Reactive Synthesis from Temporal and Satisficing Goals

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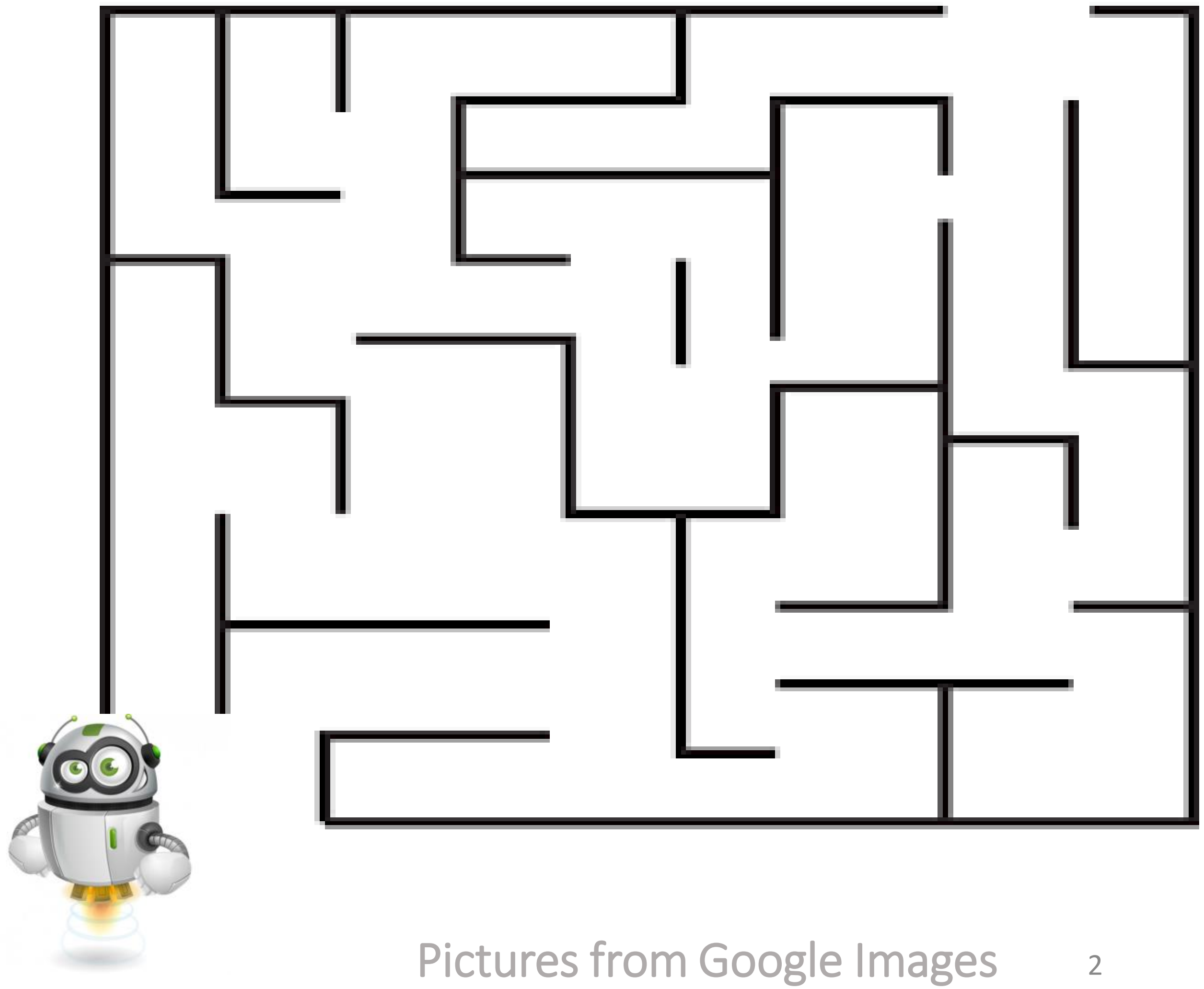
Let’s help the robot navigate

