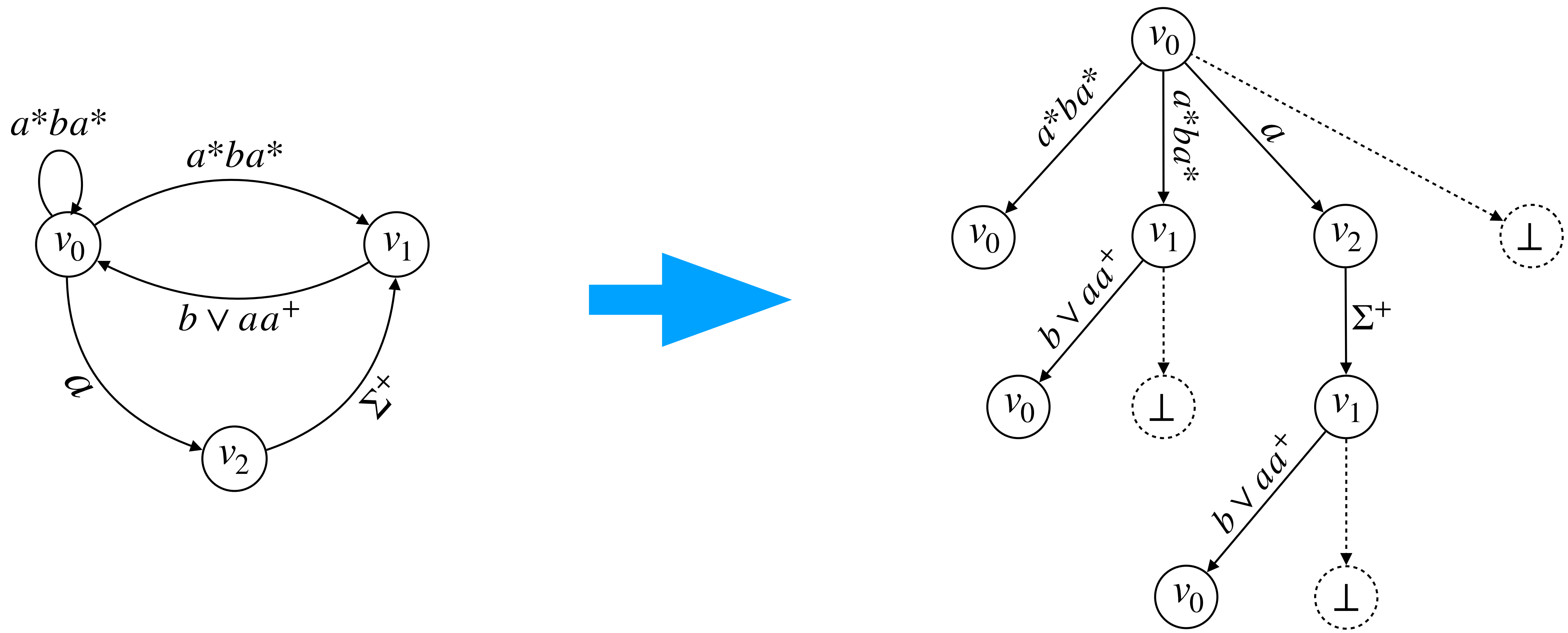
Resolution of safe coalition problem



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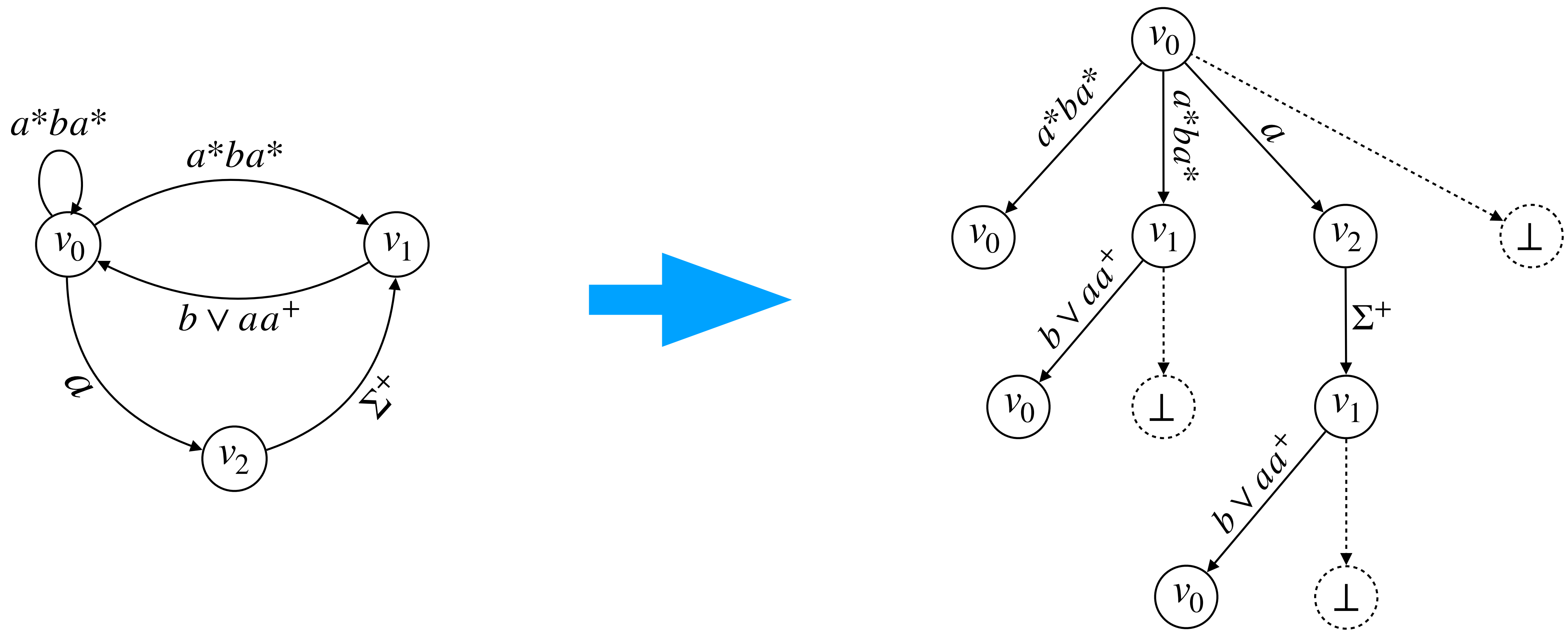

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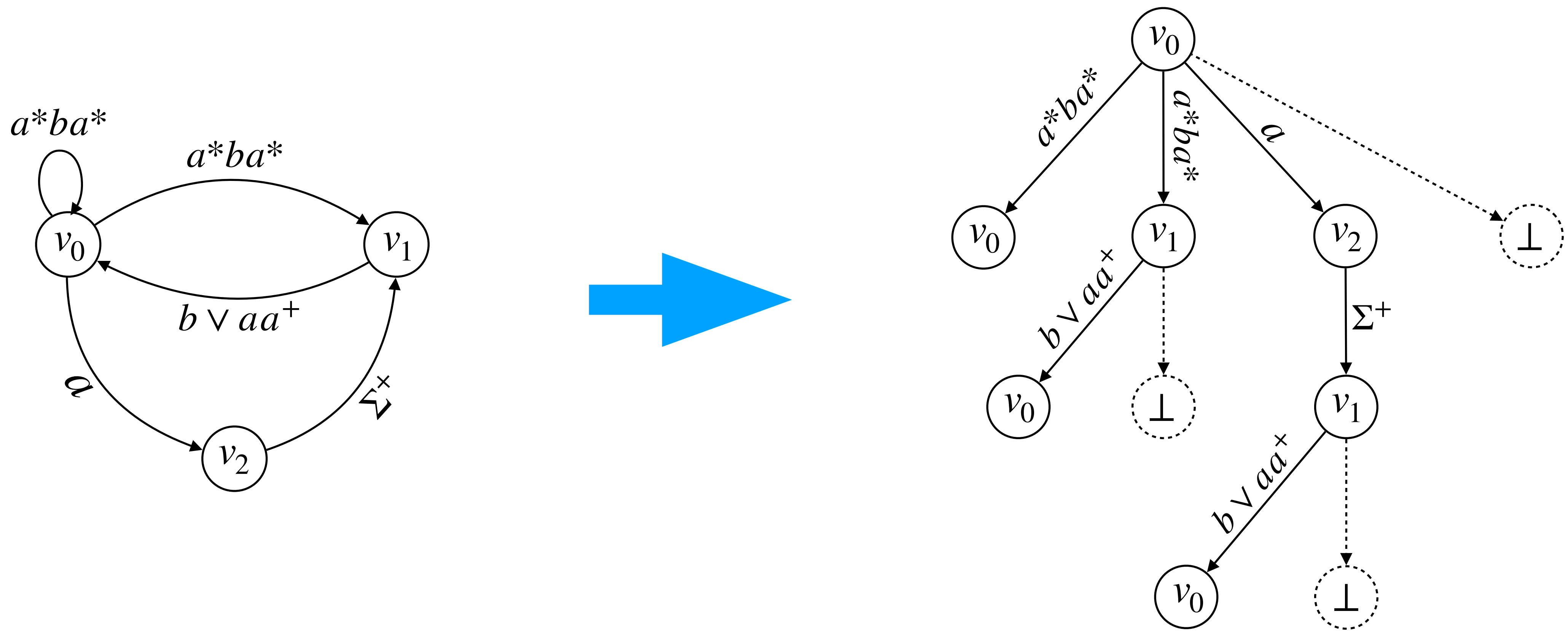

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  - Label nodes with corresponding vertices, and edges with languages.
- Terminate a branch if:
  - either some label repeats in the same branch,
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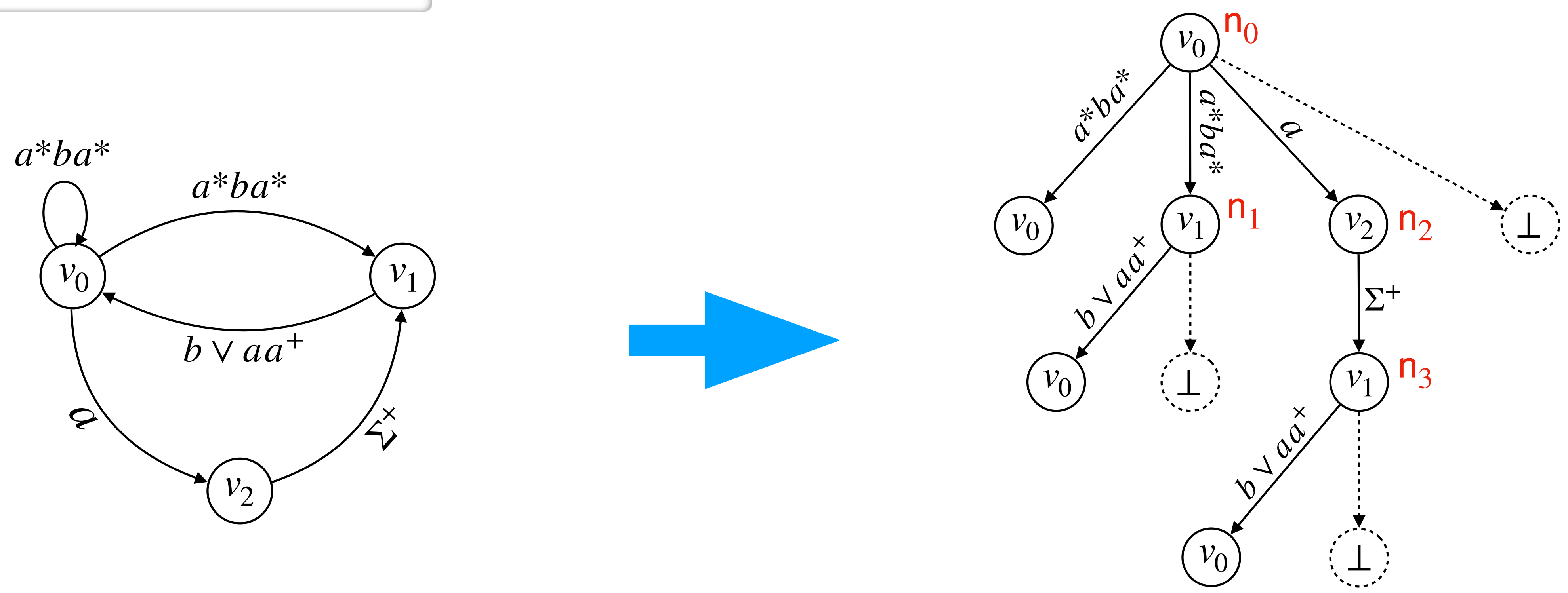
- Intuitively, if a vertex repeats in $\mathscr{A}$, coalition may take the same strategy.
  - If it ensures safety in the first occurrence, then also for the later.

