

INTRODUCTION TO HYBRID SYSTEMS: *ORIGINS, EXAMPLES, APPLICATIONS*

C. G. Cassandras

***Dept. of Manufacturing Engineering
and***

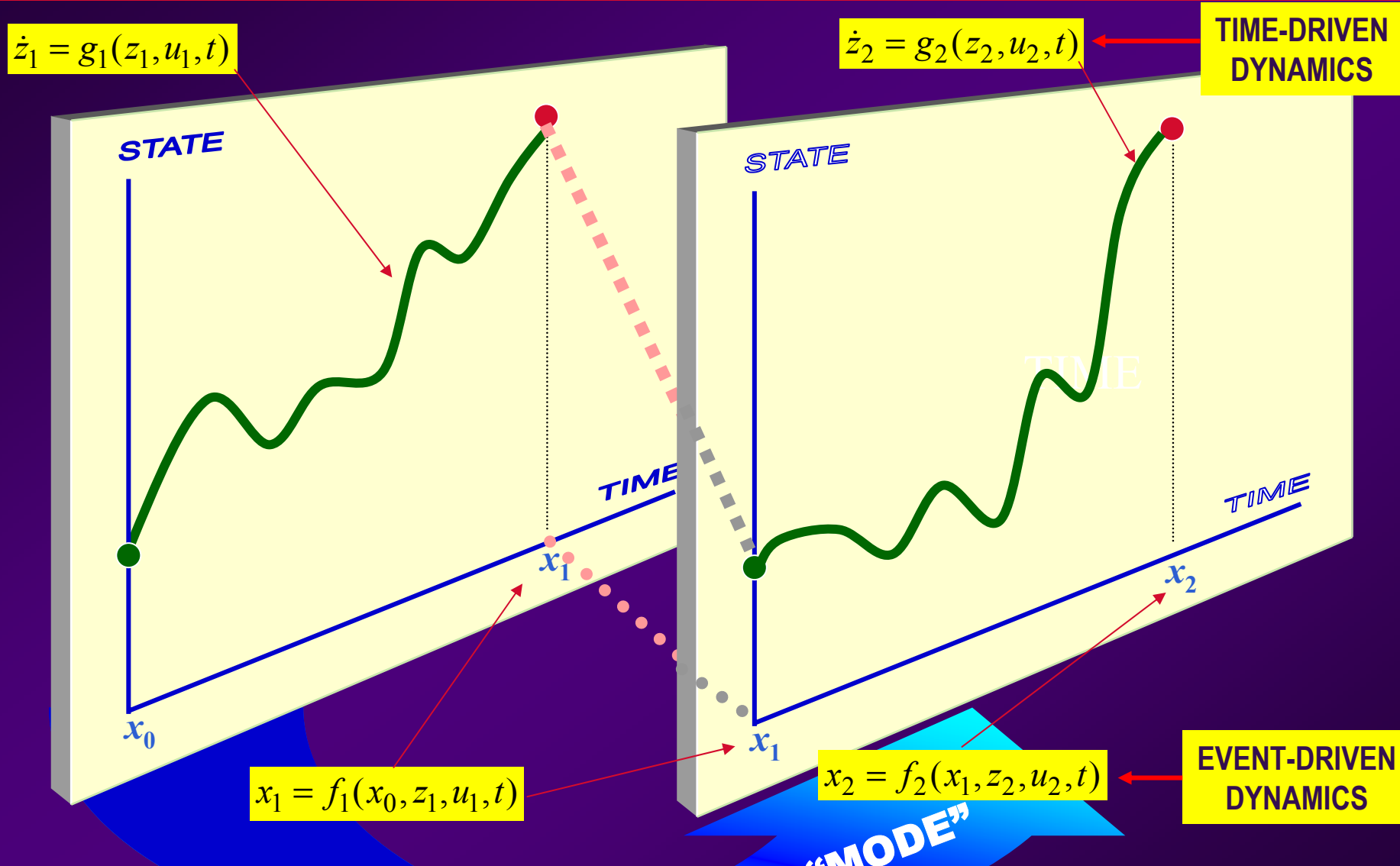
***Center for Information and Systems Engineering (CISE)
Boston University***

cgc@bu.edu

http://vita.bu.edu/cgc

- WHAT'S A HYBRID SYSTEM...
- HYBRID SYSTEMS AND COMPLEXITY:
 - DECOMPOSITION*: HYBRID SYSTEM \rightarrow DES
 - ABSTRACTION*: DES \rightarrow HYBRID SYSTEM
- EXAMPLES, APPLICATION AREAS

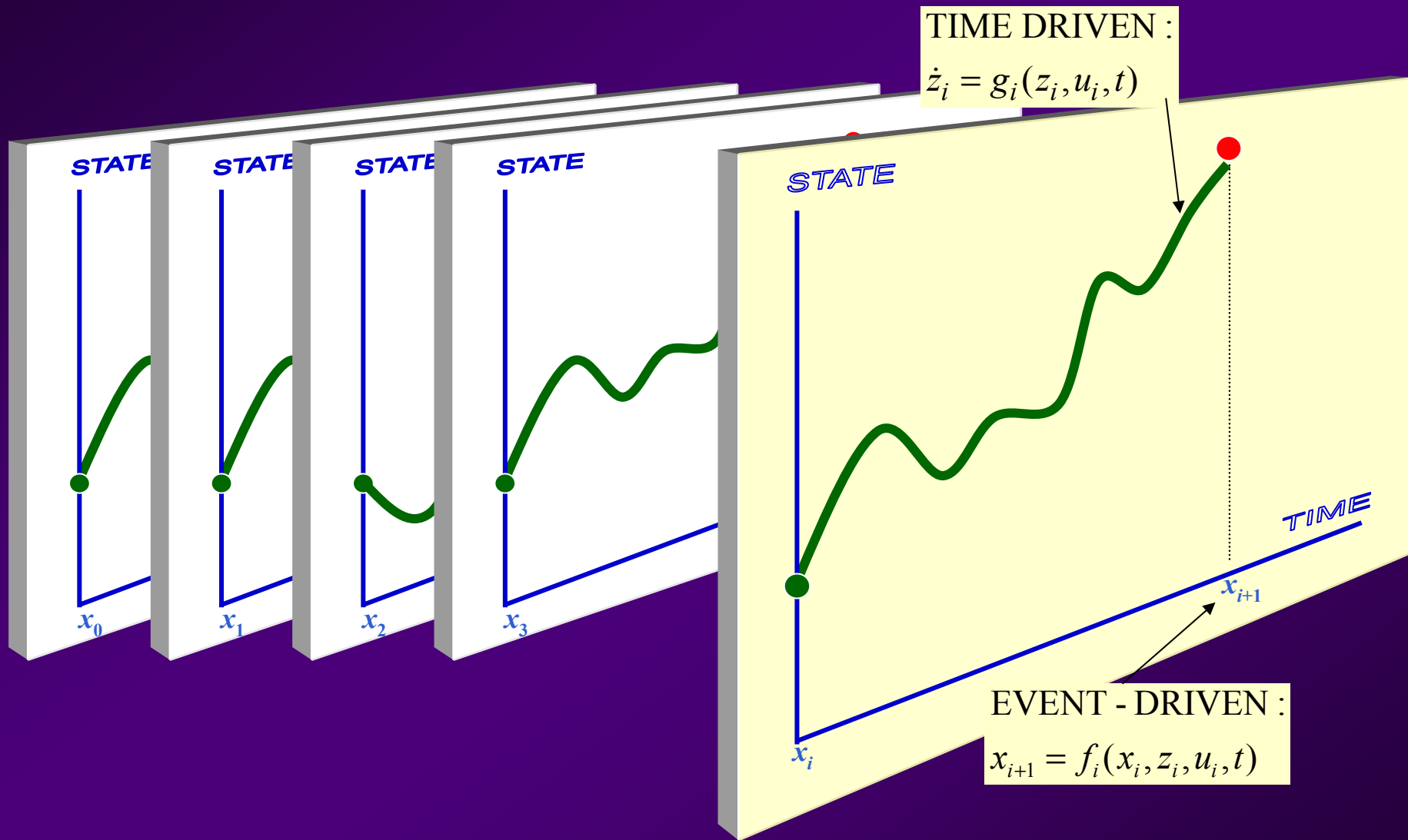
WHAT'S A HYBRID SYSTEM?



More on modeling frameworks, open problems, etc: [Proc. of IEEE Special Issue (Antsaklis, Ed.), 2000]

WHAT'S A HYBRID SYSTEM?

CONTINUED



WHAT'S A HYBRID SYSTEM?

CONTINUED

Physical State, z

$$\dot{z}_i = g_i(z_i, u_i, t)$$

hybrid

x_i

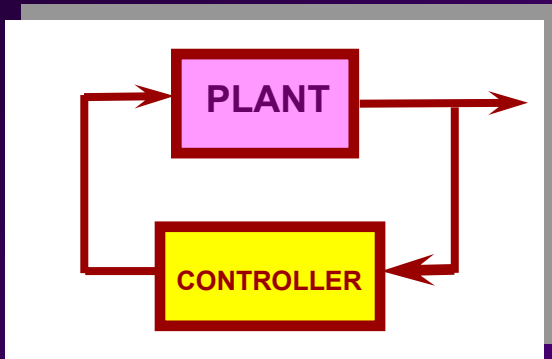
Switching Times

$$x_{i+1} = f_i(x_i, u_i, t)$$

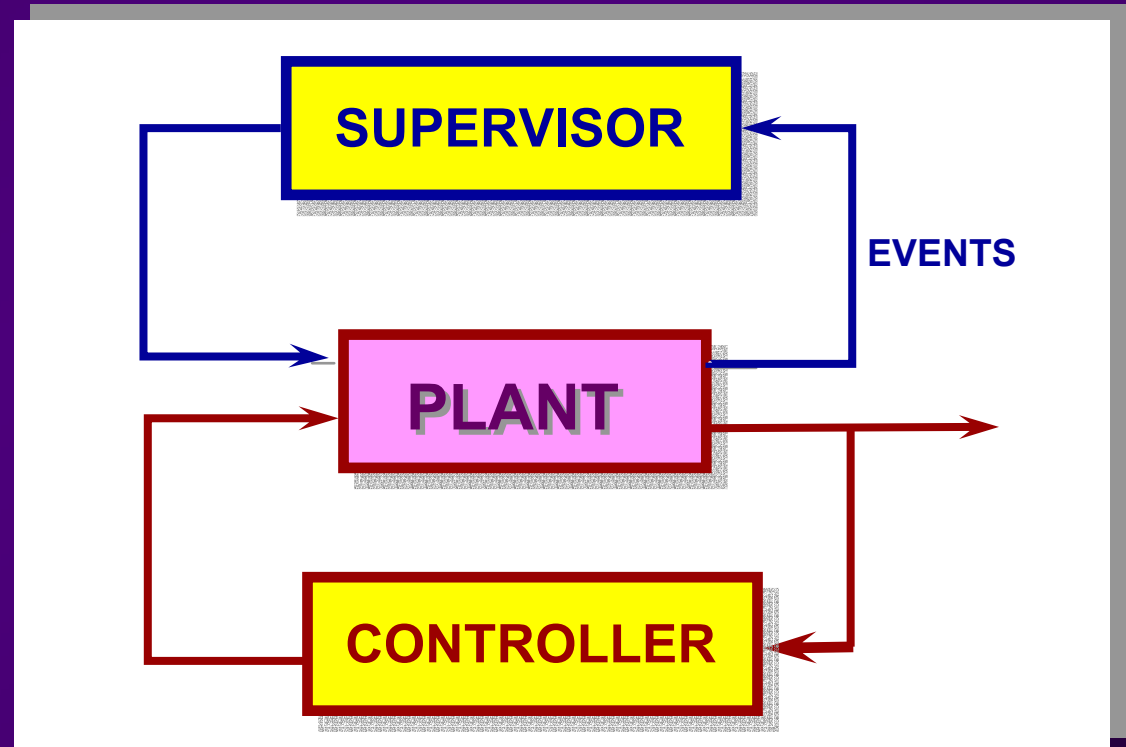
**SWITCHING TIMES
HAVE THEIR OWN
DYNAMICS!**

