ESE 601: Hybrid Systems

Instructor: Agung Julius

Teaching assistant: Ali Ahmadzadeh

Schedule

- Class schedule :
  - Monday & Wednesday 15.00 – 16.30
  - Towne 305
- Office hours : to be discussed (3 hrs/week)
- Emails:

agung@seas.upenn.edu

aliahmad@grasp.upenn.edu

Course website

- Visit the course website: www.seas.upenn.edu/~agung/ese601.htm
- I will post course plan, announcements, downloadable course materials, homework sets.
- Join the course mailing list in the website. Q&A and announcements outside of the class can be done through the mailing list.
- **Important**: Following the university regulation, some course materials on the website will be password protected.

Grading

- There will be three homework sets (15 points each), due after 2 weeks.
- You can discuss the homework, but do not copy, i.e. work independently.
- Tentative homework schedule is on the website.
- There will be no exam, but final project (55 points).
- If time permits, there will be project presentation.

Final project

- You have to submit a project proposal (1-2 pages) that describes:
  - What you want to do in the project
  - How the project is related with the course
  - References (if any)
- A project can be, for example:
  - A summary of a few coherent papers
  - Modeling and/or analysis of hybrid systems
  - Controller design
- You have to submit a project report (>6 pages)

Course contents

- Review on background materials (continuous and discrete event systems)
- Introduction to hybrid systems, modeling formalisms.
- Modeling and analysis tool CHARON.
- Verification of hybrid systems and software tools.
- Stability analysis of hybrid systems

Course contents

- Controller design
- Stochastic hybrid systems
- Guest lectures on HS in biology and robotics.

Hybrid systems

- Hybrid systems: systems that have both continuous and discrete aspects in the dynamics.
- Continuous: continuous time, differential equations, smooth evolution, infinite/noncountable states.
- Discrete: discontinuities, finite/countable states, discrete time.