Resolution of safe coalition problem

Correctness of Tree Unfolding



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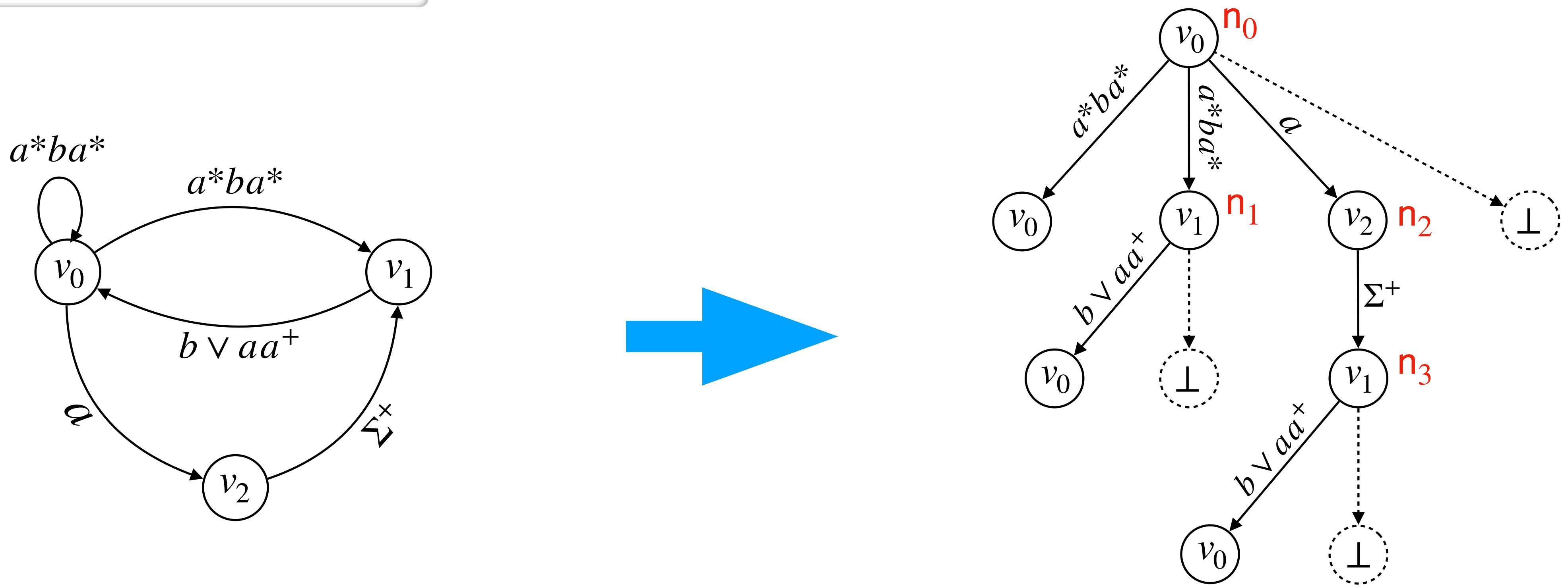

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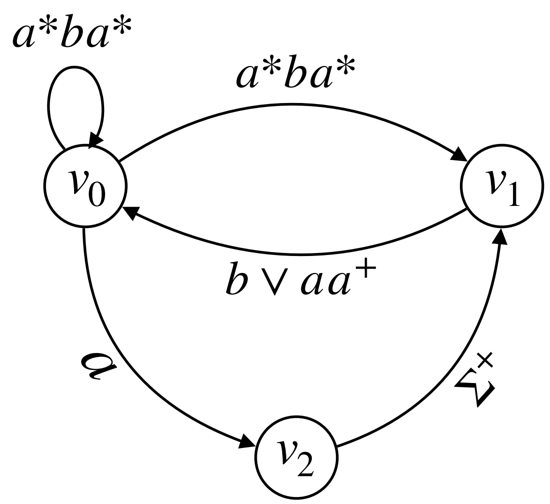

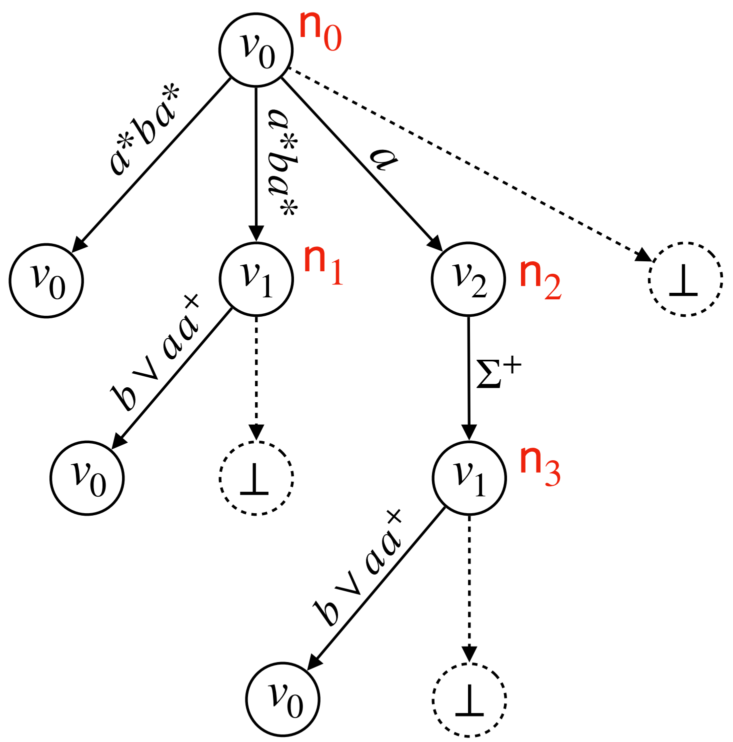

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Coalition has a winning strategy in $\mathscr{A}$ ⟺ Coalition has a winning strategy in $\mathscr{T}$

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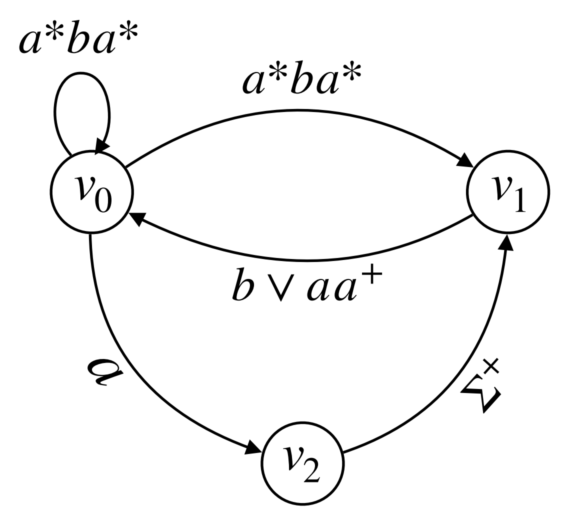

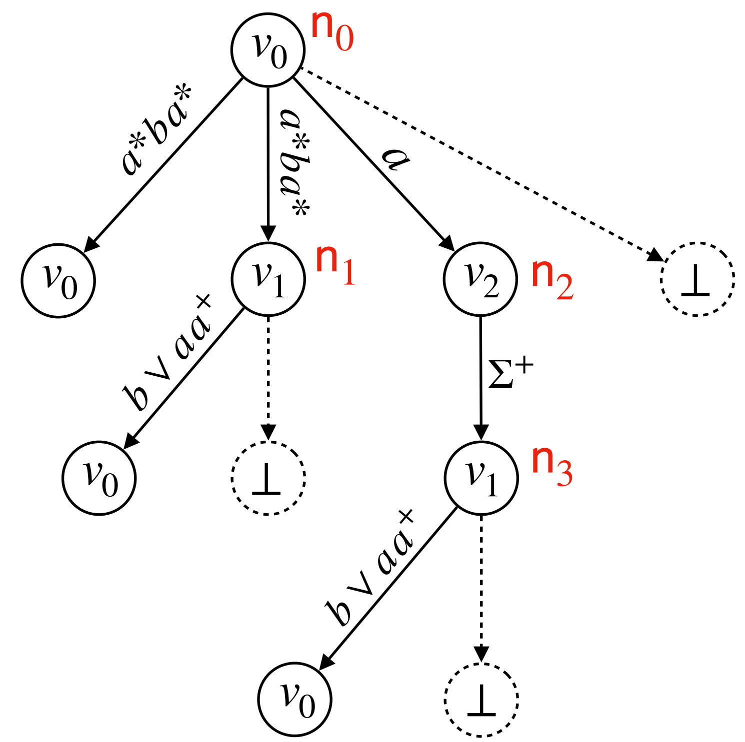

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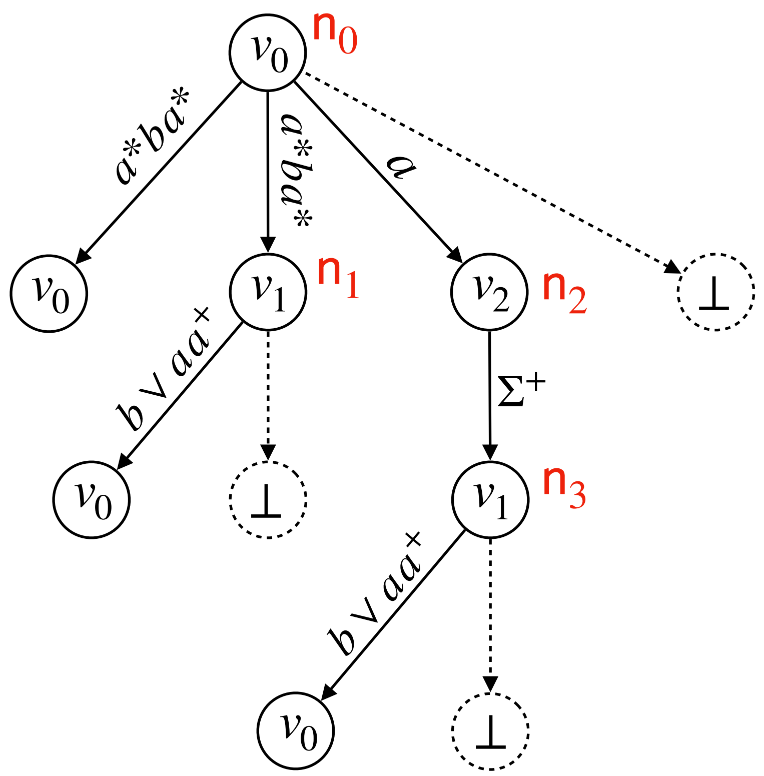
Safe coalition problem reduces to existence of a winning coalition strategy in the finite tree unfolding.