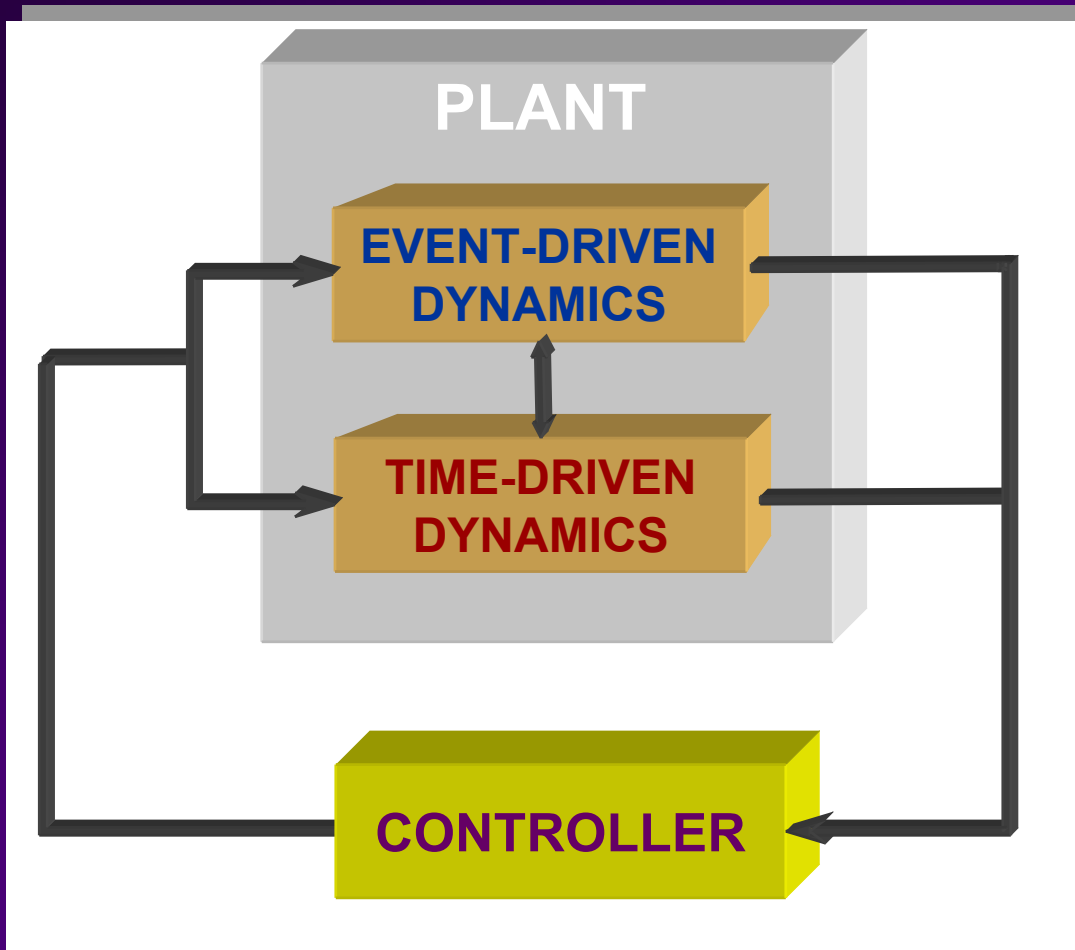
WHAT'S A HYBRID SYSTEM?

CONTINUED

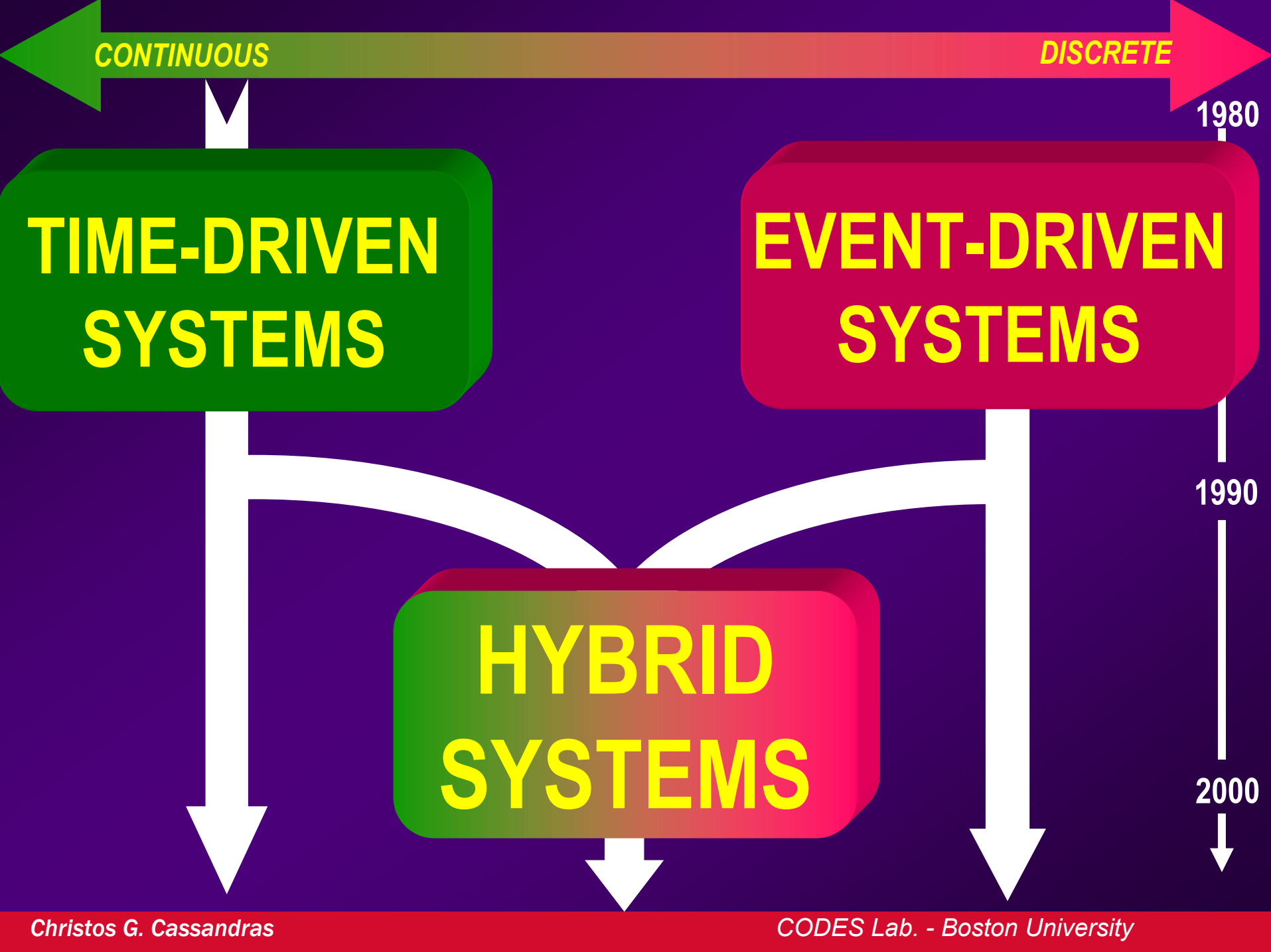


REPLACE THE USUAL CONTROL LOOP BY





- Plant: *time-driven* + *event-driven* dynamics
- Controller affects both *time-driven* + *event-driven* components
- Control may be continuous signal and/or discrete event



DECOMPOSITION

LESS COMPLEX

MORE COMPLEX

TIME-DRIVEN
SYSTEM

What exactly
does that mean?