Scene 1:

Fixed Environment

Find **one** path



Pictures from Google Images

Let's help the robot navigate

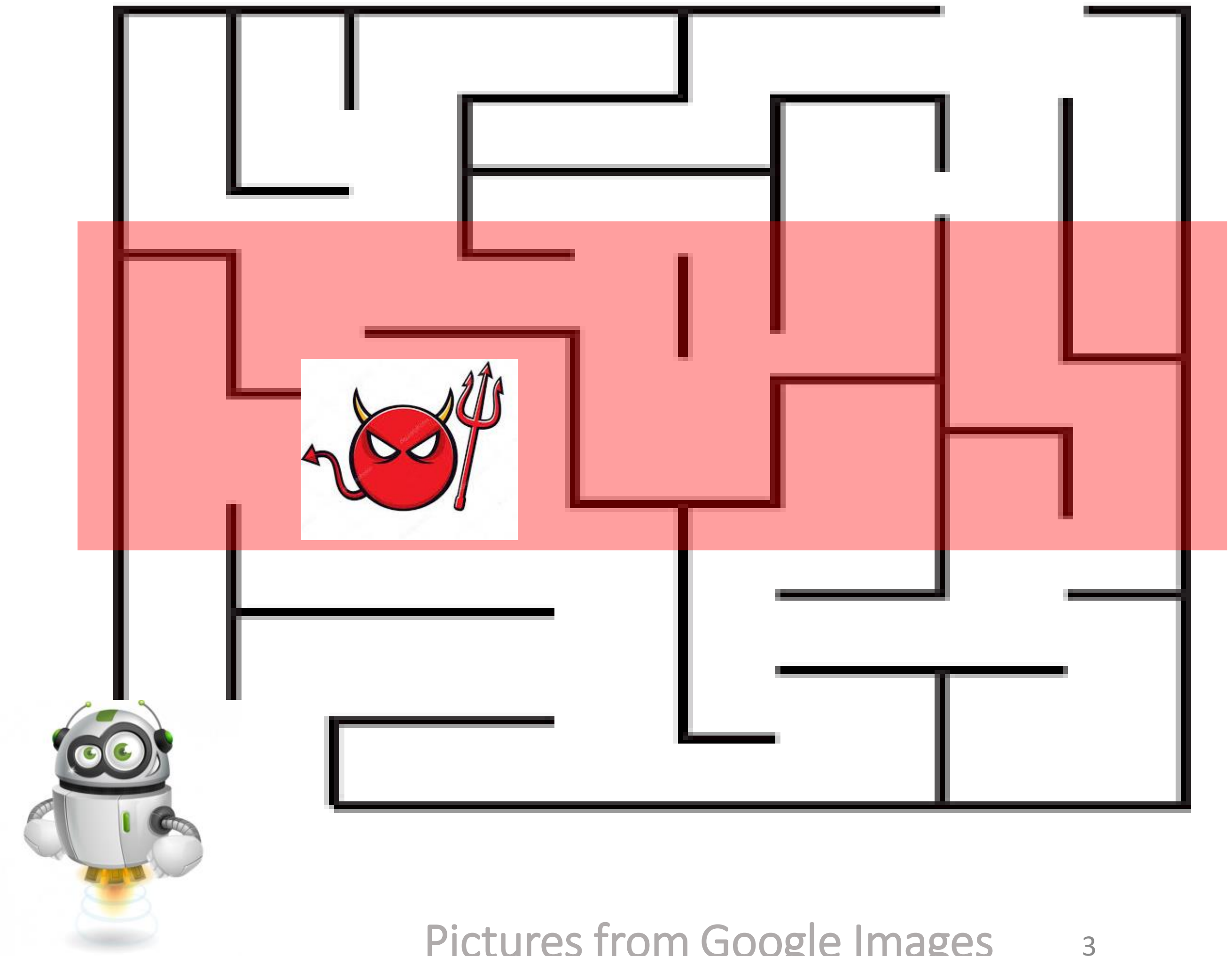
Scene 2:

Dynamic Environment

Find a **strategy**

Reactive synthesis

Given a specification, find **a strategy** that satisfies the spec.



