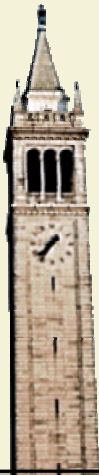


# Modeling of Hierarchical Multi-Modal Systems in Ptolemy II



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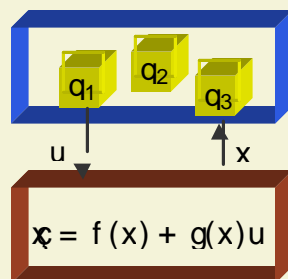
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## Multi-Modal Control

- 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  $q_i$ ;

$q_i$   $o=p : y_i = h_i(x)$   
 $i=p : u = k_i(x; r_i)$   
 $y_i \neq r_i$  by design

Assume that  $r_i \in R_i$   
 $x(t_0) \in S_i(r_i) \subseteq X_i$   
 $x(t) \in X_i; t \geq t_0$

## Example of Control Mode

Design Specification for  $q_i$ ;  $\mathbb{R}^x$

Given  $v_i = p_x$

Design  $u = k_i(x; r_i)$



s.t:  $v_i \neq r_i$

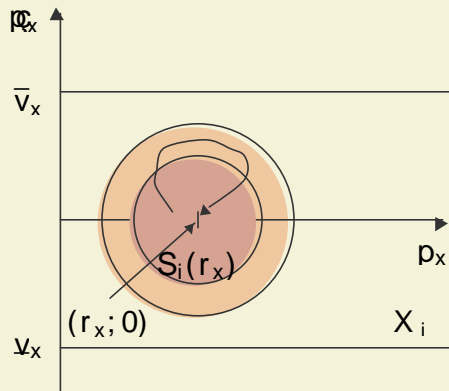
subj: to  $\dot{x} = f(x) + g(x)u$

$x(t) \in X_i; t \in [0, t_0]$

$r_i \in R_i$

If feasible; it requires

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

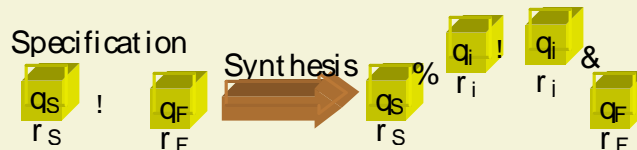


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## Multi-Modal Control

### ■ 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

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## 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.

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## Multi-Modal Control of a Helicopter Model

- **Dynamics: Helicopter model in longitudinal and vertical axes**

$$\ddot{\theta} = \frac{1}{m} R(\theta) K^T(\dot{\theta}) \dot{h}^D(V) - \frac{T_M \sin \alpha}{T_M \cos \alpha} \ddot{h} + \frac{0}{g}$$

$$\dot{\theta} = \frac{1}{I_y} M_M \alpha + h_M T_M \sin \alpha \quad \dot{\alpha} = \dot{\theta} \tan \alpha^1 \quad \ddot{\alpha} = \ddot{\theta} \frac{1}{\cos \alpha}$$

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

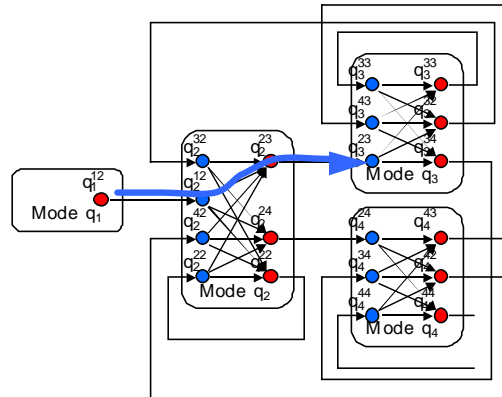
( Hover to Ascend )



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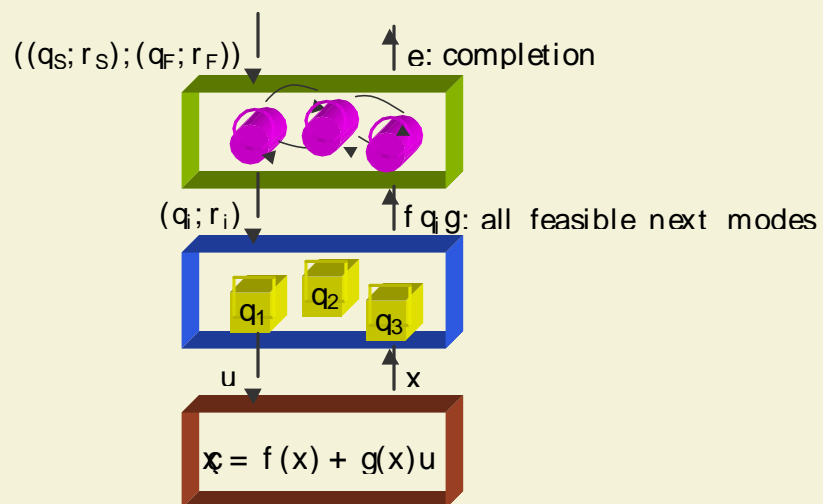
## Multi-Modal Control of a Helicopter Model

- Output of the Mode Switching Algorithm
  - Control Mode Graph



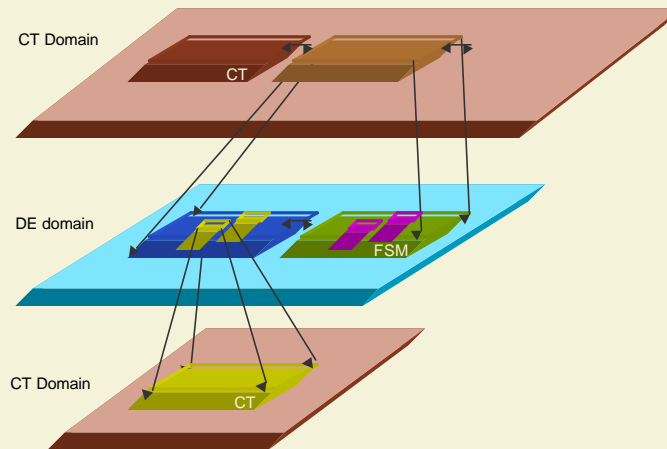
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## Hierarchical Architecture for Multi-Modal Control



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## Modeling in Ptolemy II



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## References

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- J. Liu, E. A. Lee, "Component-Based Hierarchical Modeling of Systems with Continuous and Discrete Dynamics," In *Proceedings of IEEE Conference on Computer-Aided Control System Design*, Anchorage, Alaska, September 2000.
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- T. J. Koo, S. Sastry, "Output Tracking Control Design of a Helicopter Model Based on Approximate Linearization," In *Proceedings of IEEE Conference on Decision and Control*, Florida, December 1998.

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