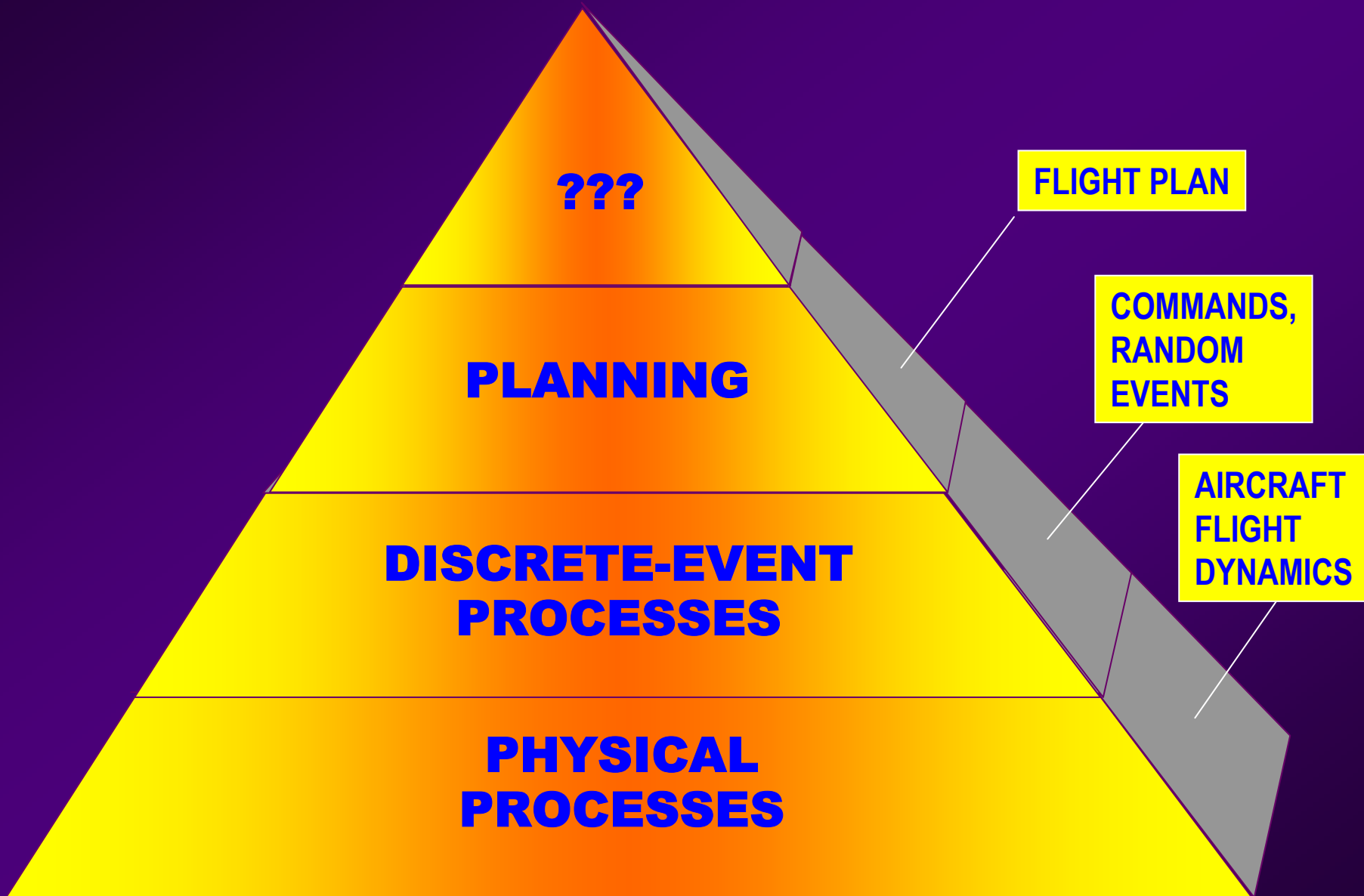
HYBRID
SYSTEM

EVENT-DRIVEN
SYSTEM

LESS COMPLEX

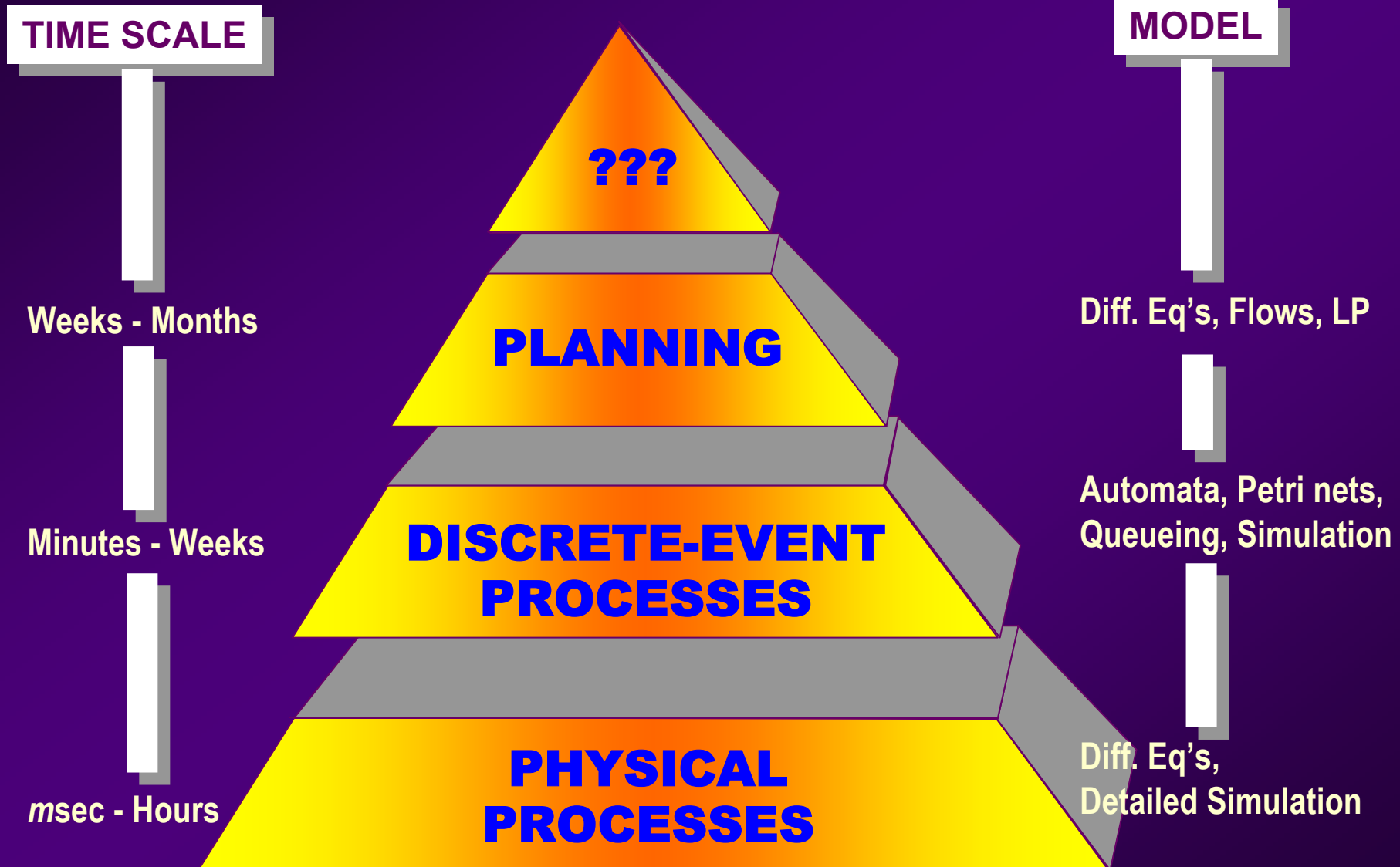
DECOMPOSITION

HIERARCHICAL DECOMPOSITION

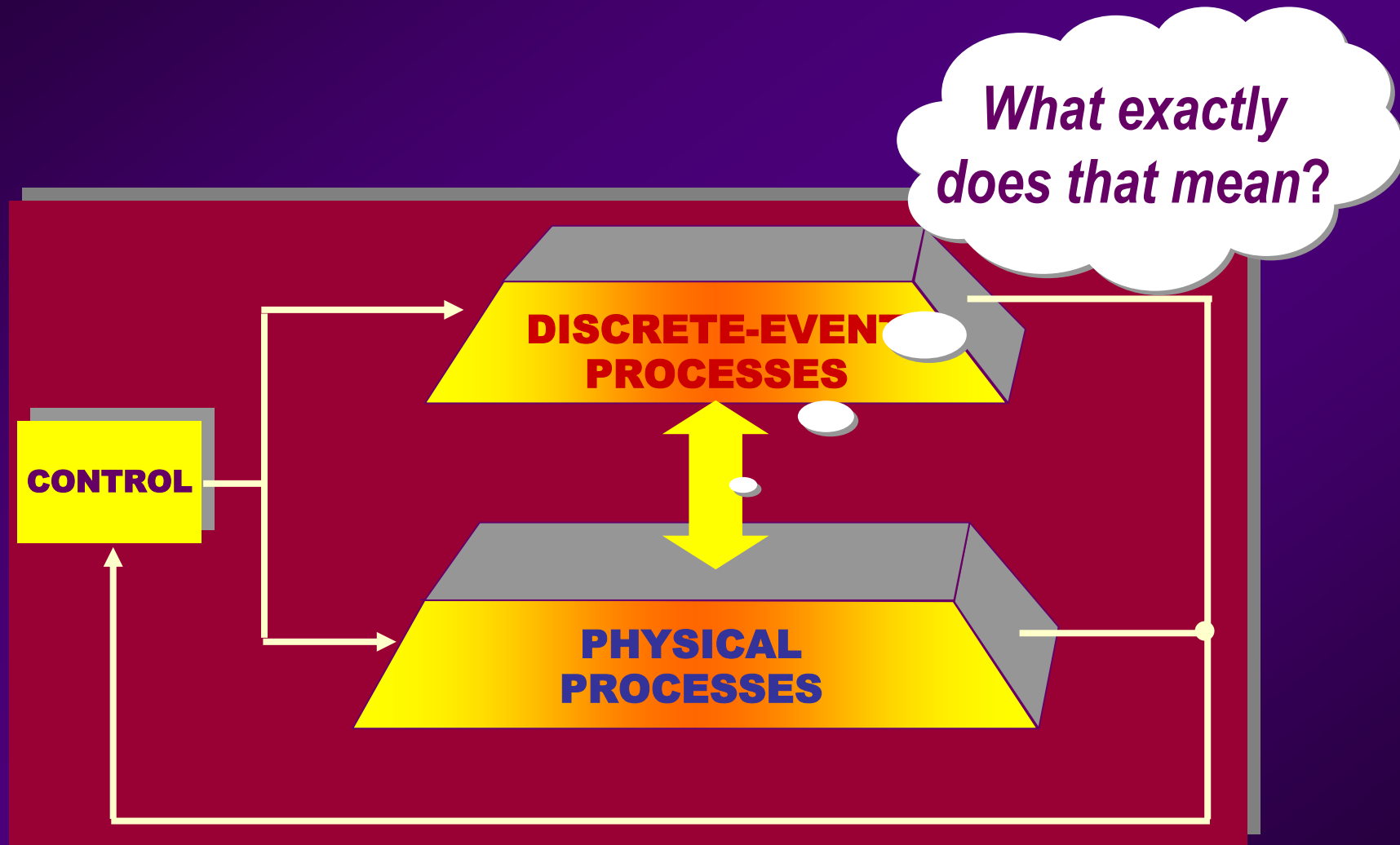


HIEARARCHICAL DECOMPOSITION

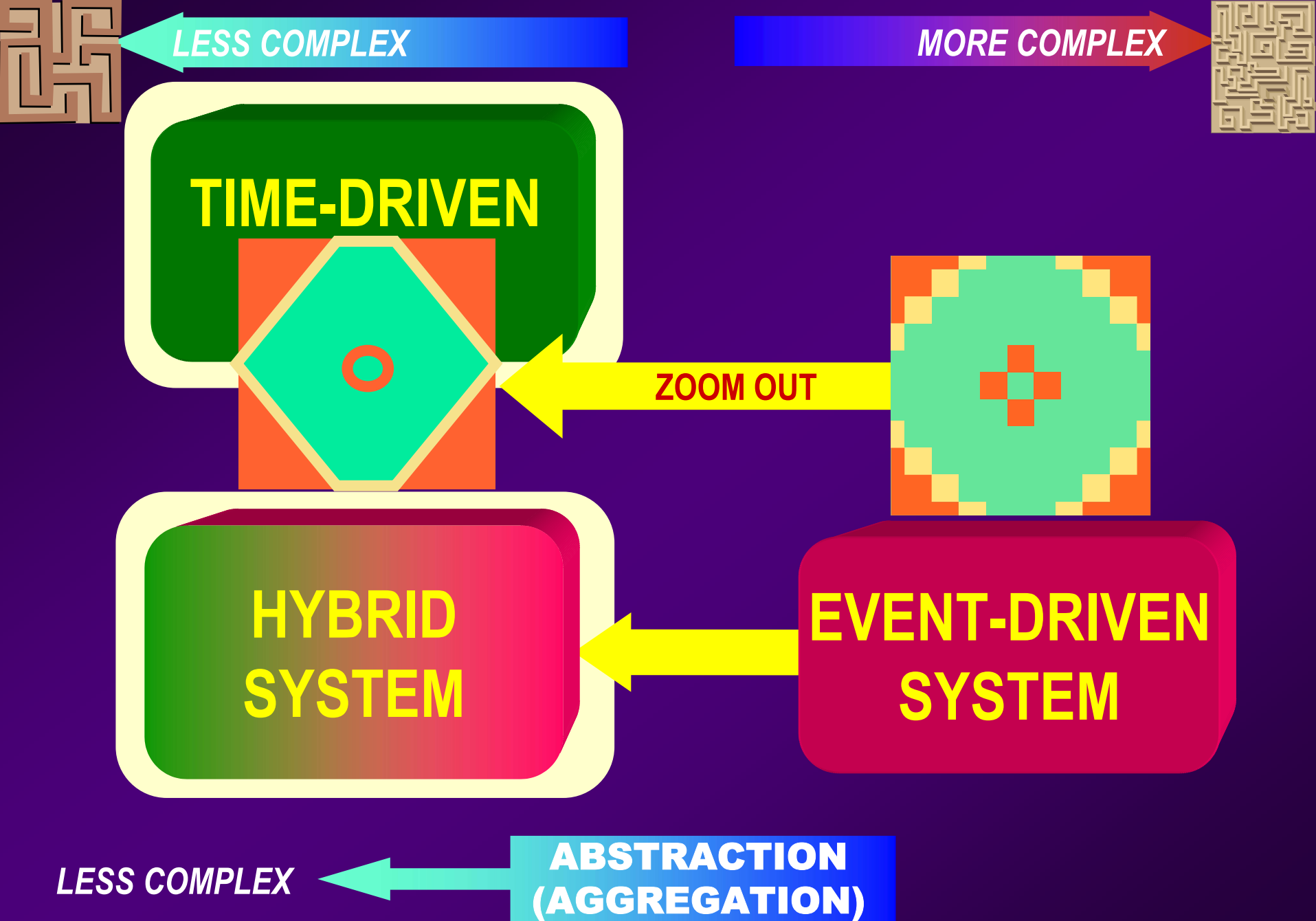