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Synthesis from Temporal and Satisficing Goals

Temporal Goals: LTL

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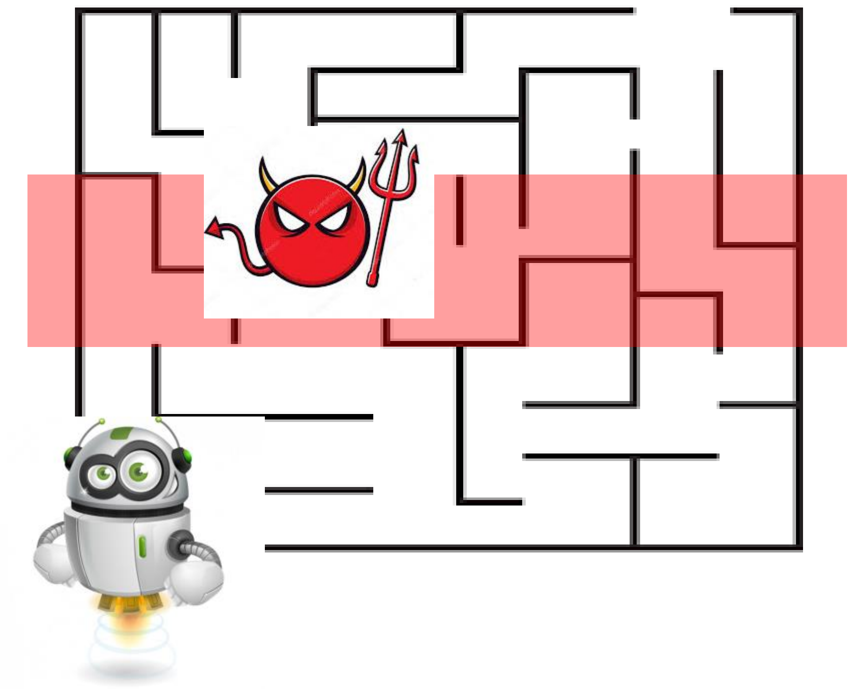
Satisficing Goals : Discounted-sum cost exceeds a given threshold value



Synthesize a strategy that satisfies both goals simultaneously

[Chatterjee et. al. 2017; Wen, Ehlers, Topcu, 2015; Kwiatkowska, Parker, Wiltsche; 2017]

No Sound algorithm so far!