Decidability of safe coalition problem

EXPSPACE algorithm



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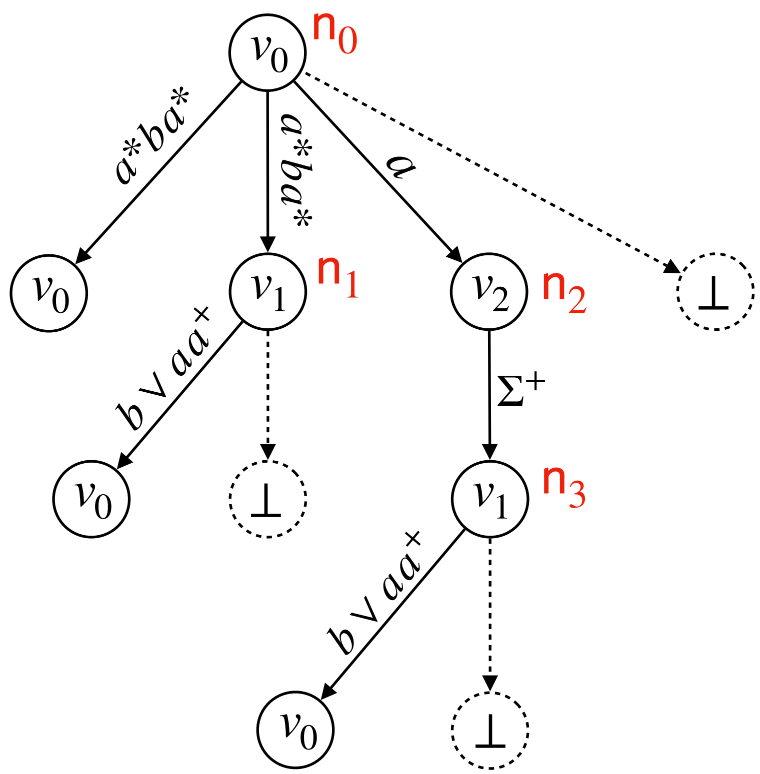

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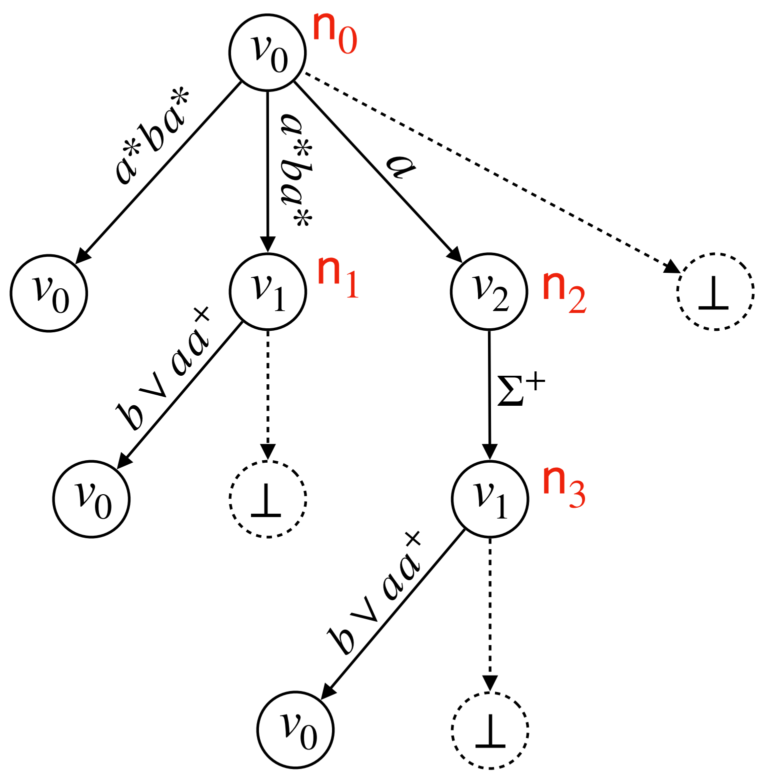

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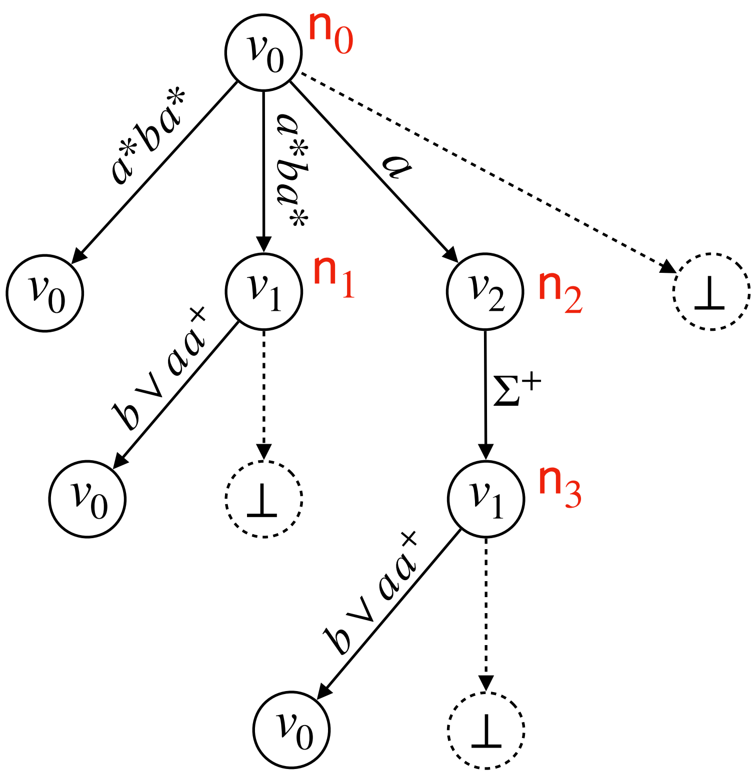

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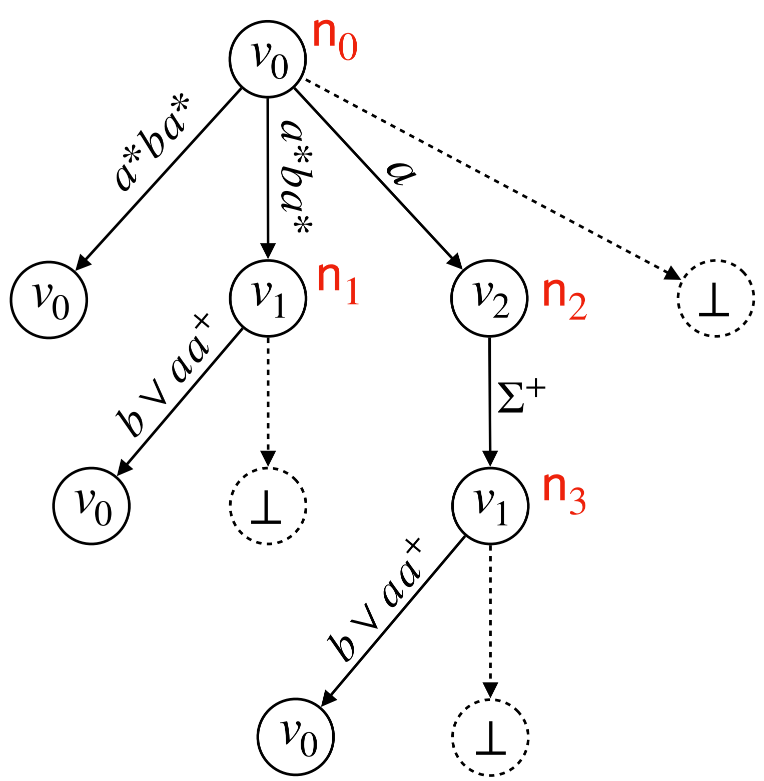

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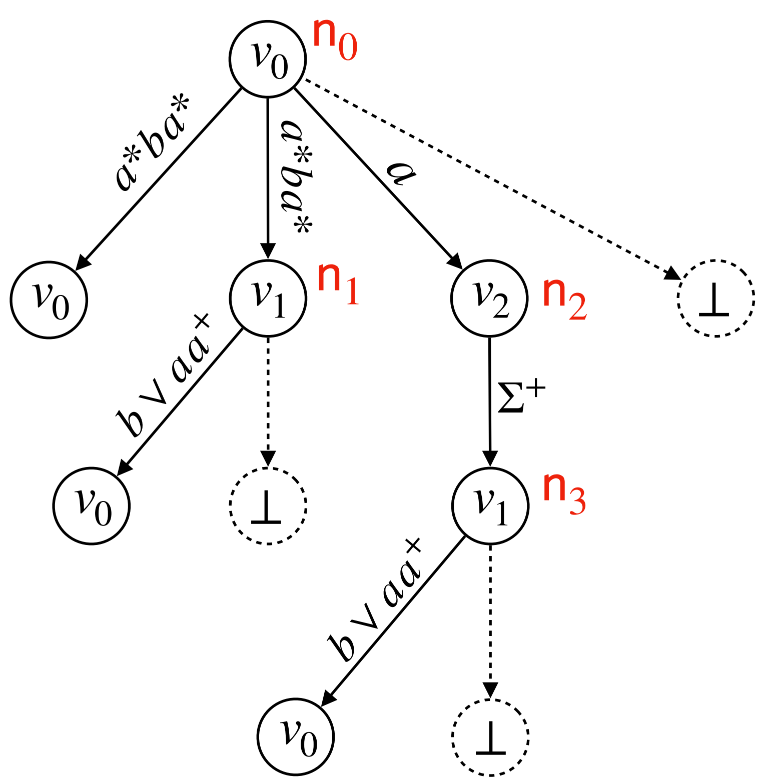
  - a (global) state is an r tuple of (local) states.
  - a (global) state corresponds to different branches.

Decidability of safe coalition problem

EXPSPACE algorithm



- m = number of internal nodes in $\mathscr{T}$; $m = O(2^{|V|})$.
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- A coalition Strategy in $\mathscr{T}$ is a mapping $\tau : N_{int} \to \Sigma^\omega$.
  - Equivalently, $\tau \in (\Sigma^\omega)^m$.
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- Construct safety automaton $\mathscr{B}$ over alphabet Σ^m :
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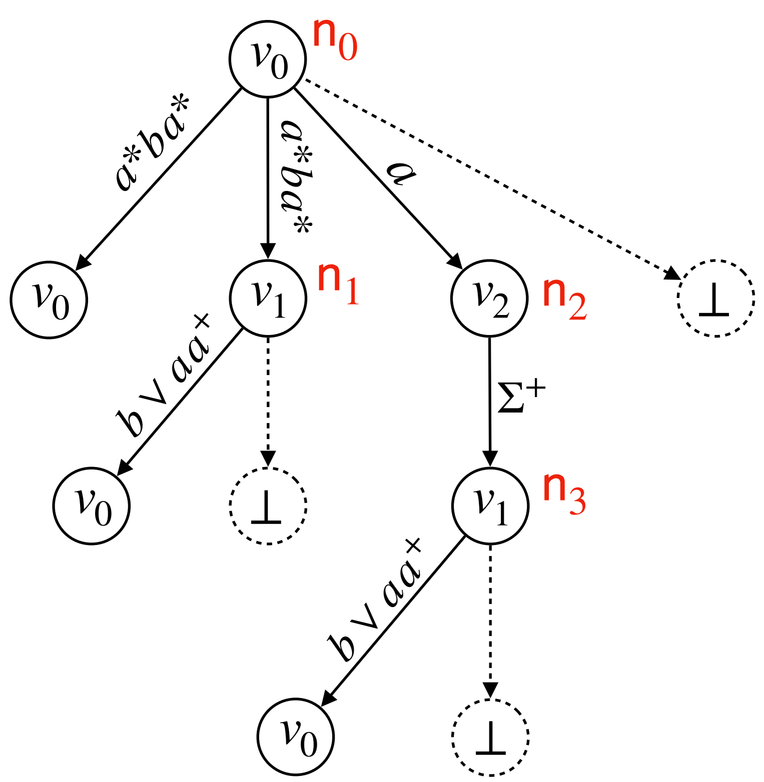