CONTINUED

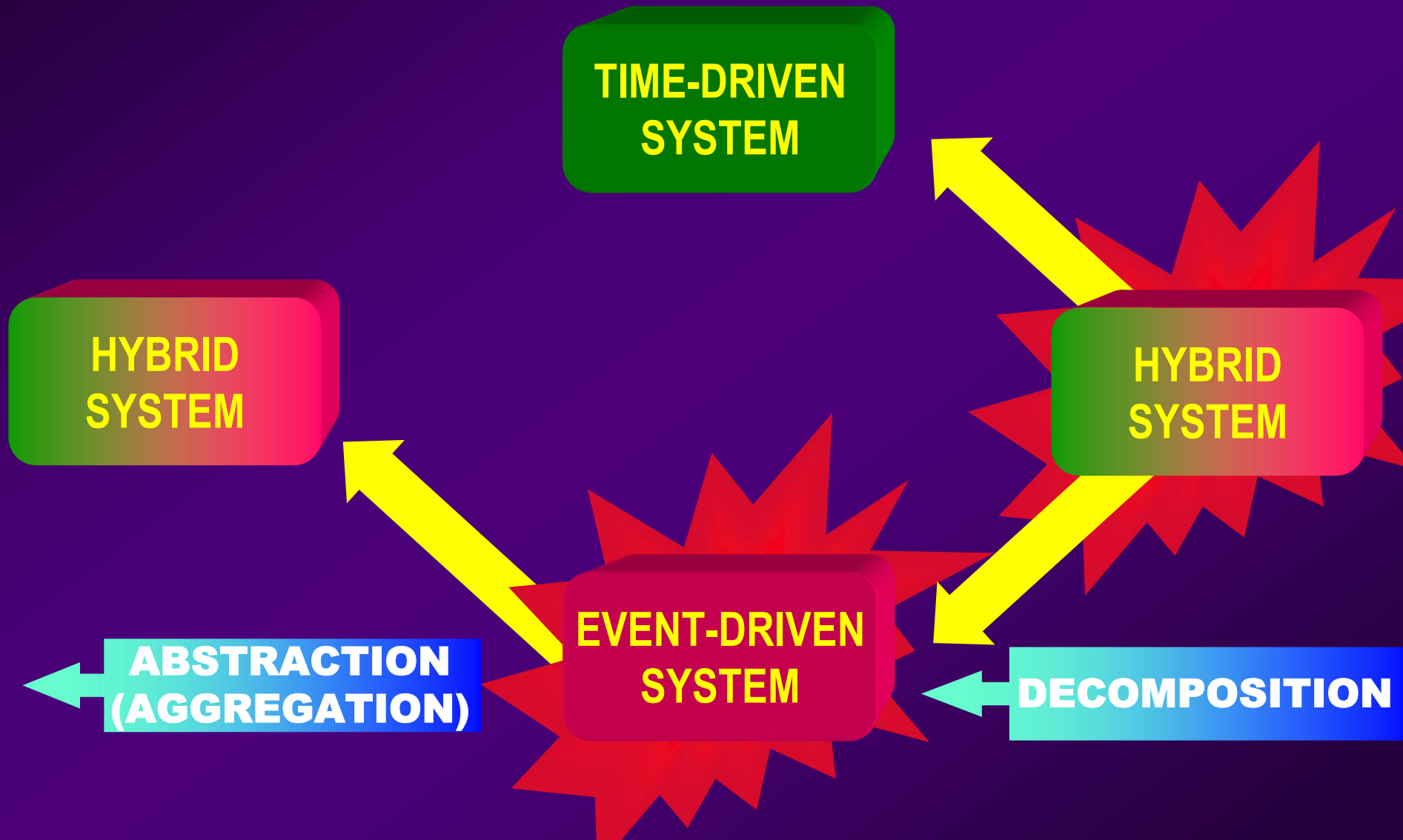
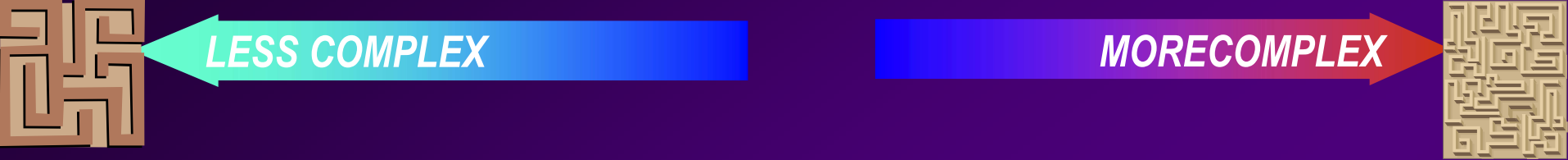


HYBRID CONTROL SYSTEM



ABSTRACTION (AGGREGATION)

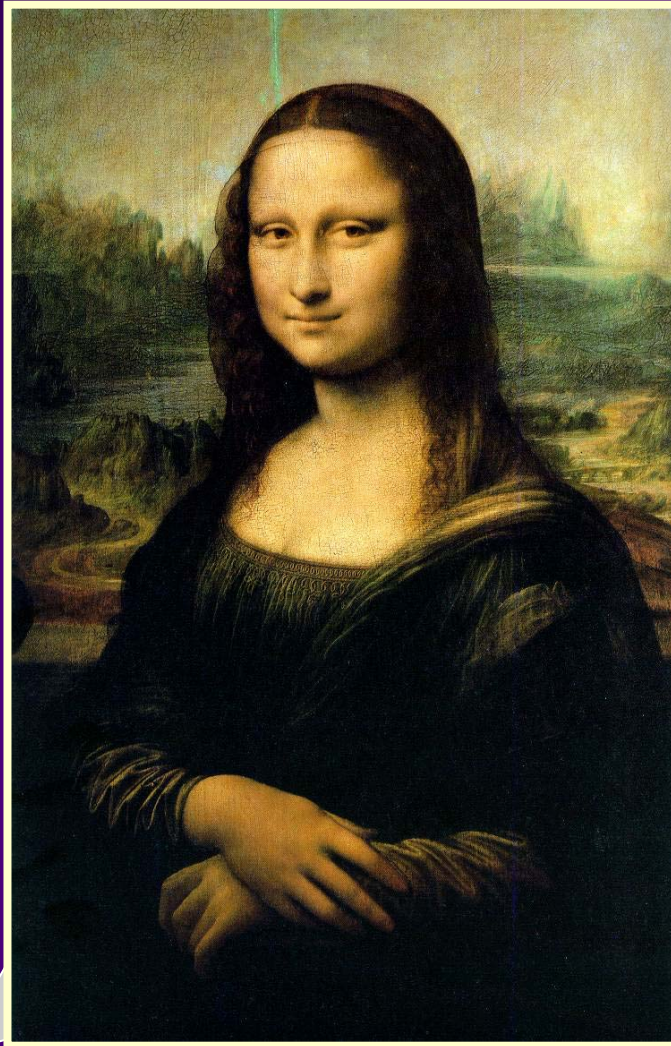




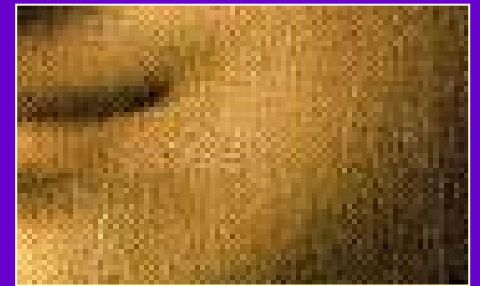
WHAT IS THE RIGHT ABSTRACTION LEVEL ?