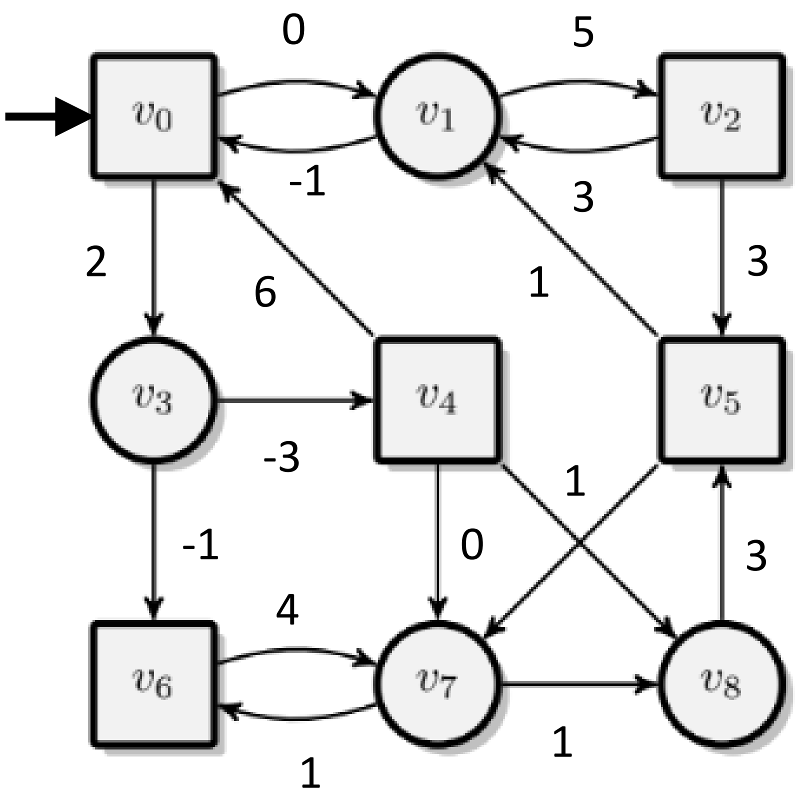
Pictures from Google Images

Quantitative Game

- Two-player graph game with costs on edges
  - Plays begin in initial state; From each state, its player choses the next state
- Cost of a play (Discounted-sum):
  - For cost sequence A and discount factor $1 < d < 2$,

$$DS(A, d) = A[0] + \frac{A[1]}{d} + \frac{A[2]}{d^2} + \cdots$$

- Adversarial players
  - Max-player: To maximize cost of plays
  - Min-player: To minimize cost of plays



Synthesis from Temporal and Satisficing Goals

Strategy: Decides the next state based on the history of a play

Problem: Generate a strategy for the max-player that

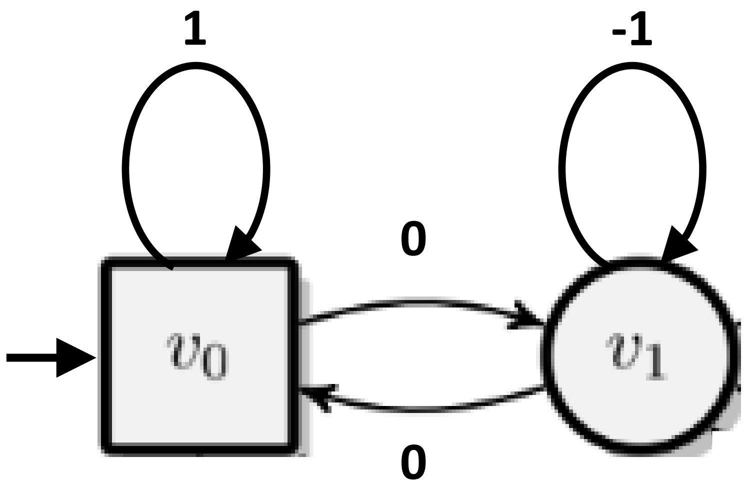
(a). satisfies a given LTL formula, and

(b). ensures the cost of all plays exceeds a given threshold value.

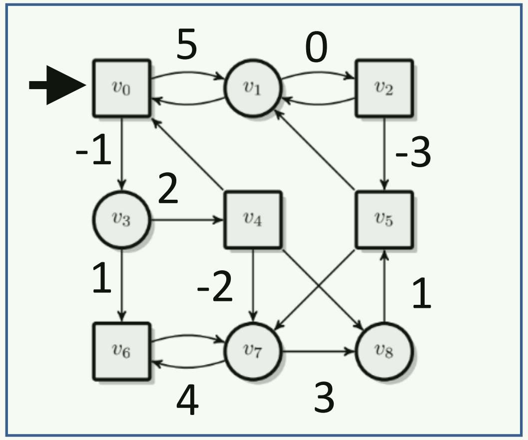
Example

LTL Goal: Visit state v_1

Satisficing Goal: Ensure cost exceeds 0.5



Solution Approach



Quantitative Game

$d > 1$

LTL Formula

Equivalent Deterministic Automata

Threshold Value

Sound and Complete Algorithms for LTL Goals

Comparator automata

[Bansal, Chaudhuri, and Vardi. FoSSaCS 2018; Bansal et. al. CAV 2018; Bansal and Vardi, CAV 2019]