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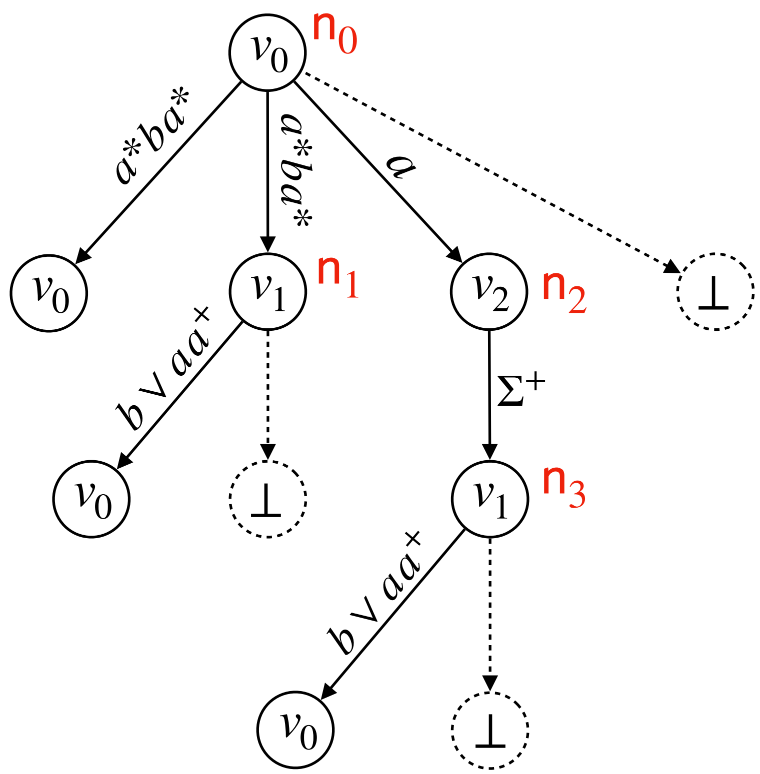

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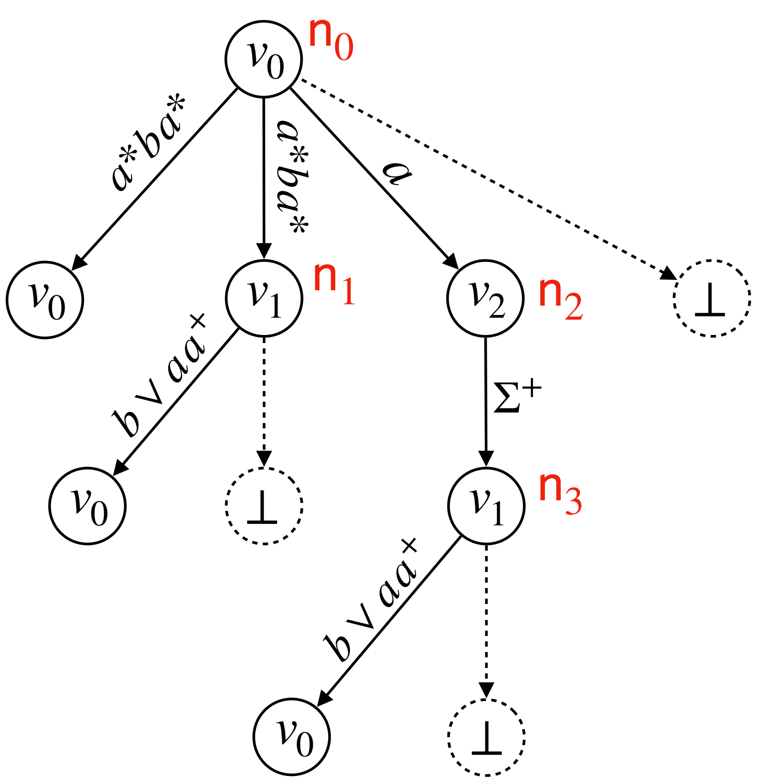

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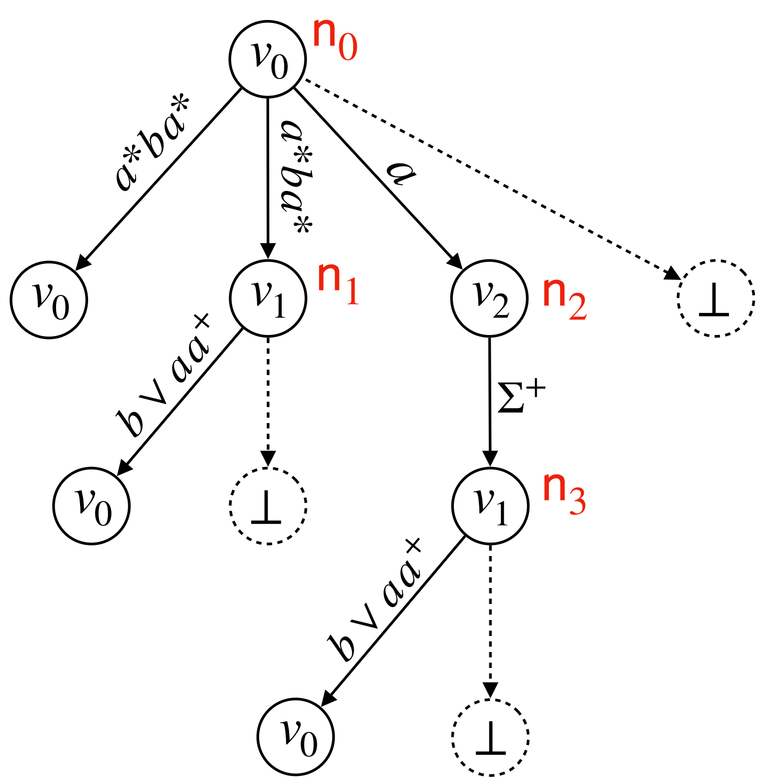
Decidability of safe coalition problem

EXPSPACE algorithm



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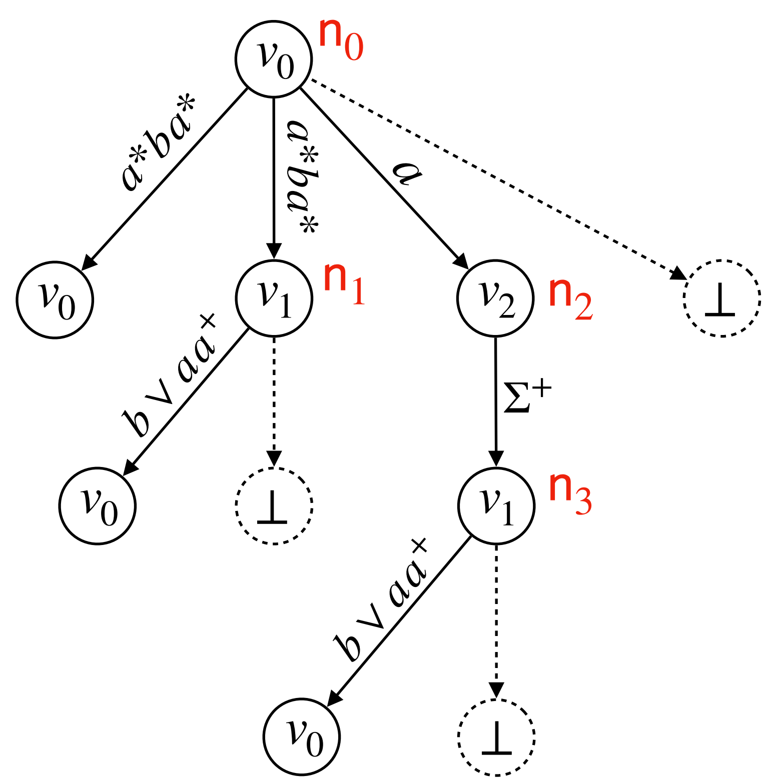
Safe coalition problem is in **EXPSPACE**

Decidability of safe coalition problem

EXPSPACE algorithm



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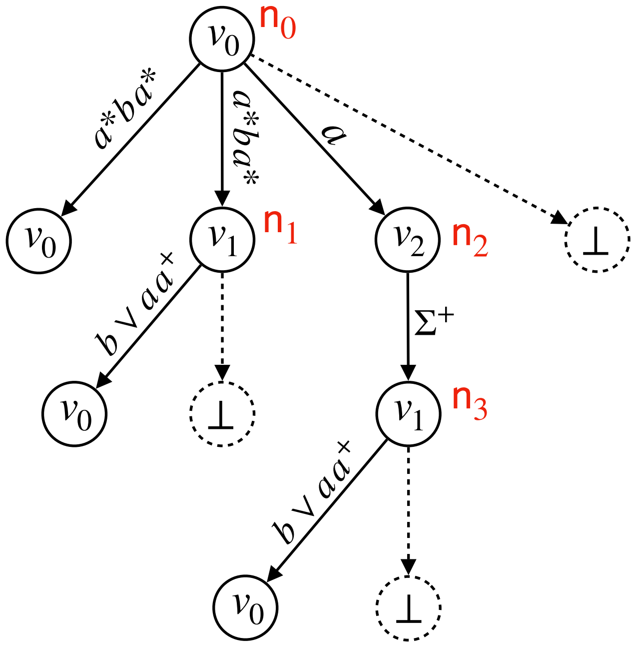
Safe coalition problem is in **EXPSPACE** and PSPACE-hard.

Example



v_0
n_0
a^*ba^*
a^*ba^*
a
v_0
v_1
n_1
v_2
n_2
$\perp$
$b \vee aa^+$
Σ^+
v_0
$\perp$
v_1
n_3
$b \vee aa^+$
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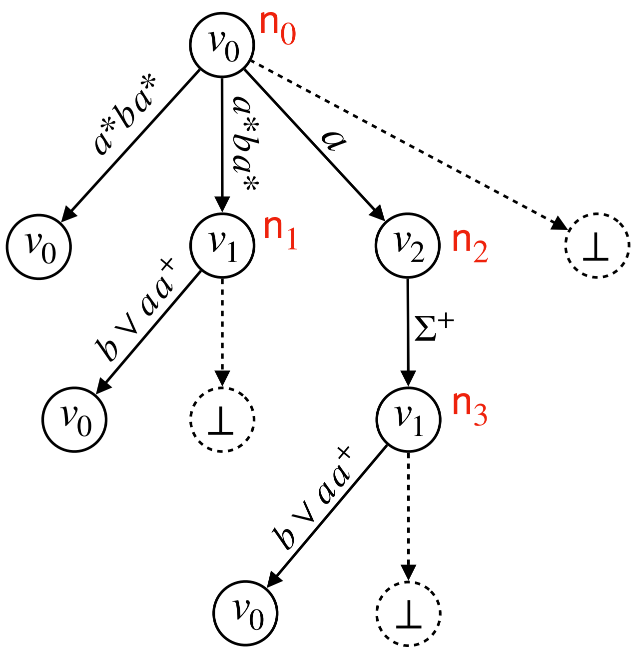
Example



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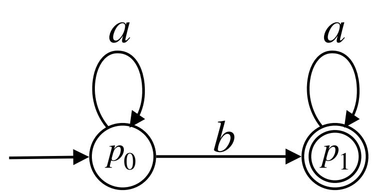
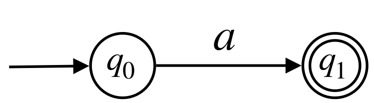


a :



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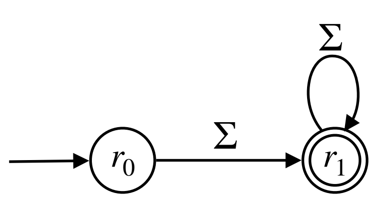

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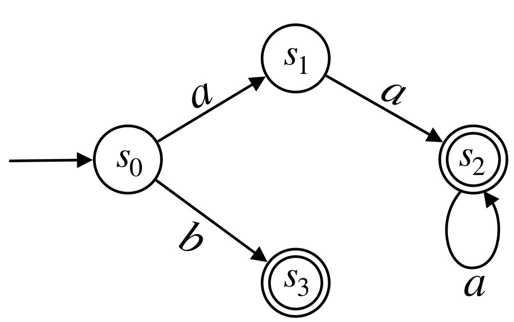