TOO FAR...
model not
detailed enough



JUST RIGHT...
good model

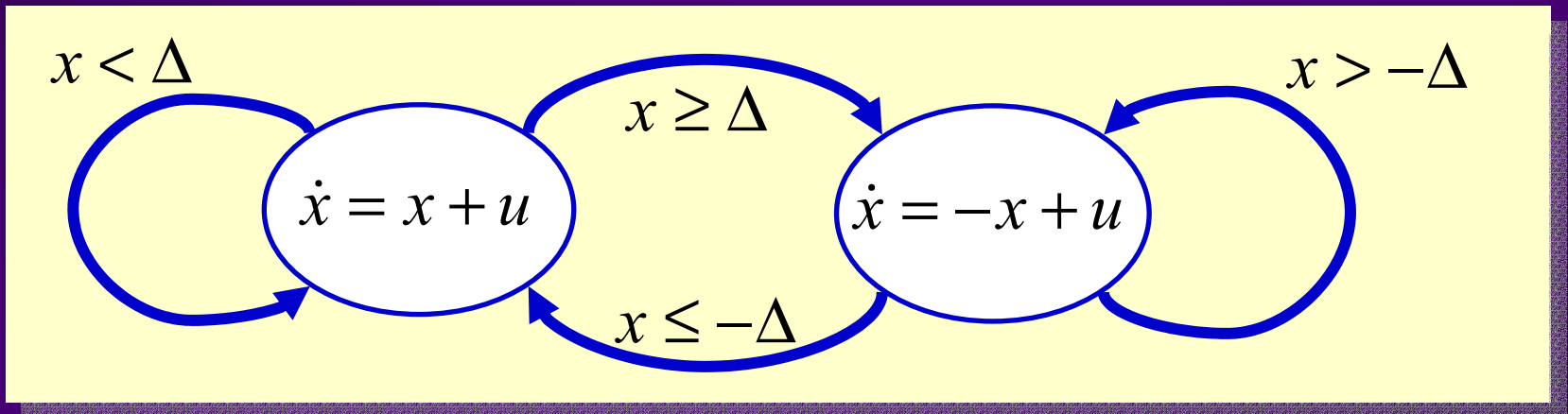


TOO CLOSE...
too much
undesirable
detail

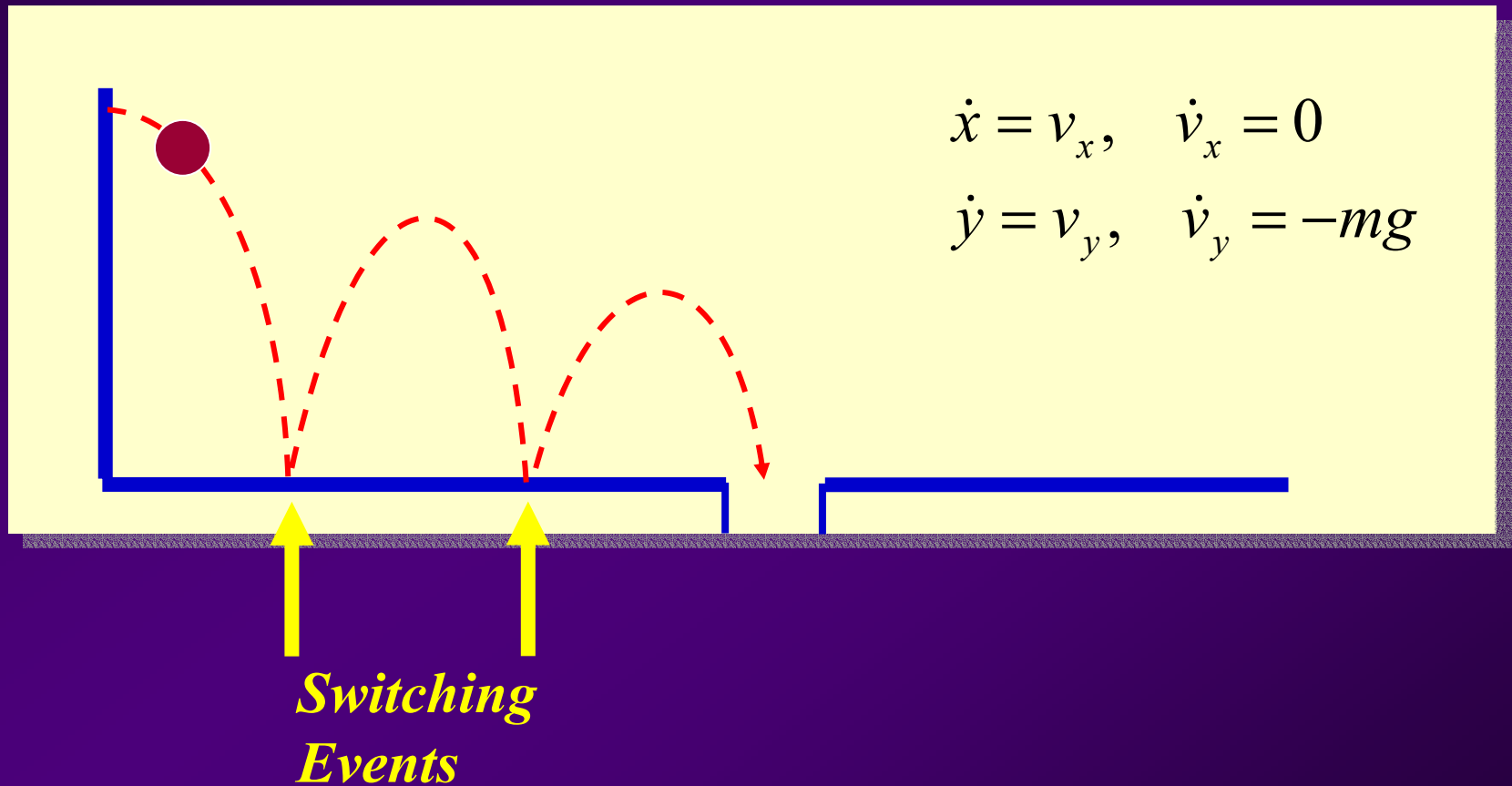
EXAMPLES

HYBRID SYSTEM EXAMPLES

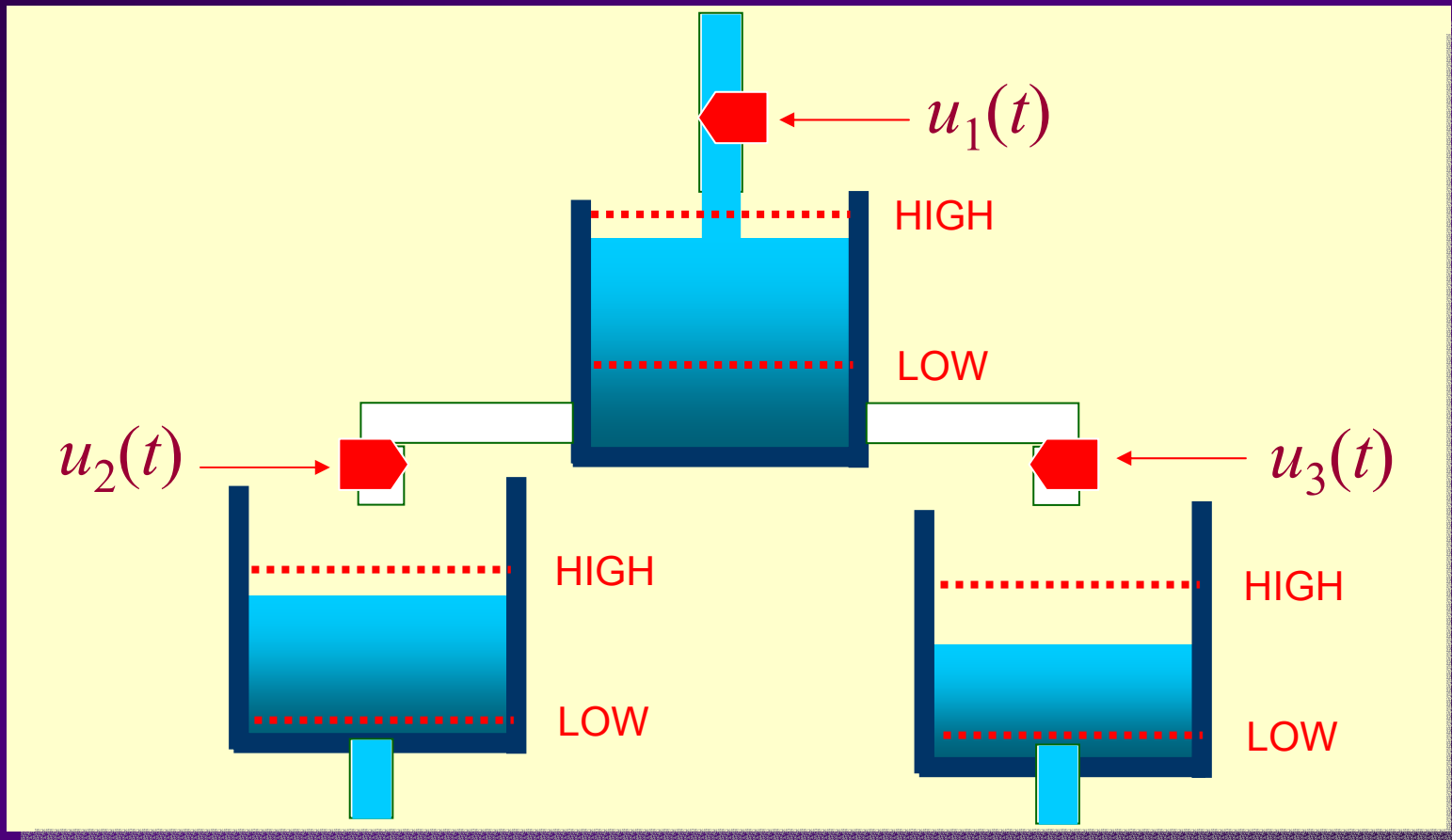
1. Autonomous Switching, e.g., *Hysteresis*