Given, discount factor $d > 1$ and rational threshold value v,

Comparator automata (comparator) accepts a bounded cost sequence $A \in$ iff $DS(A, d) > v$

Theorem:

Comparator is a Büchi automata iff the discount factor is an integer

Comparator expresses winning condition for threshold conditions , when discount factor is an integer

Issue: We require fractional discont factor, i.e., $1 < d < 2$

This work: Approximate Comparator

Given, discount factor $1 < d = 1 + 2^{\{-k\}} < 2$,

threshold value v, and

approximation factor $\varepsilon = 0 < 2^{\{-p\}} < 1$

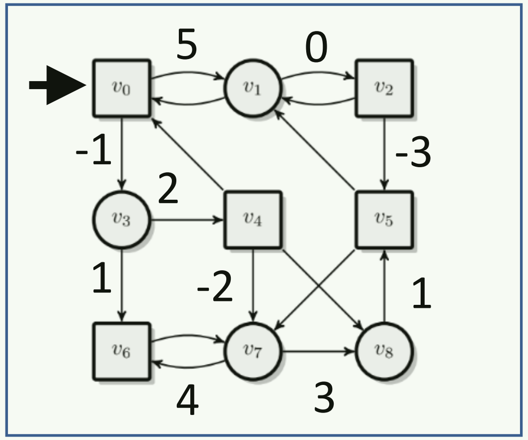
($k, p > 0$ are positive integer parameters)

Approximate comparator **accepts** bounded cost sequence A, then $DS(A, d) > v$

Approximate comparator **rejects** bounded cost sequence A , then $DS(A, d) \leq v + d \cdot \varepsilon$

Theorem: Approximate Comparators are Büchi automata

Solution Approach



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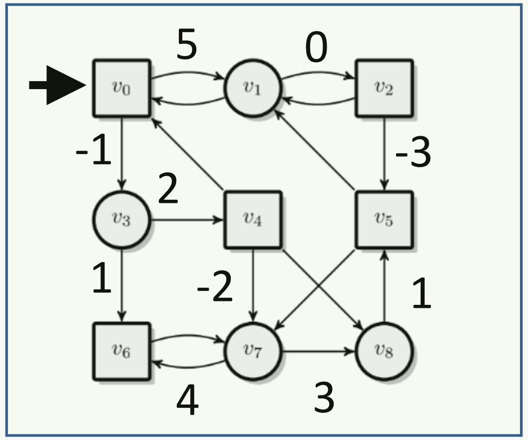

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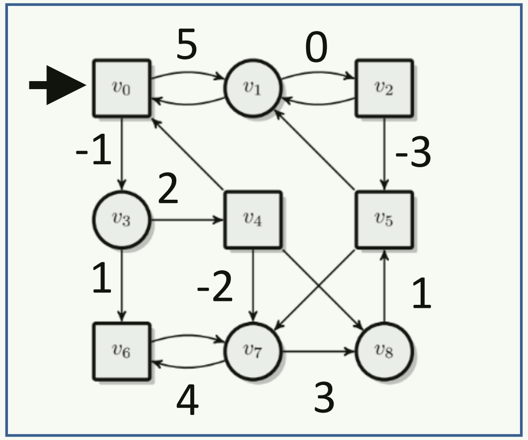

Quantitative Game

$d > 1$

LTL Formula

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Approximate Comparator

Soundness Guarantee: If max-player has a winning strategy in product game, then strategy satisfies LTL formula and exceeds threshold value

In a nutshell

Reactive synthesis from temporal and satisficing goals

- Previously, sound and complete algorithms for integer discount factors [Bansal, Chatterjee, Vardi, TACAS 21]
- **First** sound algorithm for fractional discount factors $1 < d < 2$

Future directions

- Decidability of temporal and satisficing goals is **open**
- Practical scalability challenges