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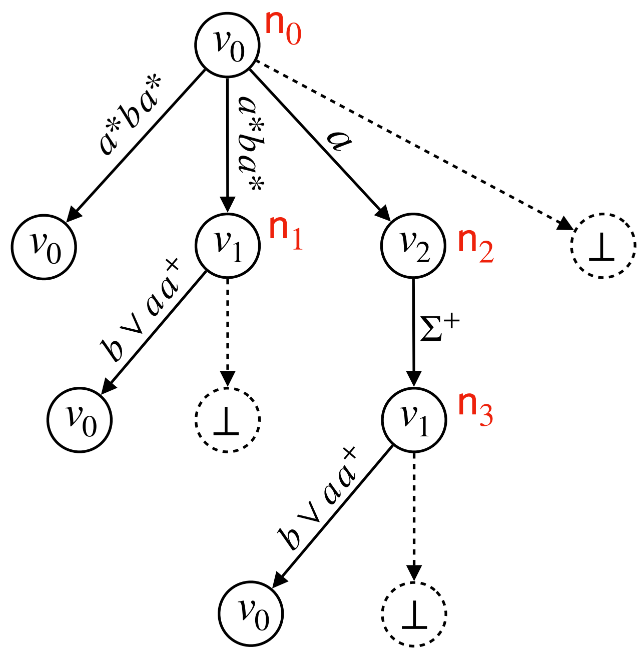
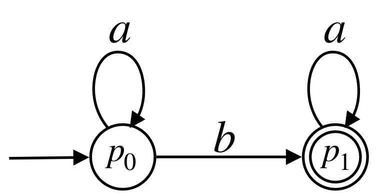
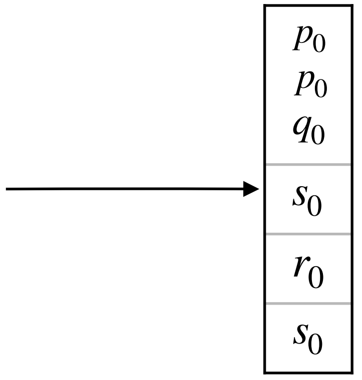


a^*ba^* :





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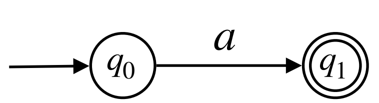

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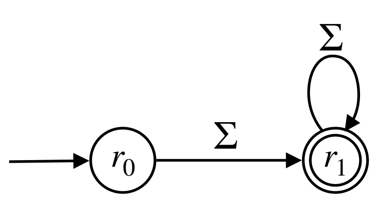

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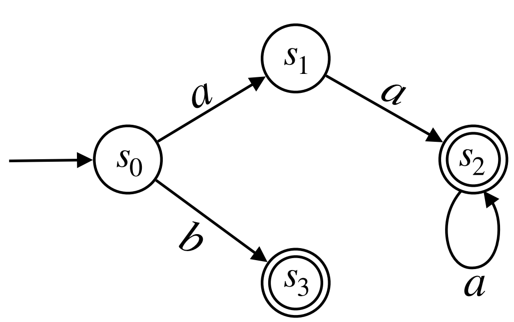

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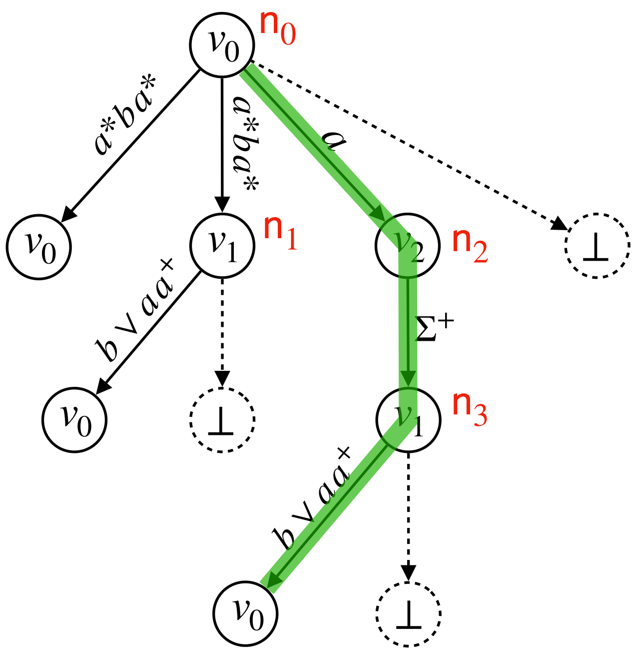

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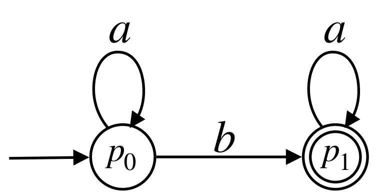

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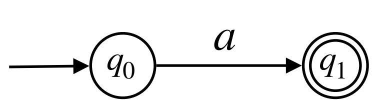

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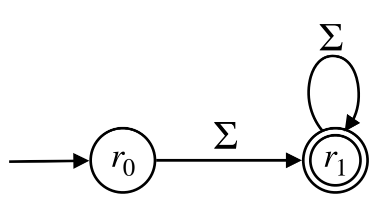

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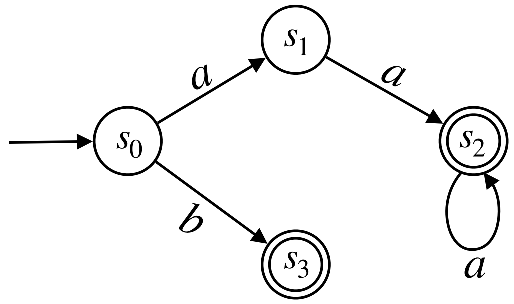

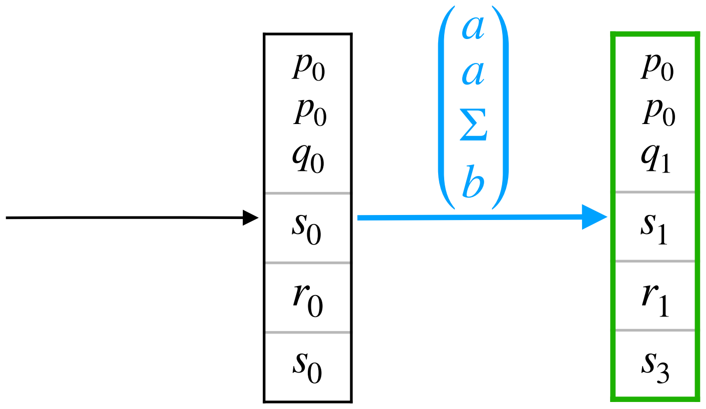

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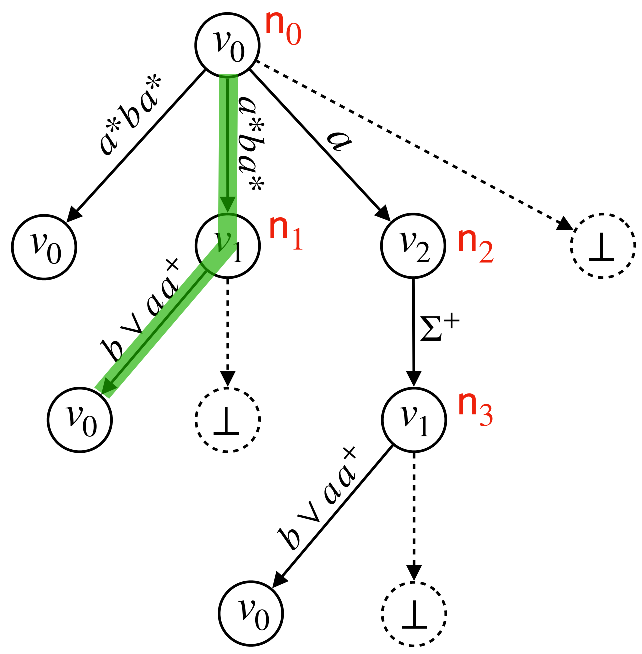

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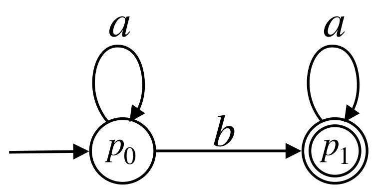

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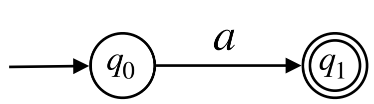

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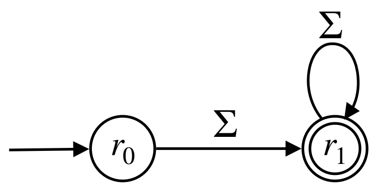

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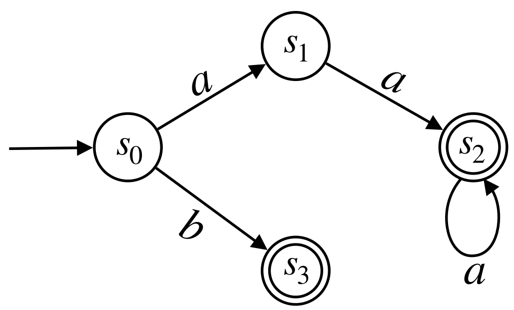

