Motion Planning for Hybrid Dynamical Systems

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Robotics manipulator (da Vinci)

Goal

Design a general motion planning algorithm for hybrid systems that produces a motion plan for states and inputs connecting initial and target state sets satisfying given static and dynamic constraints

Challenges

- Standard motion planning algorithms are solely for purely continuous-time or purely discrete-time models
- The state of a hybrid system may evolve continuously and also jump
- Jump times are not known in advance and need to be determined by planner

Methodology

- Forward propagation of hybrid motion from initial set and backward propagation from target sets
- Iteratively propagate the states forward and backward, during flow and jump, until overlap is found. If none is found, report infeasibility of planning.
- Compute motion plan by connecting intermediate forward and backward plans

$$\mathcal{H}\begin{cases} \dot{x} = f(x,u) & (x,u) \in C, \\ x^+ = g(x,u) & (x,u) \in D, \end{cases}$$

General model of a hybrid dynamical system

Self-driving vehicles (Samsung)

Walking robots (UMich)

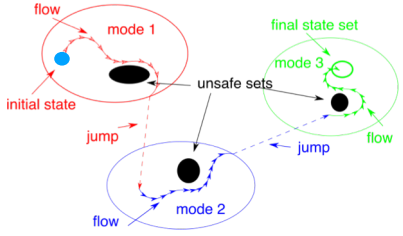
Algorithm 1 Motion Planning Algorithm for Hybrid Systems

Input: Initial state x_0, final state set X_f, unsafe set X_u, input set U, hybrid system $\mathcal{H}$ and its backward system $\mathcal{H}^{\text{bw}}$
Output: state and input (x, u)

1: Set i = 1, $X_0^i = \{x_0\}$.
2: Propagate backward in hybrid time from the X_f by $u \in U$ using $\mathcal{H}^{\text{bw}}$ until the state reaches D^{bw} and compute the set T of all the potential states in D^{bw}.
3: **while** $X_0^i \cap T \neq \emptyset$ **do**
4: Propagate forward in hybrid time from the X_0^i by $u \in U$ using $\mathcal{H}$ until the state reaches D and compute the set V_i of all the potential states in D.
5: Propagate forward in hybrid time from the V_i by $u \in U$ using $\mathcal{H}$ until the state reaches C and compute the set Q_i of all the potential states in C.
6: $X_0^{i+1} = Q_i$, $i = i + 1$,
7: **end while**
8: Pick $x_p \in Q_i \cap T$, propagate forward from x_p to X_f and backward from x_0 to x_p. Concatenate the solutions and return.

$$\mathcal{H}^{\text{bw}}: \begin{cases} \dot{x} = -f(x,u) & (x,u) \in C \\ x^+ = g^{\text{bw}}(x,u) & (x,u) \in D^{\text{bw}} \end{cases}$$

General model of backward-in-time hybrid dynamical system



Motion planning goal

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Applications