2. External Switching, e.g., *Zeno's bouncing ball*



3. Controlled Switching, e.g., *Interconnected tanks*



4. Other cases of controlled switching:

- *Diving: control depths for decompression*

TRADEOFF: Safety vs. Time

- *Vehicle transmission: control gear switching*

TRADEOFF: Efficiency vs. Time

- *Low-power electronics: power control*

TRADEOFF: Power conservation vs. Time

- *Manufacturing: process control + operational control*

TRADEOFF: Product quality vs. Time



HYBRID SYSTEMS IN *MANUFACTURING*

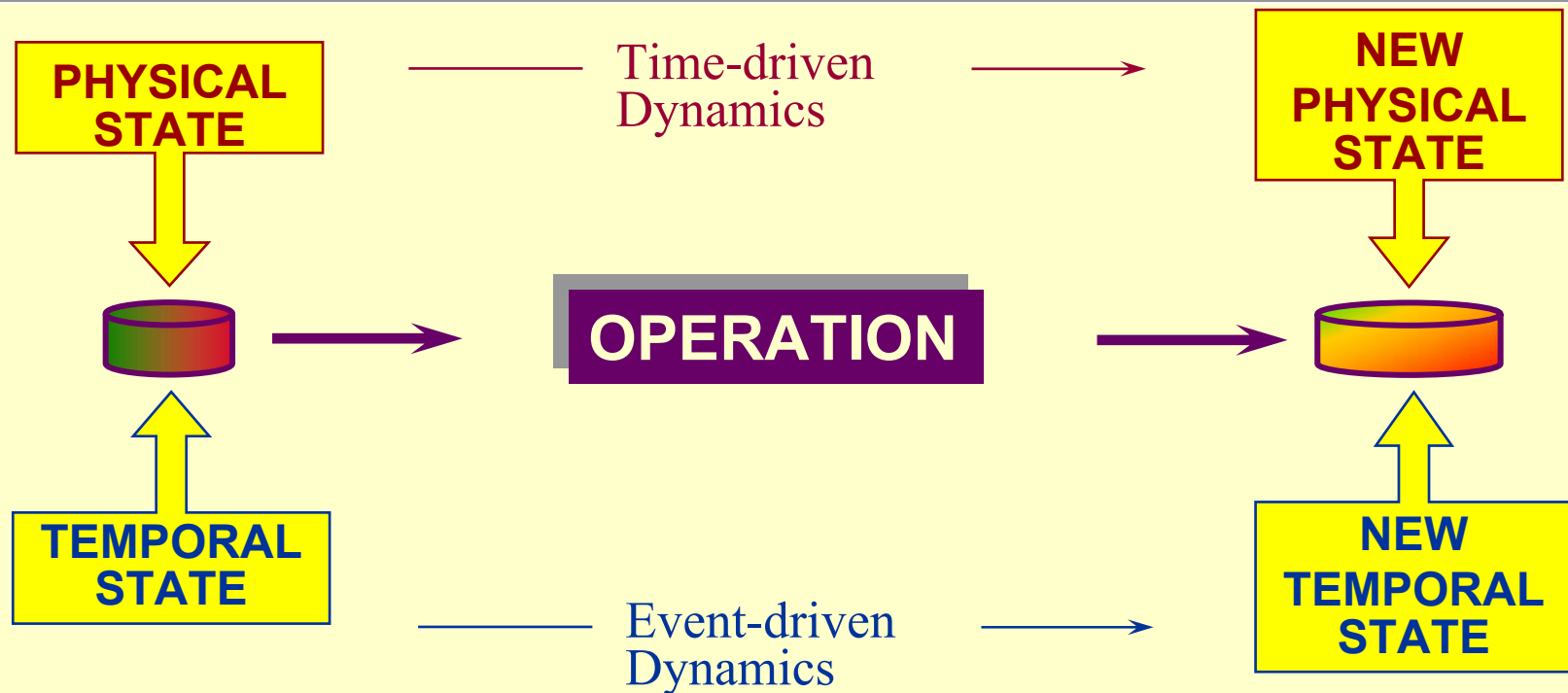
Key questions facing manufacturing system integrators:

- How to integrate '*process control*' with '*operations control*' ?
- How to improve product *QUALITY* within reasonable *TIME* ?



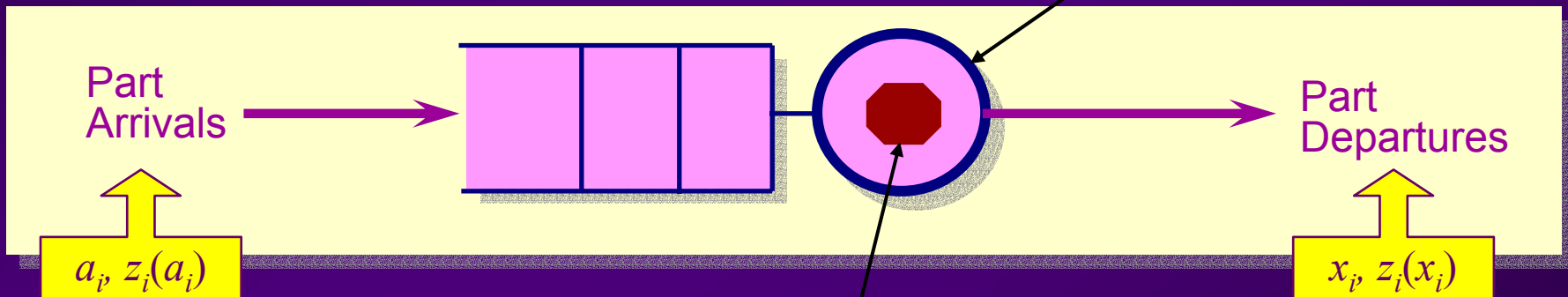
Throughout a manuf. process, each part is characterized by

- A **PHYSICAL** state (e.g., **size, temperature, strain**)
- A **TEMPORAL** state (e.g., **total time in system, total time to due-date**)



*EVENT-DRIVEN
COMPONENT*

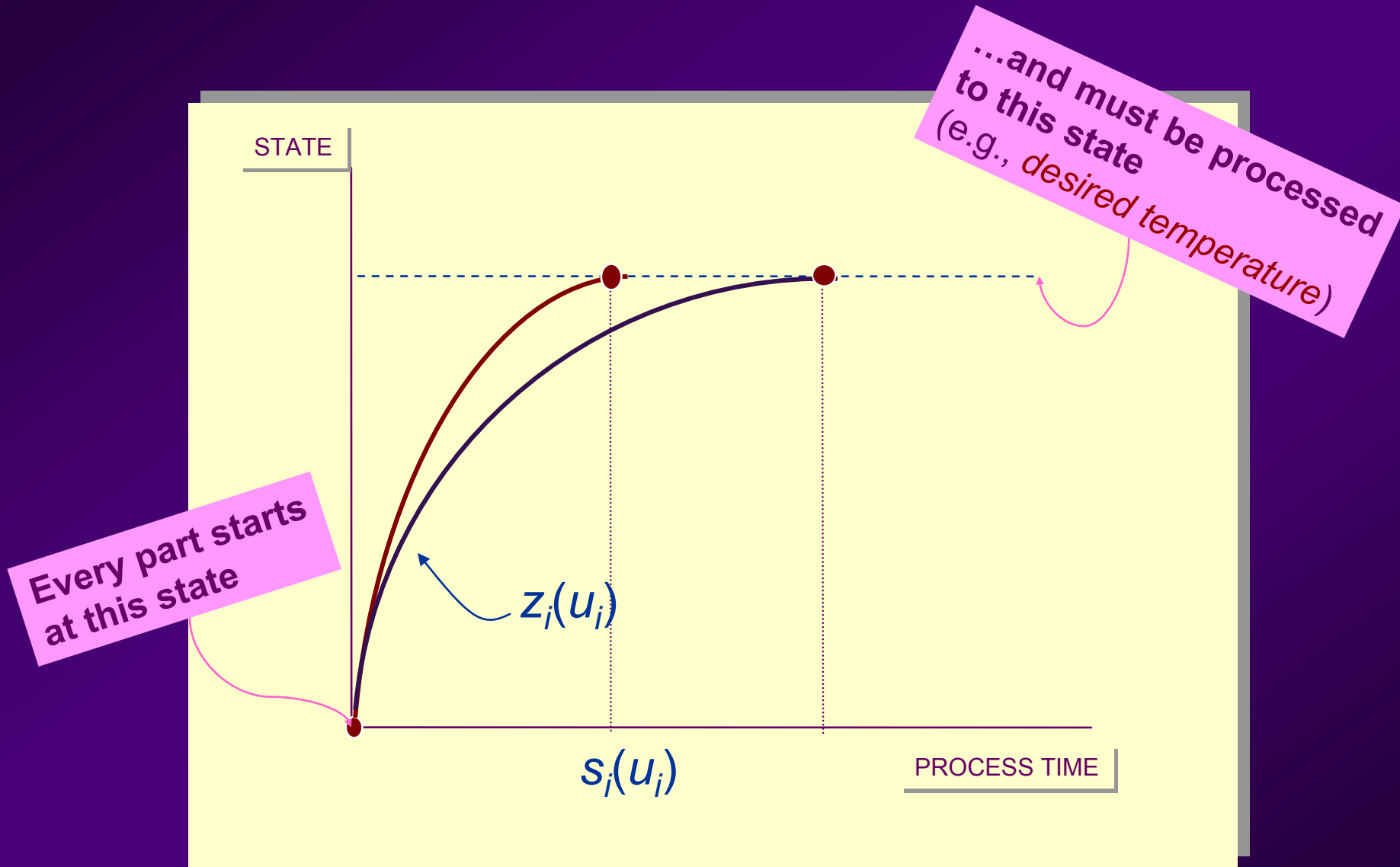
$$x_i = \max \{x_{i-1}, a_i\} + s_i(u_i)$$