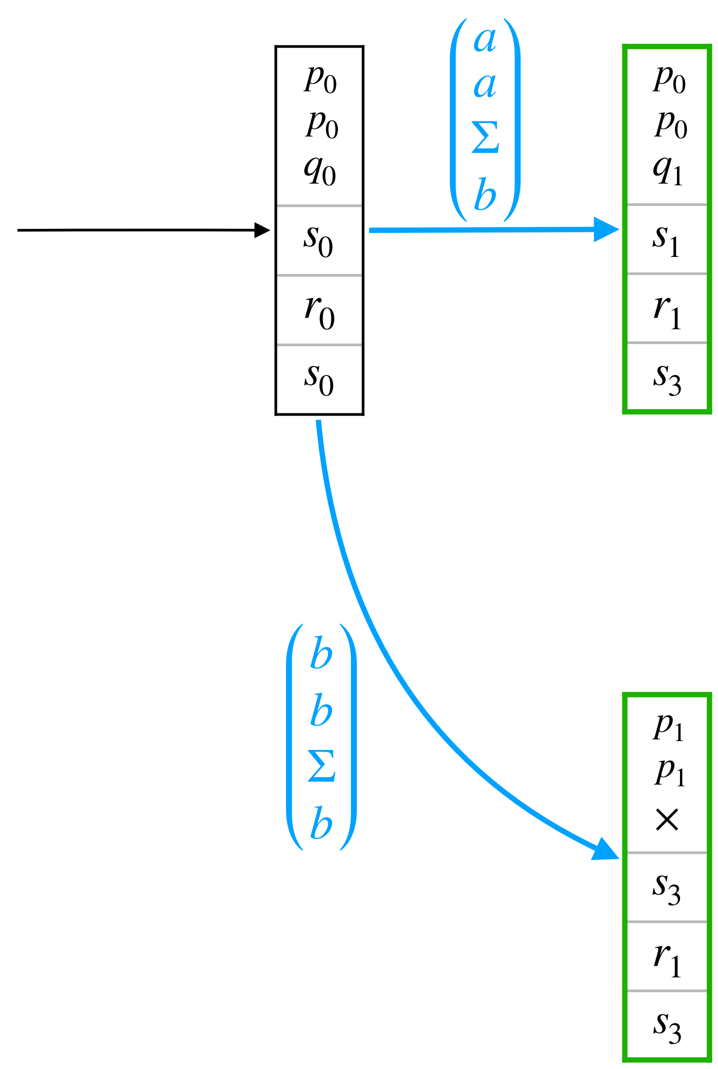

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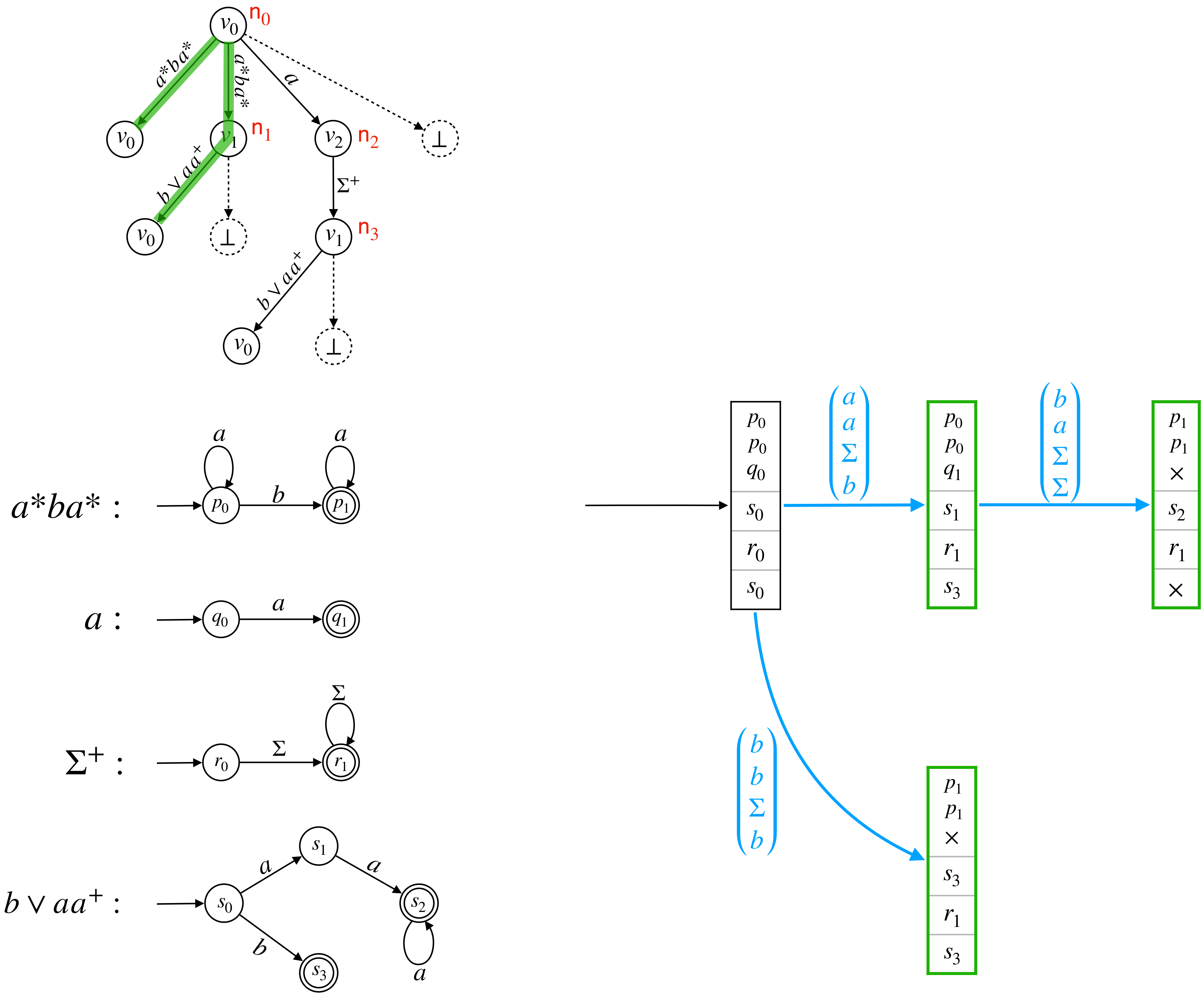

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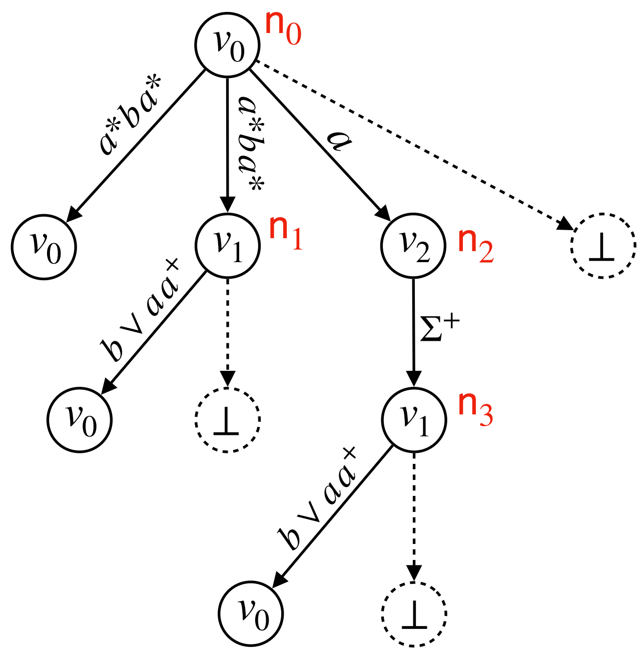

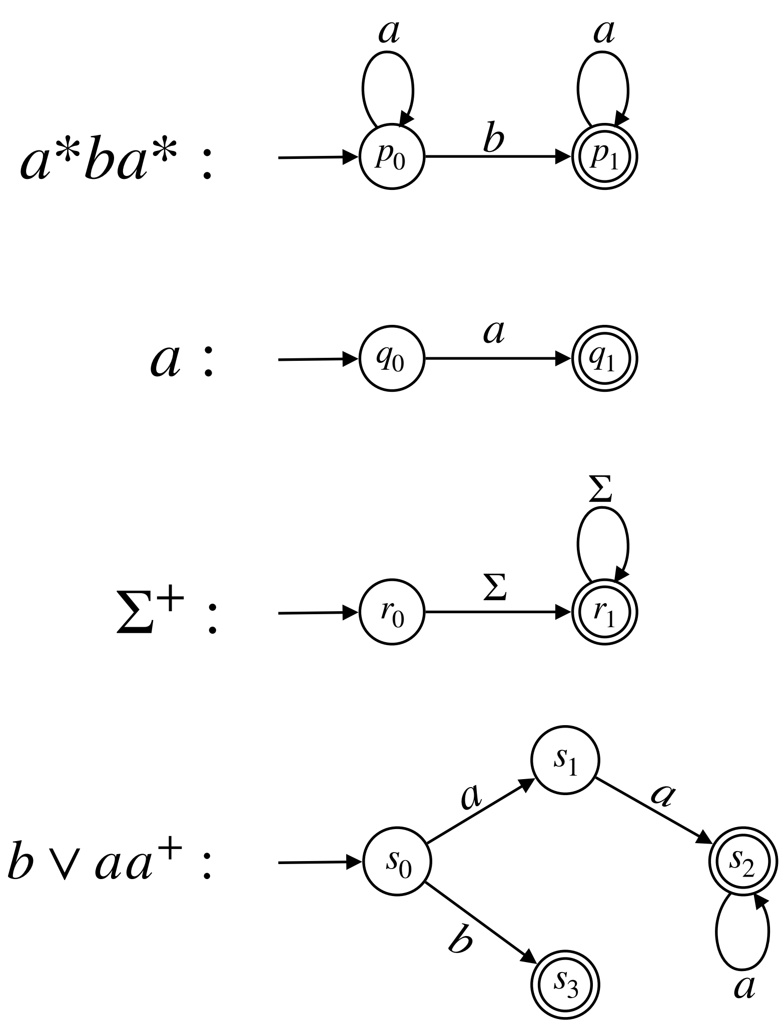

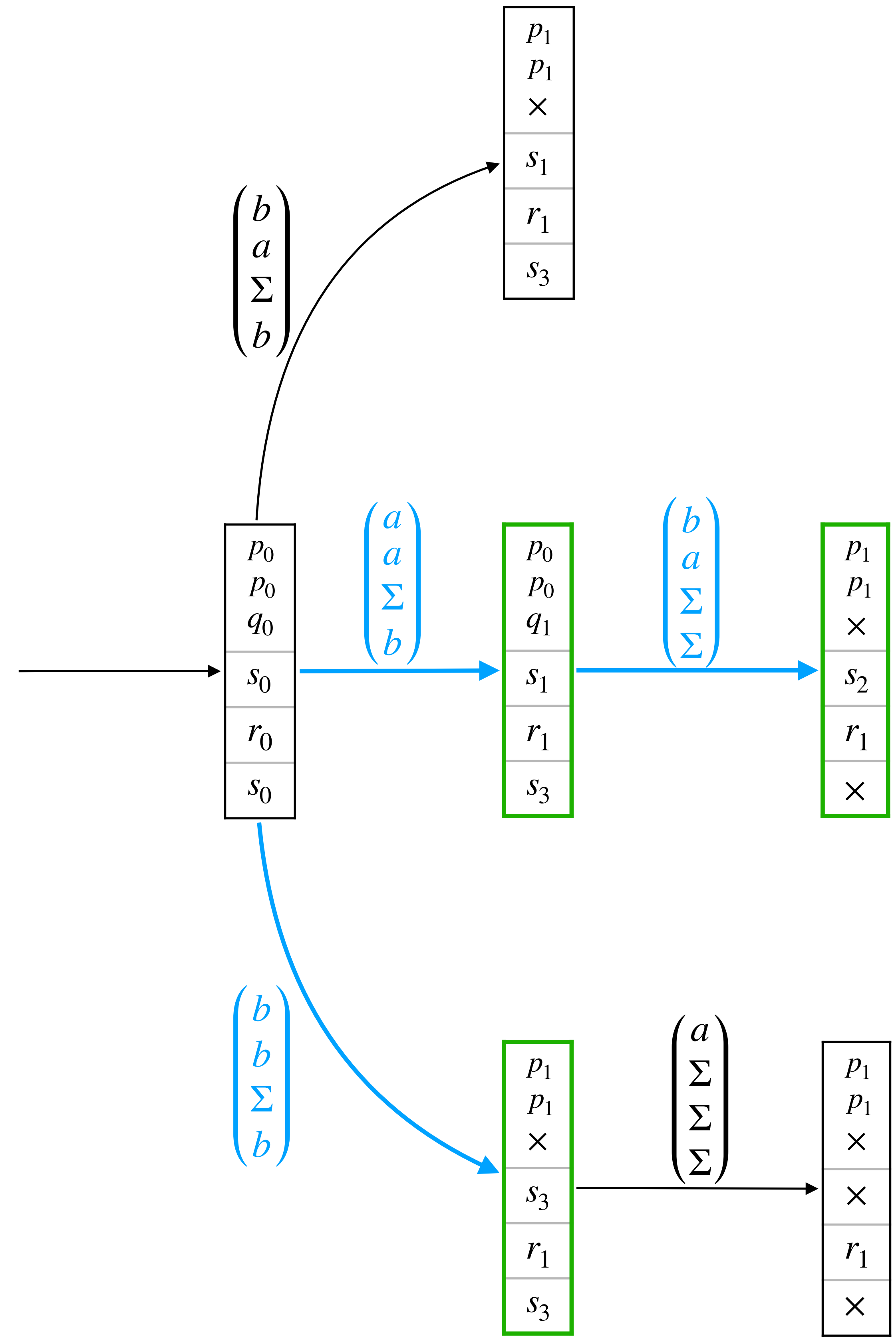

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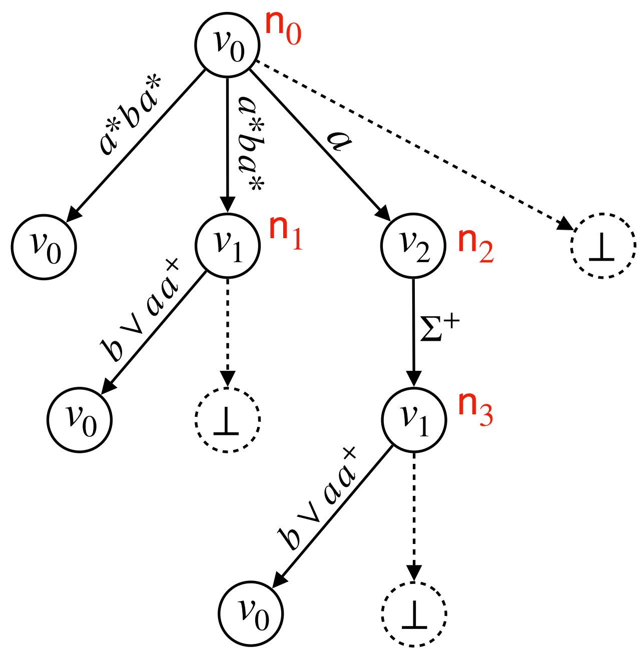

