Modeling of Hierarchical Multi-Modal Systems in Ptolemy II

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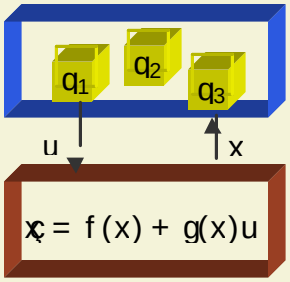
Multi-Modal Control

- Multi-agent, multi-objective systems designed to be operating in many modes of operation
- Given a continuous control system, a collection of *control modes* are designed



For control mode q_i;

$o=p : y_i = h_i(x)$
$i=p : u = k_i(x; r_i)$
y_i ! r_i by design
Assume that $r_i \in R_i$
$x(t_0) \in S_i(r_i) \cap X_i$
$x(t) \in X_i;\ t \geq t_0$

Example of Control Mode

Design Specification for q_i:

Given $y_i = p_x$

Design $u = k_i(x; r_i)$

s.t. $y_i \in r_i$

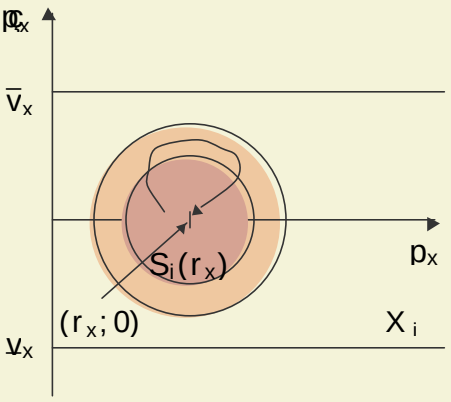
subject to $\dot{x} = f(x) + g(x)u$

$x(t) \in X_i;\ t \geq t_0$

$r_i \in R_i$

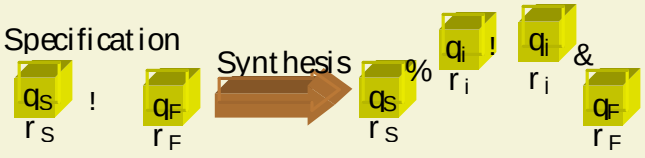
If feasible, it requires

$x(t_0) \in S_i(r_i) \subseteq X_i$



Multi-Modal Control

- **Problem Statement**
  - **Does there exist a finite sequence of *control modes* for satisfying a set of given reachability specifications?**



  - **If does exist, can the switching conditions be determined?**
    - **When/ Where? Time/Event-triggered architecture**
    - **What Trajectory? Depending on the cost function**

Framework for Multi-Modal Control

- Mode Switching Algorithm
  - Decouple the discrete and continuous aspects of the problem to allow efficient & effective computations
  - Generate all possible solutions
  - Allow selection of optimal solution
- Computation
  - Offline: Synthesis of control mode graph
    - Reachability and Intersection
  - Online: Synthesis of control switching sequence
    - Reachability on Graph
- Reference
  - T. J. Koo, G. J. Pappas, and S. Sastry, “Mode Switching Synthesis for Reachability Specifications,” Hybrid Systems: Computation and Control, Lecture Notes in Computer Science, Springer, 2001.

Multi-Modal Control of a Helicopter Model

- Dynamics: Helicopter model in longitudinal and vertical axes

$$\dot{p}_x = \frac{1}{m} R(\theta) R_T(\varepsilon) \begin{pmatrix} -D(V) \\ 0 \end{pmatrix} + \begin{pmatrix} T_M \sin\alpha \\ T_M \cos\alpha \end{pmatrix} + \begin{pmatrix} 0 \\ -g \end{pmatrix}$$

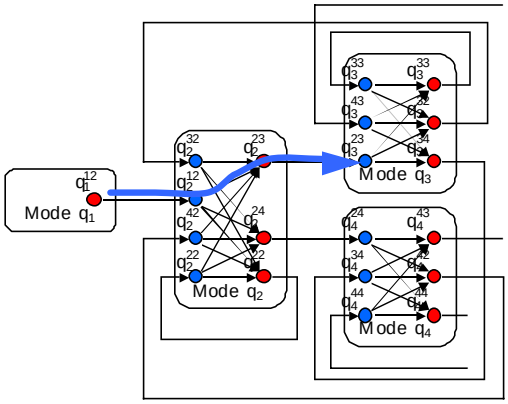
$$\dot{\theta} = \frac{1}{I_y} \left(-h_M T_M \sin\alpha + h_M T_M \sin\alpha \right), \quad \dot{\varepsilon} = \theta - \tan^{-1}\left(\frac{\dot{p}_z}{\dot{p}_x}\right)$$

- Control Modes: *Hover, Cruise, Ascend, Descend*
- Task Specification: High-altitude take-off

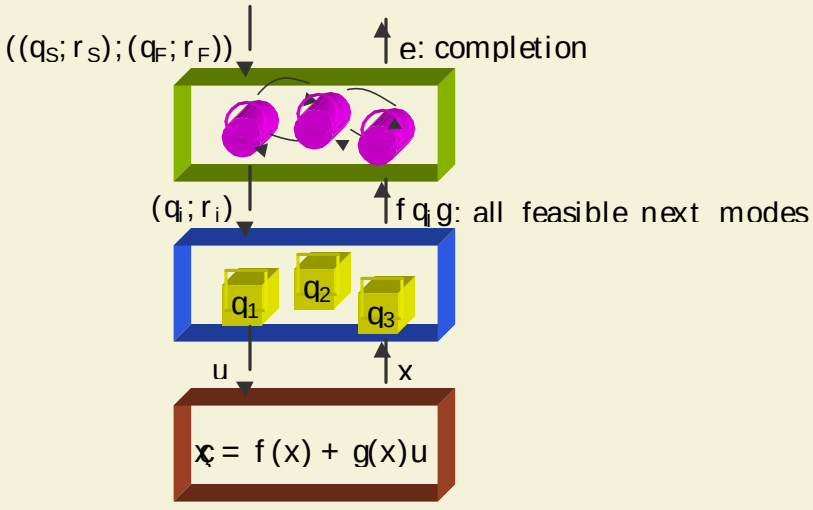
(*Hover* to *Ascend*)

Multi-Modal Control of a Helicopter Model

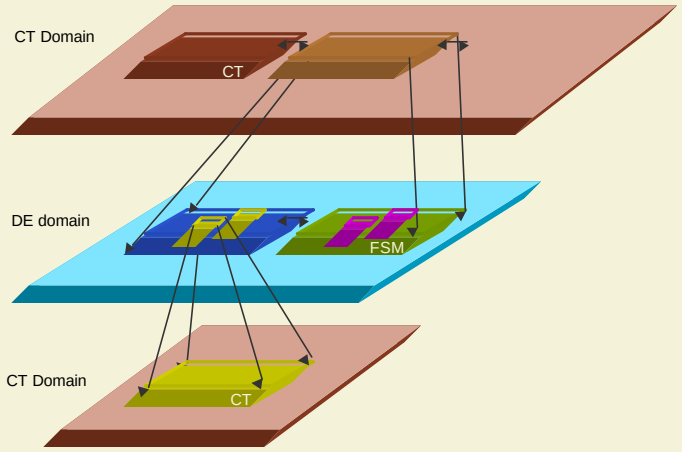
- Output of the Mode Switching Algorithm
  - Control Mode Graph



Hierarchical Architecture for Multi-Modal Control



Modeling in Ptolemy II



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