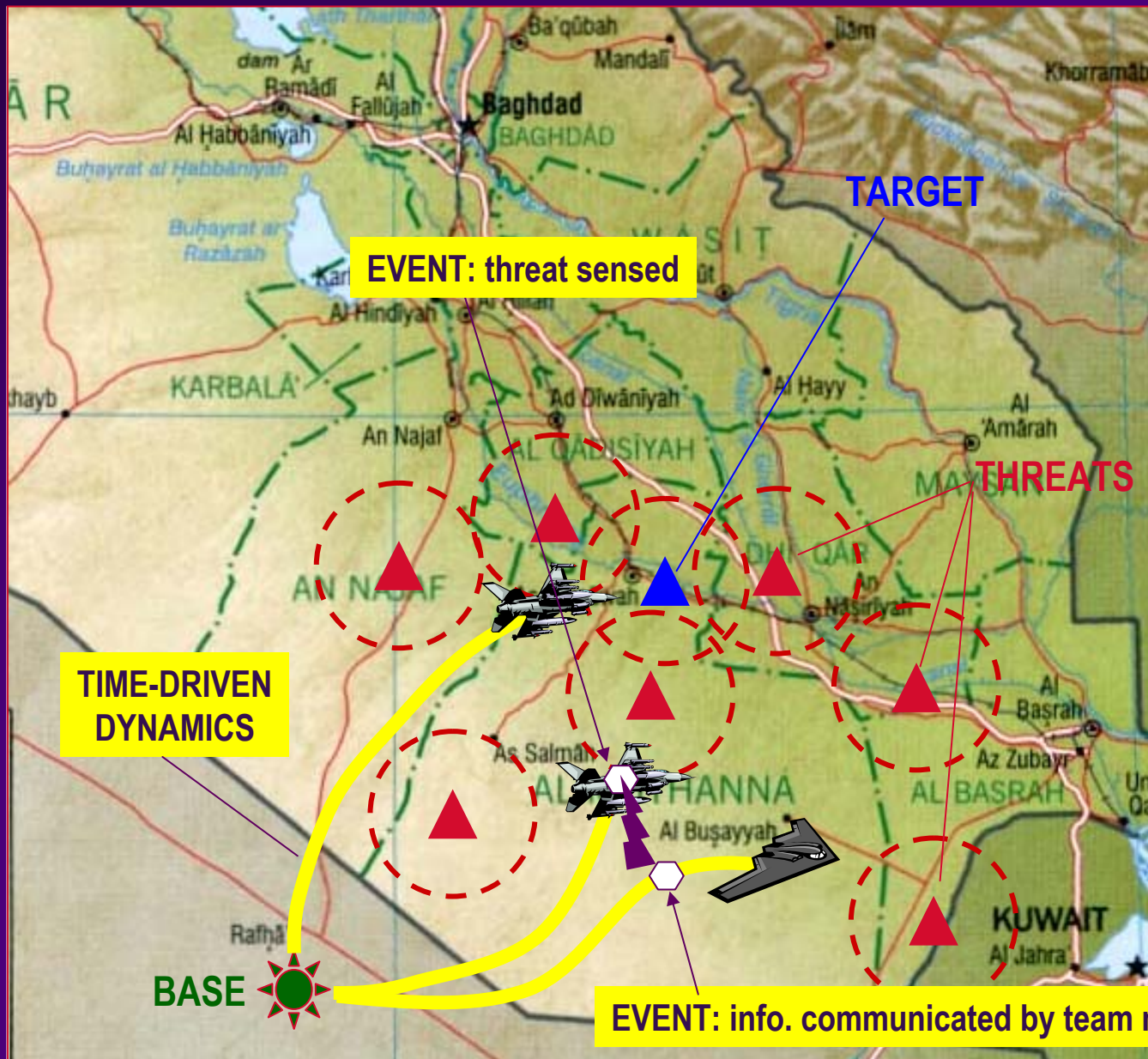
*TIME-DRIVEN
COMPONENT*

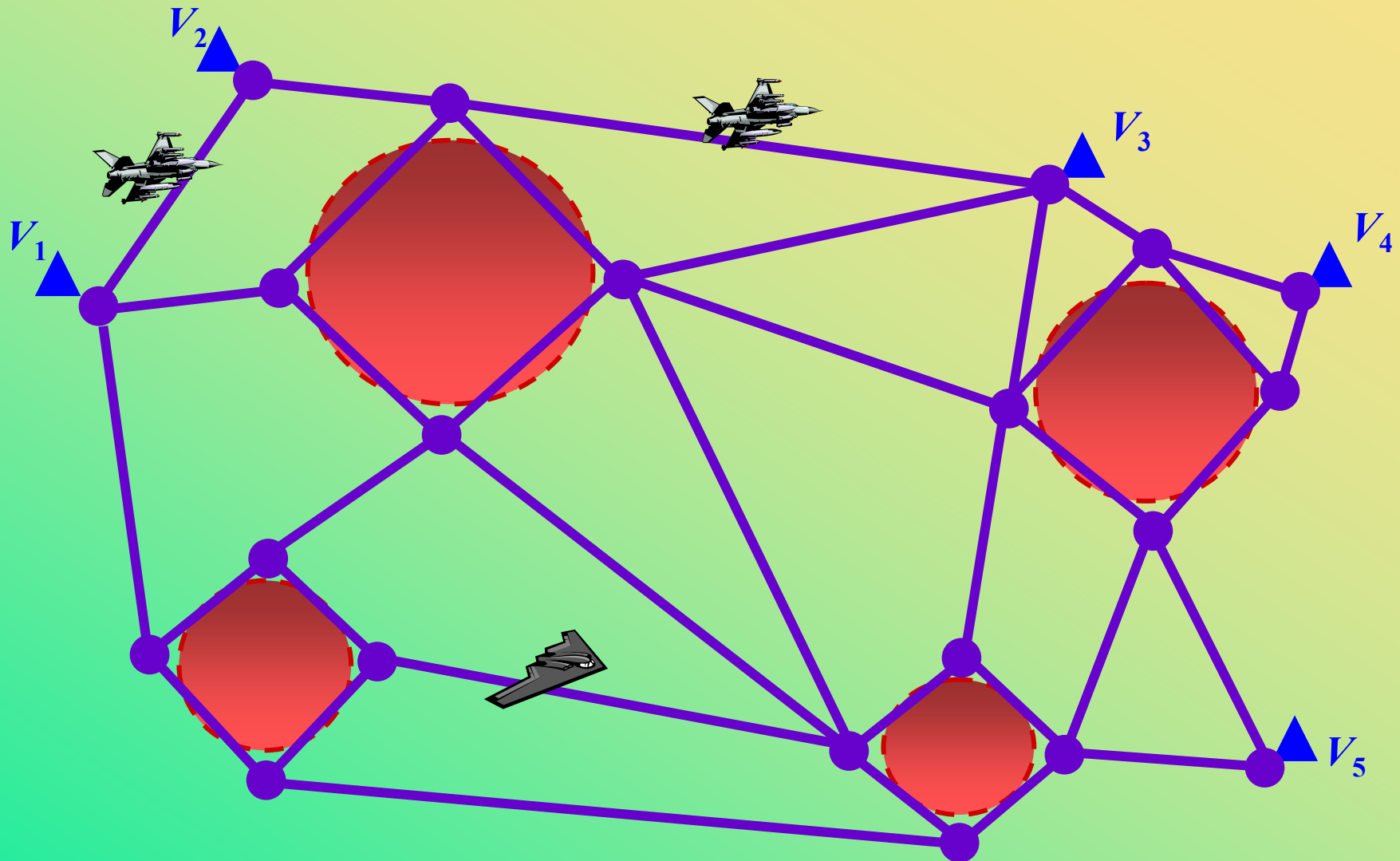
$$u_i \longrightarrow \dot{z}_i(t) = g(z_i, u_i, t)$$