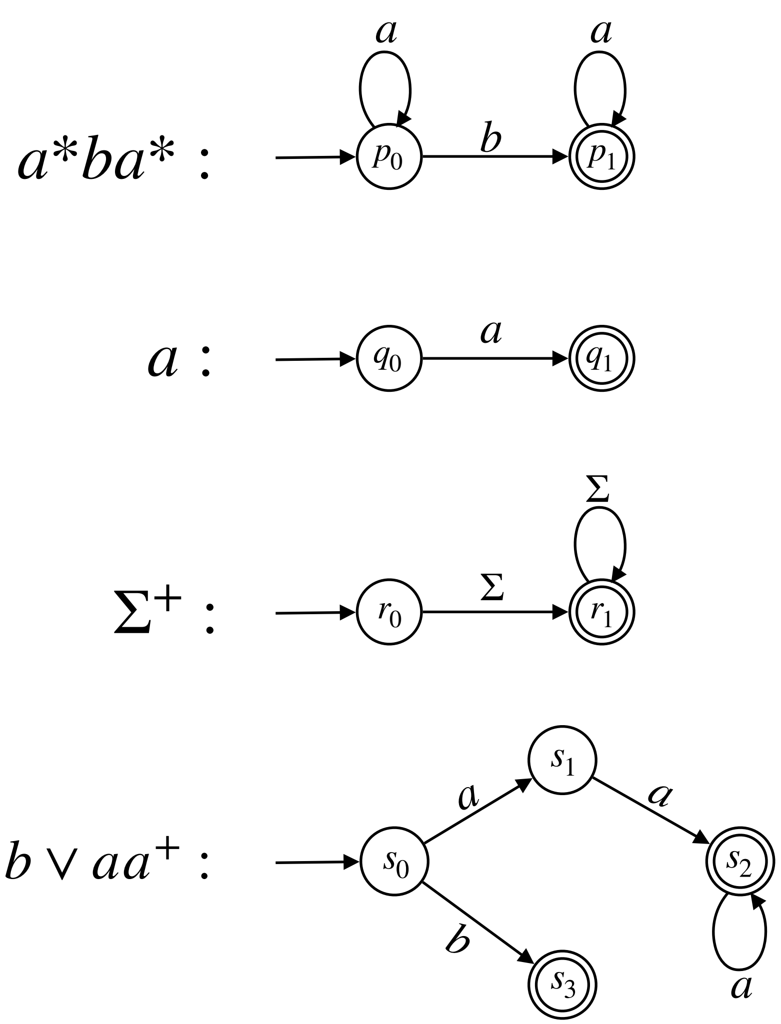

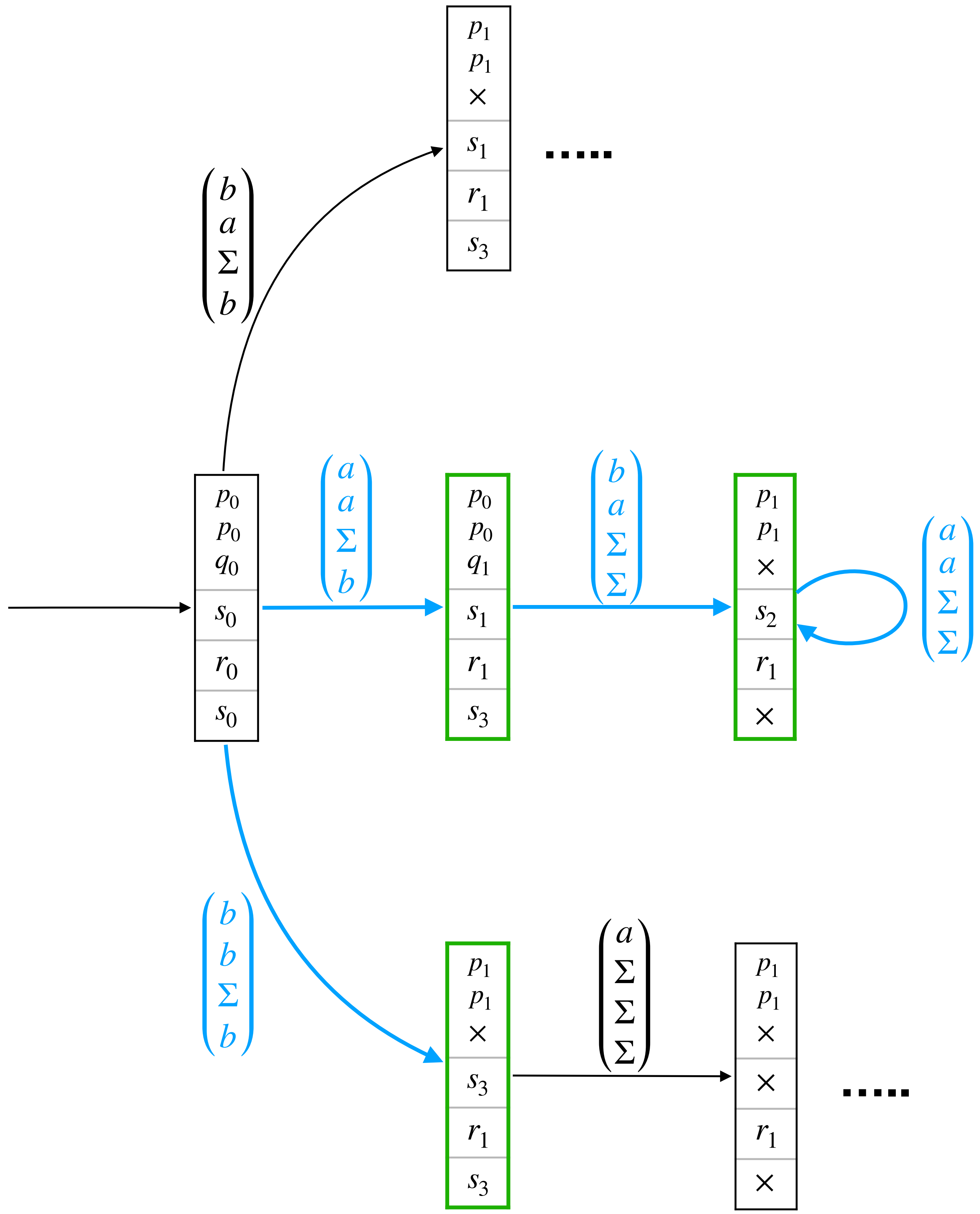

Synthesizing a winning strategy

- If $\mathscr{L}(\mathscr{B}) \neq \emptyset$, an accepting word of $\mathscr{B}$ is $\mathsf{u} \,.\, \mathsf{v}^{\omega}$.
- Define: $\lambda(\mathsf{n}_i) = \mathsf{u}_i \,.\, \mathsf{v}_i^{\omega}$
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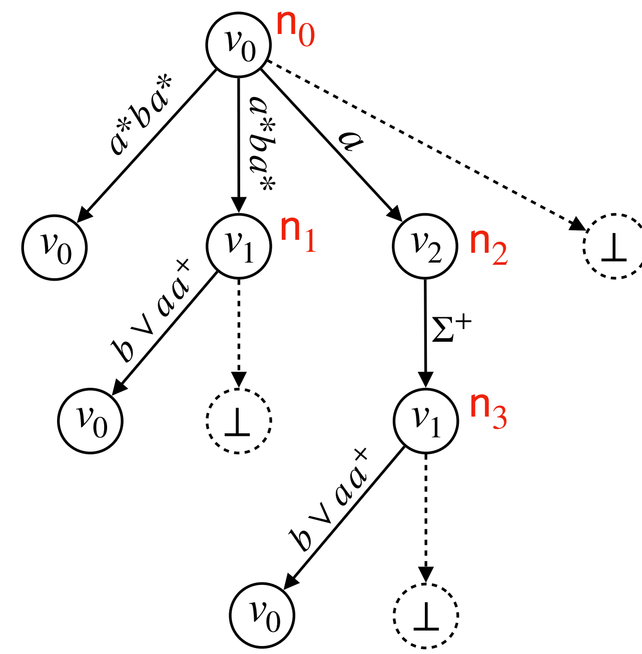

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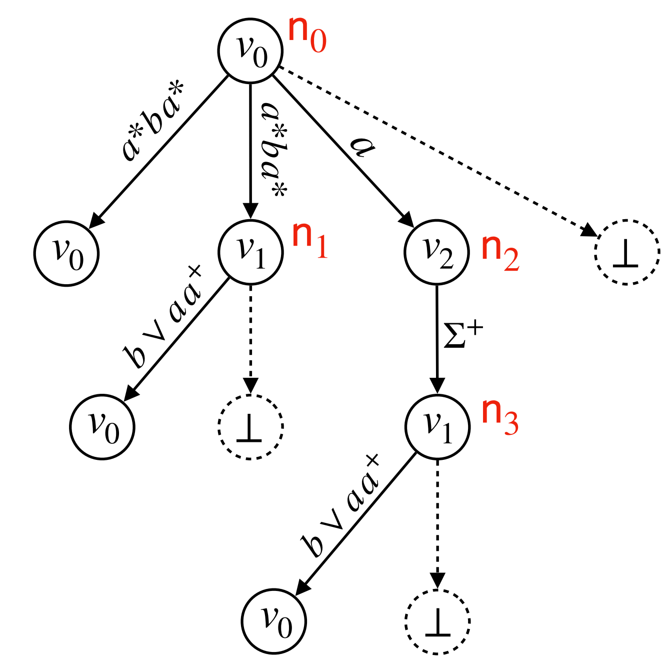
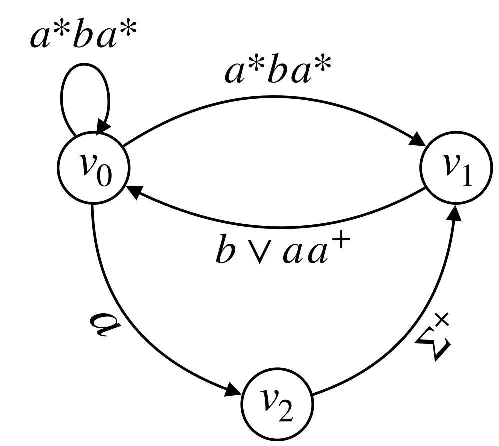
Transfer λ to a **winning** strategy $\widetilde{\sigma}$ in $\mathscr{G}$:





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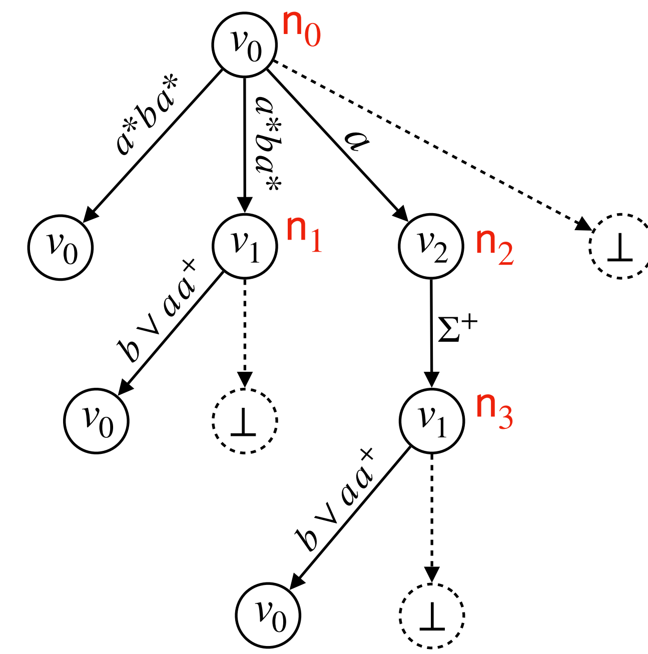

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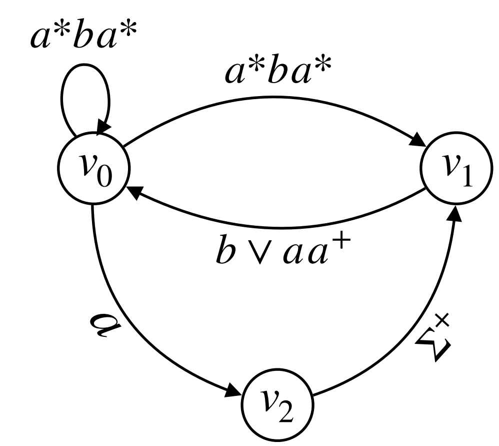

- A history V^+ in $\mathscr{A}$ uniquely maps to an internal node in $\mathscr{T}$ by $h \mapsto \mathsf{zip}(h)$.
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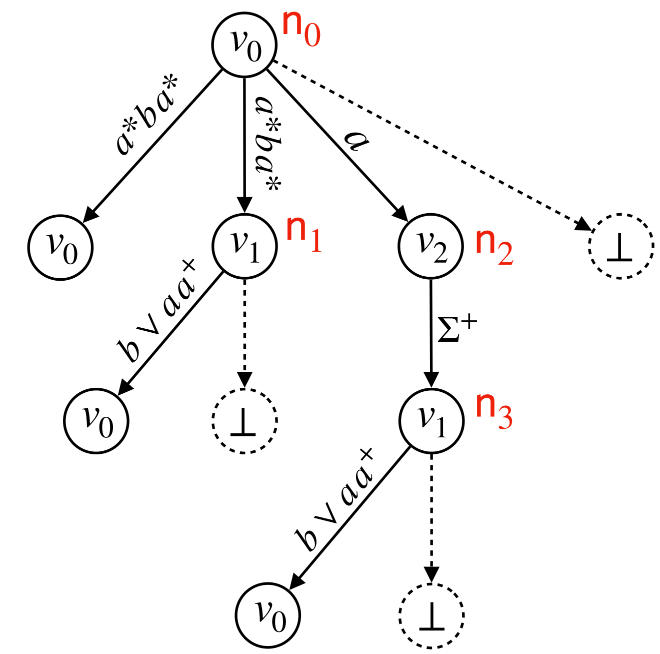

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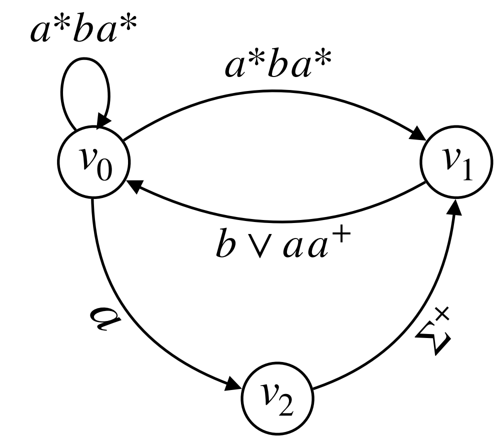

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Synthesizing a winning coalition strategy is in **EXPSPACE**.

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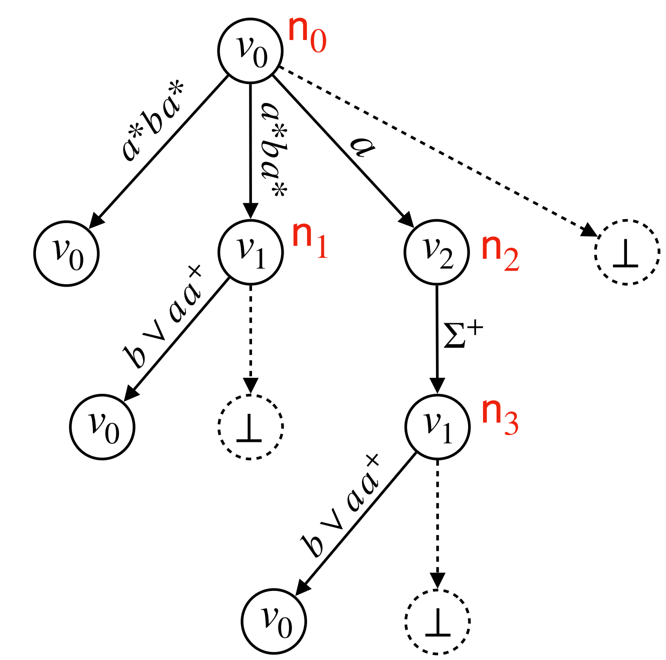

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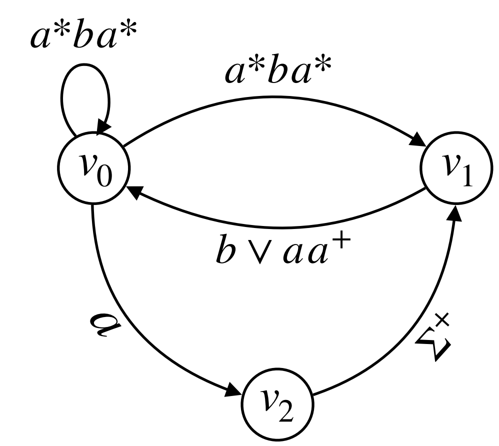
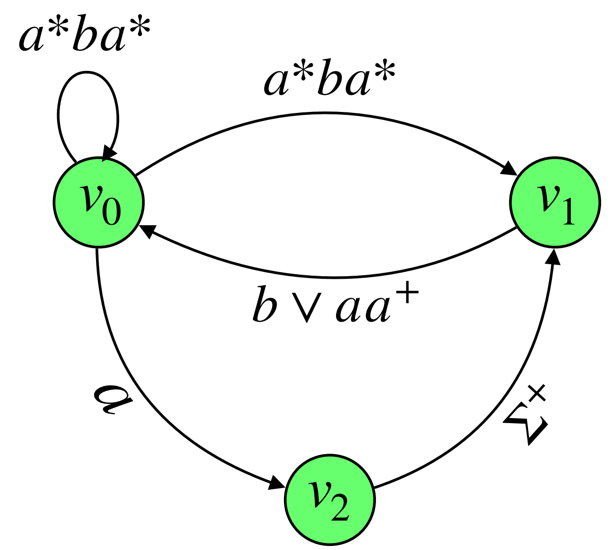


Synthesizing a winning coalition strategy is in **EXPSPACE**.

$\widetilde{\sigma}$ uses memory of size $2^{O(|V|)}$, which is unavoidable.

Conclusion



- Parameterized concurrent arena.
- Coalition problem with safety objective.
- Safe coalition problem is decidable in exponential space.
  - Reduce to coalition problem on finite tree unfolding.
  - Construct doubly-exponential size safety automaton.
  - Check non-emptiness.
- Safe coalition problem is PSPACE-hard.
- Synthesizing a winning strategy (if exists) needs exponential space.
- A winning strategy (if exists) needs exponential size memory.

Future work

- Tight complexity bound.

Future work

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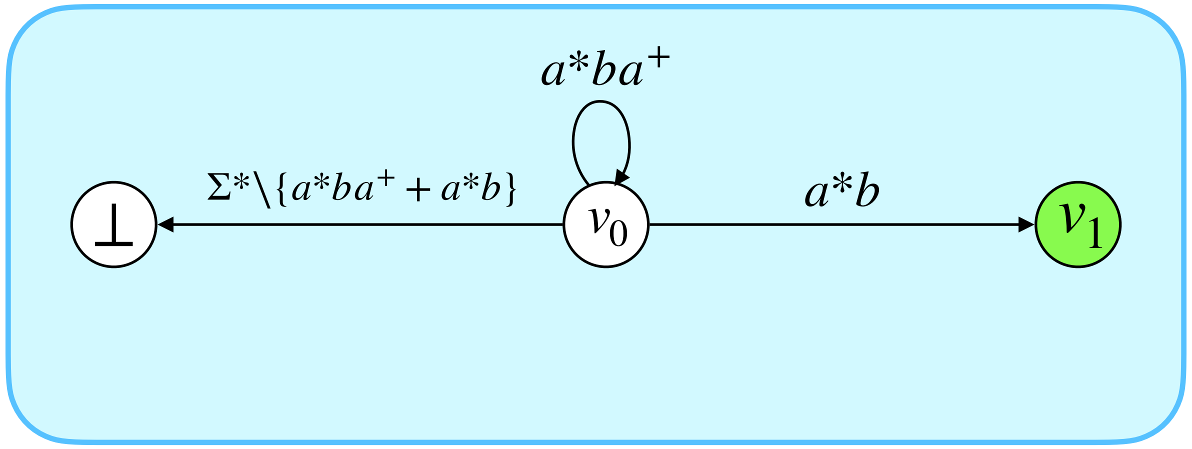
- Reachability condition:



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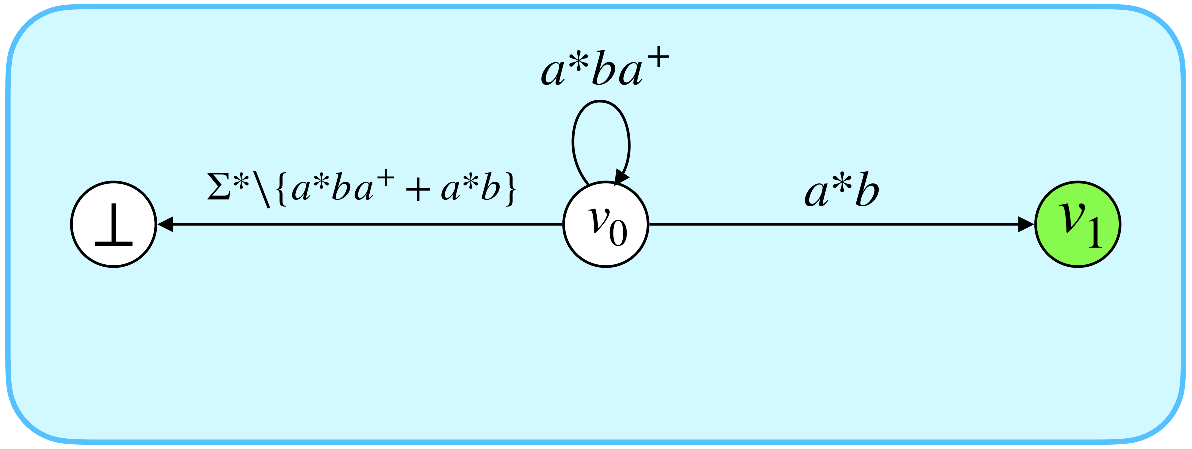

  - Players collectively want to reach v_1 .
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    - Player i plays b at i-th round, a otherwise.

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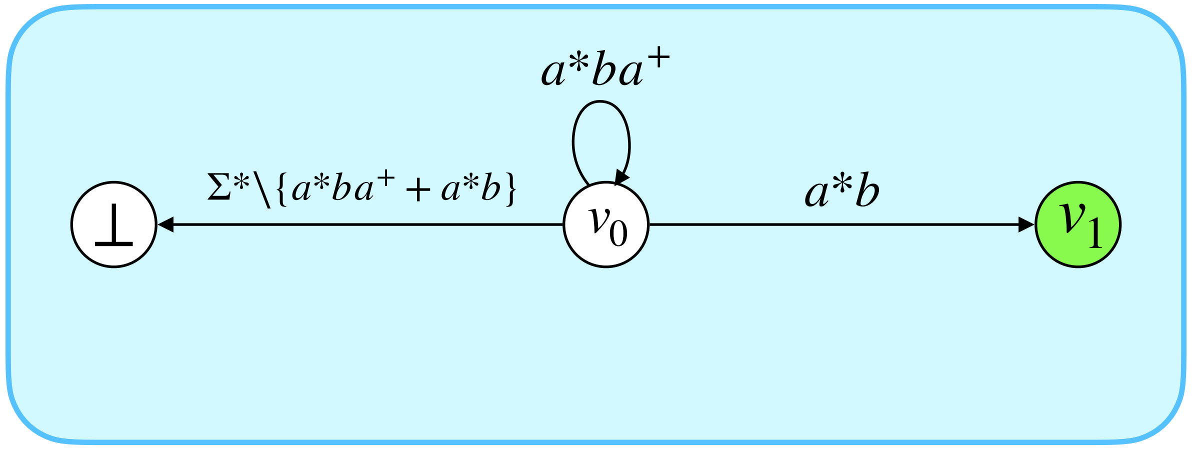

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Thank You