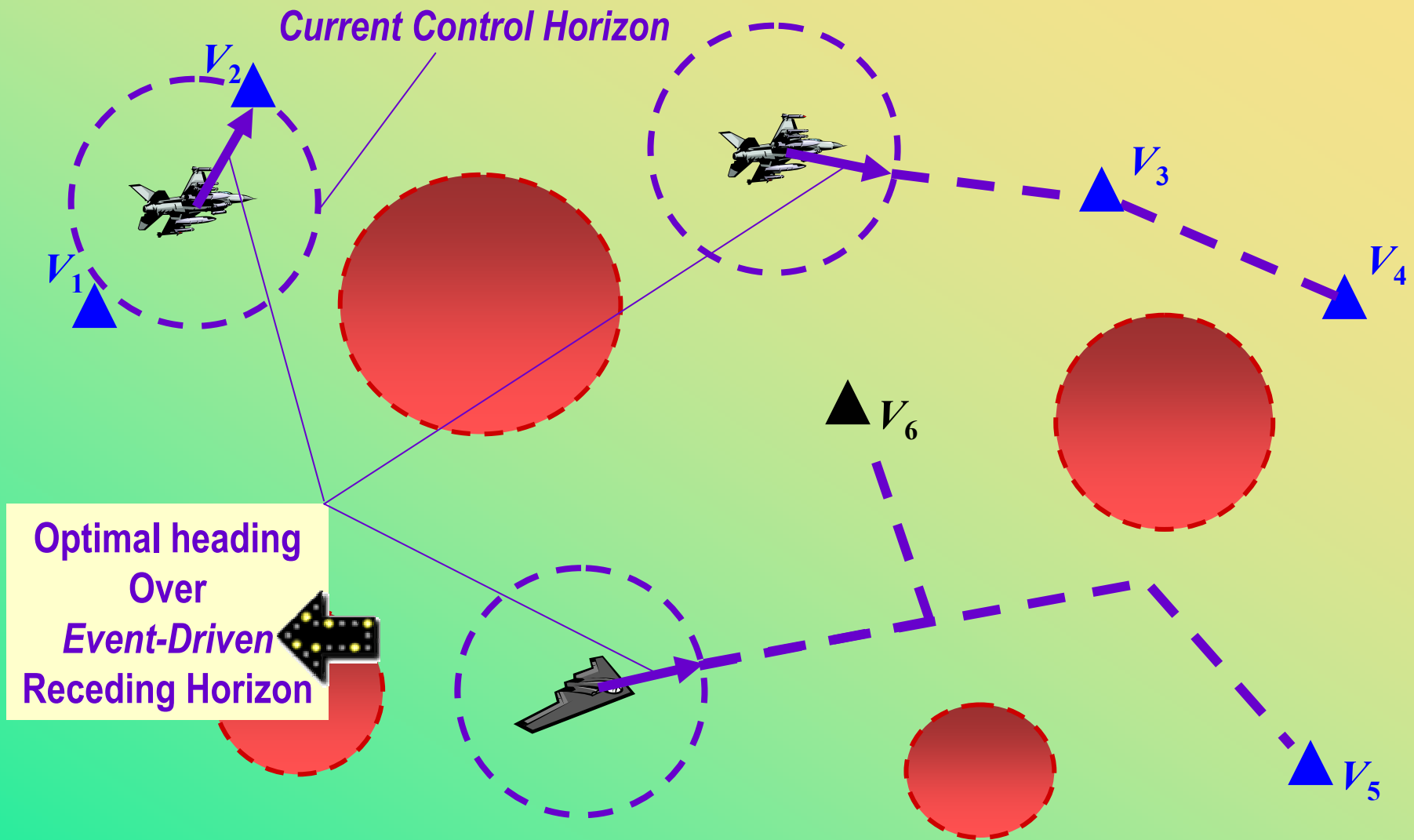
EXAMPLE



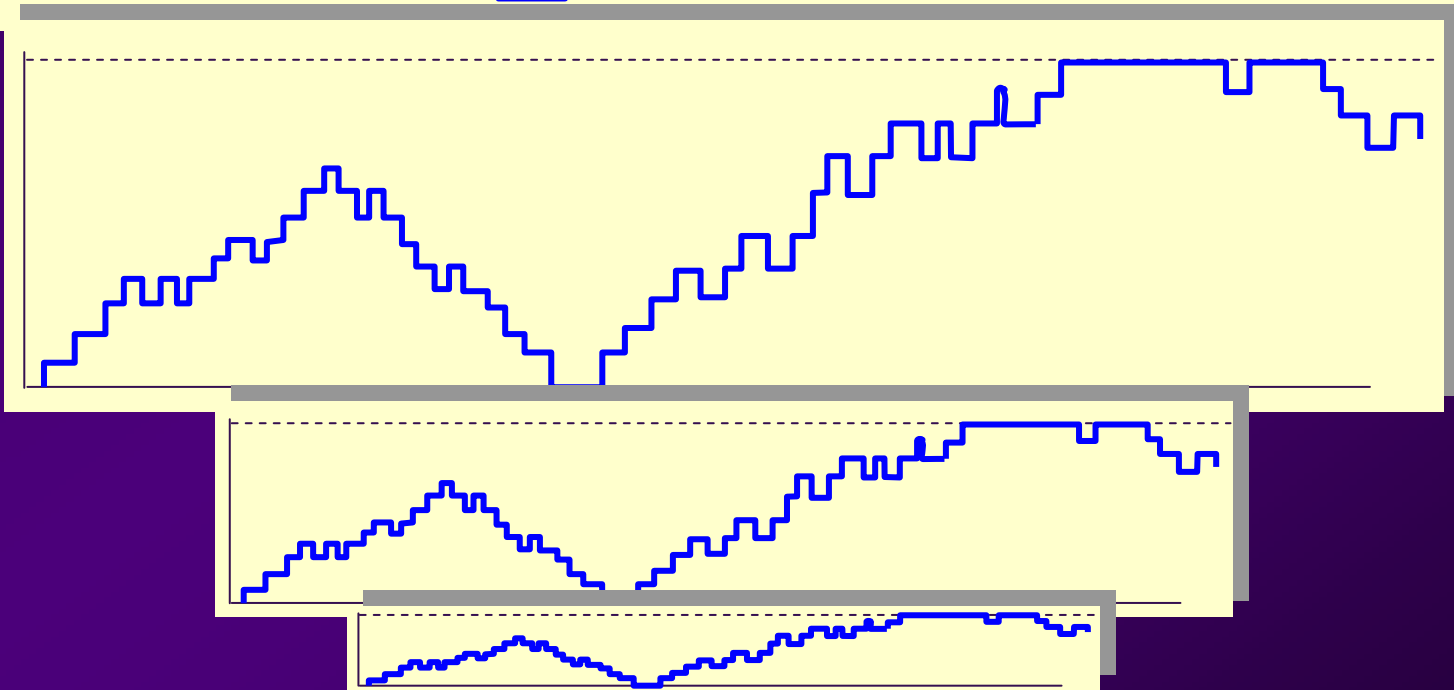
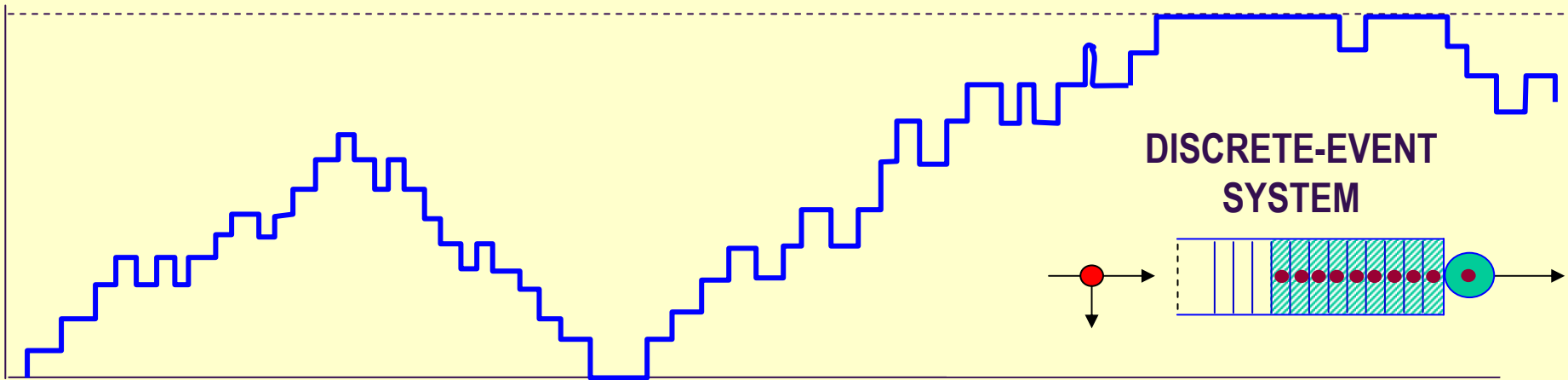
HYBRID SYSTEMS IN COOPERATIVE CONTROL



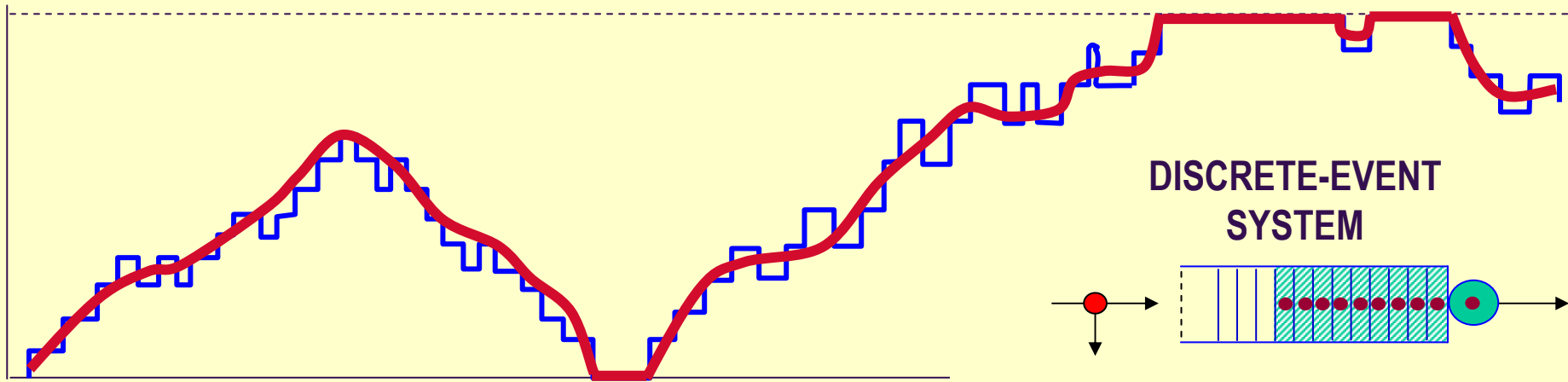




ABSTRACTION OF A DISCRETE-EVENT SYSTEM

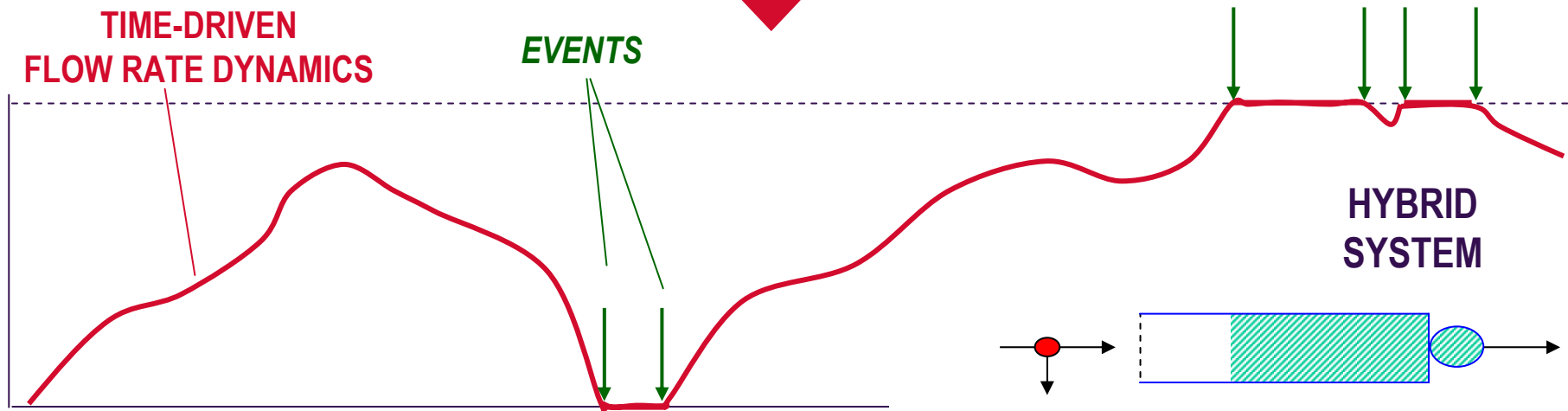


ABSTRACTION OF A DISCRETE-EVENT SYSTEM



**TIME-DRIVEN
FLOW RATE DYNAMICS**

EVENTS



Hybrid System - Netscape

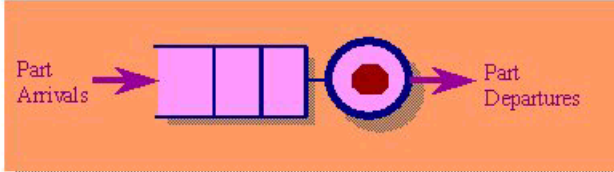
File Edit View Go Communicator Help

Back Forward Reload Home Search Netscape Print Security Shop Stop

Bookmarks Location: <http://vita.bu.edu/cgc/hybrid/> What's Related

Lookup Netscape Calendar CGC Home EDITORIAL BankBoston Get on to HomeL

Hybrid System



Part Arrivals → [Queue] → [Processing] → Part Departures

This is a single stage manufacturing process modeled as a **HYBRID SYSTEM**:

- **PHYSICAL STATE** of parts -> **Time-driven** Dynamics
- **TEMPORAL STATE** of parts -> **Event-driven** Dynamics

OBJECTIVE: Select control for each part to achieve HIGH QUALITY and TIMELY DELIVERY

Home
[Demo1](#)
[Demo2](#)
[Demo3](#)

low:

chedule)
na/- optimal
fault]
common to all

trajectory

	12	13	14	15
7.5	8.0	8.5	9.0	
6	8.140	8.598	8.999	9.592
7	0.977	1.090	0.819	1.120
9	1.631	2.183	1.248	1.686

Document Done

Start

6:13 PM

Document Done

Start

6:14 PM

Start

6:21 PM

DESIGN, ANALYSIS, SYNTHESIS ISSUES

**TIME-DRIVEN
WORLD**



Differential equations
with jumps/switches:

**Stability, Robustness
Optimal Control, etc.**



**EVENT-DRIVEN
WORLD**



Automata with state transitions
dependent on diff. equations:

**Supervisory Control, Reachability
Perturbation Analysis, etc.**



DECIDABILITY, VERIFICATION, QUANTIZATION, SIMULATION, ...

[Proc. of IEEE Special Issue (Antsaklis, Ed.), 2000]