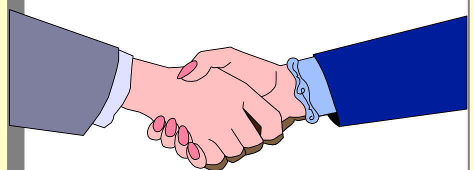
Discrete and Continuous

Control Theory

Continuous systems

Stability, control

Feedback, robustness



Computer Science

Transition systems

Composition, abstraction

Concurrency models

Hybrid Systems

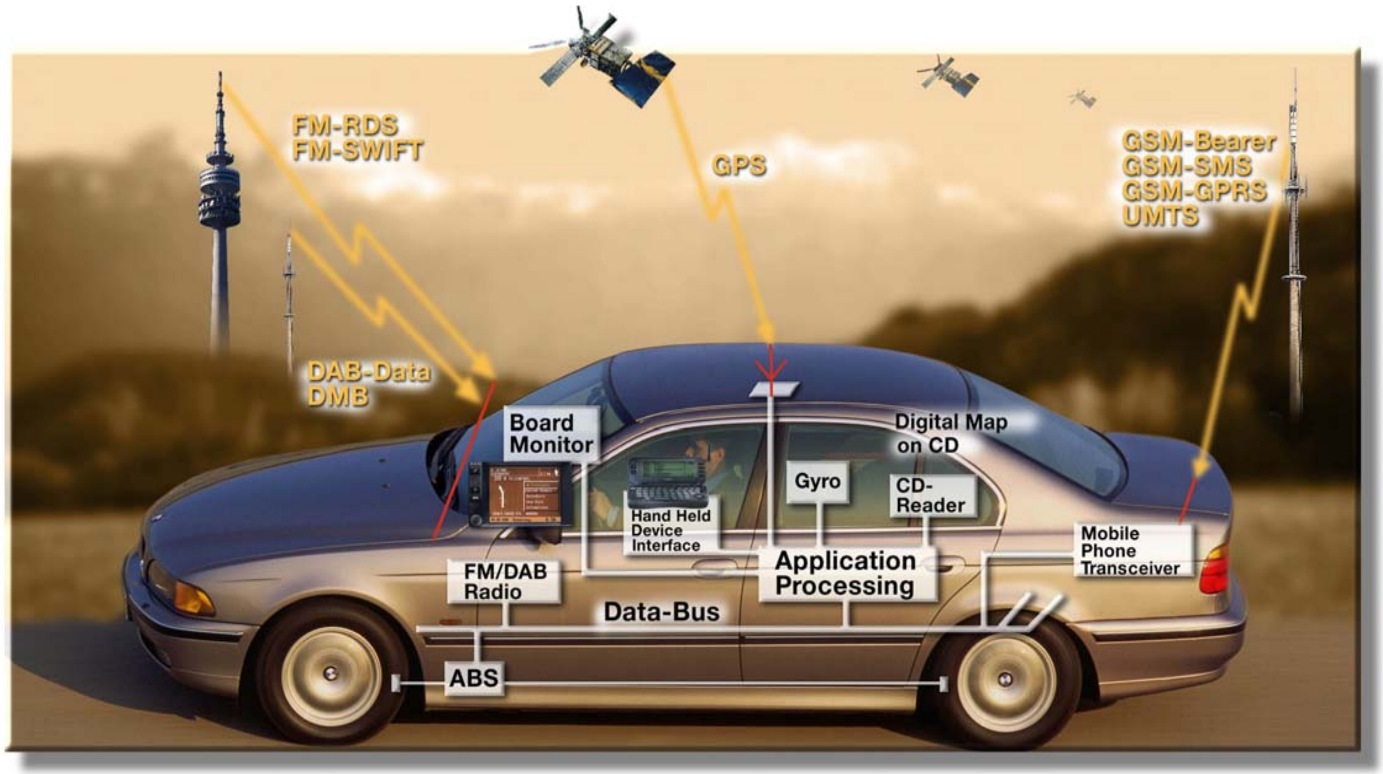
Software controlled systems

Multi-modal systems

Embedded real-time systems

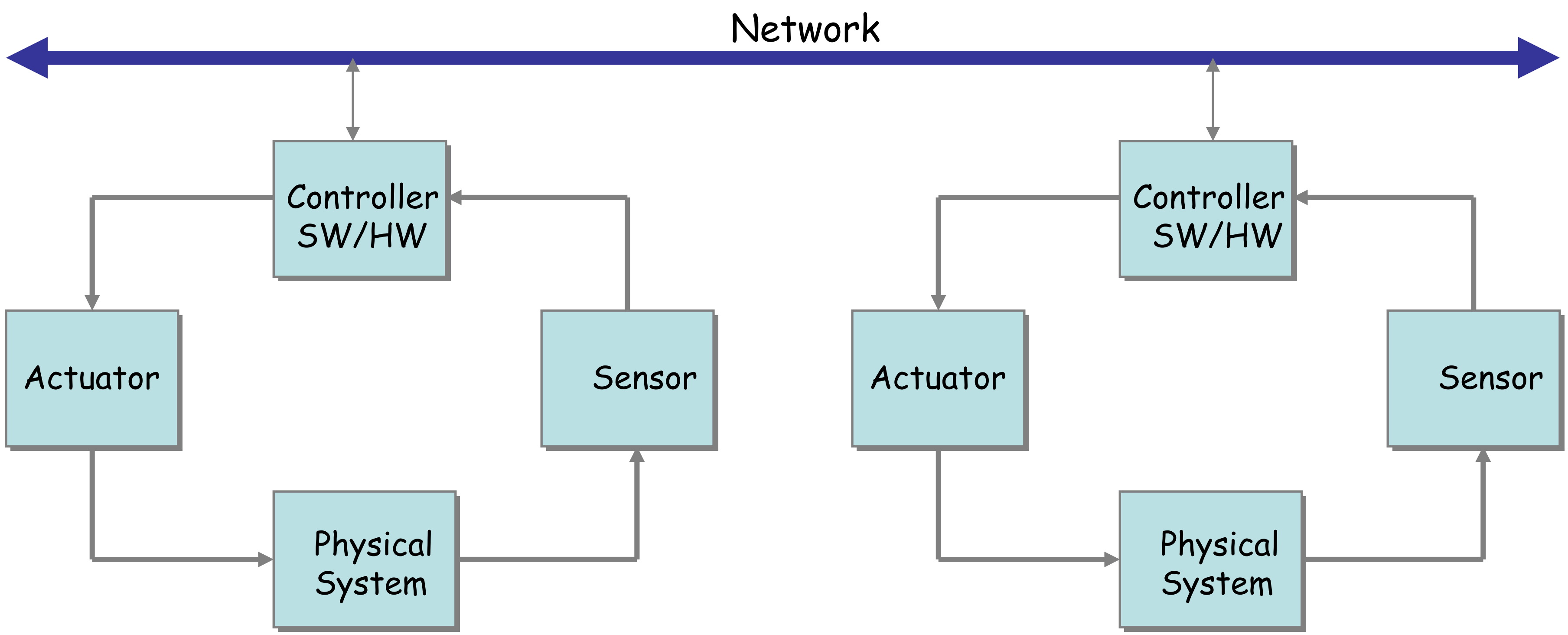
Multi-agent systems

Emerging applications…

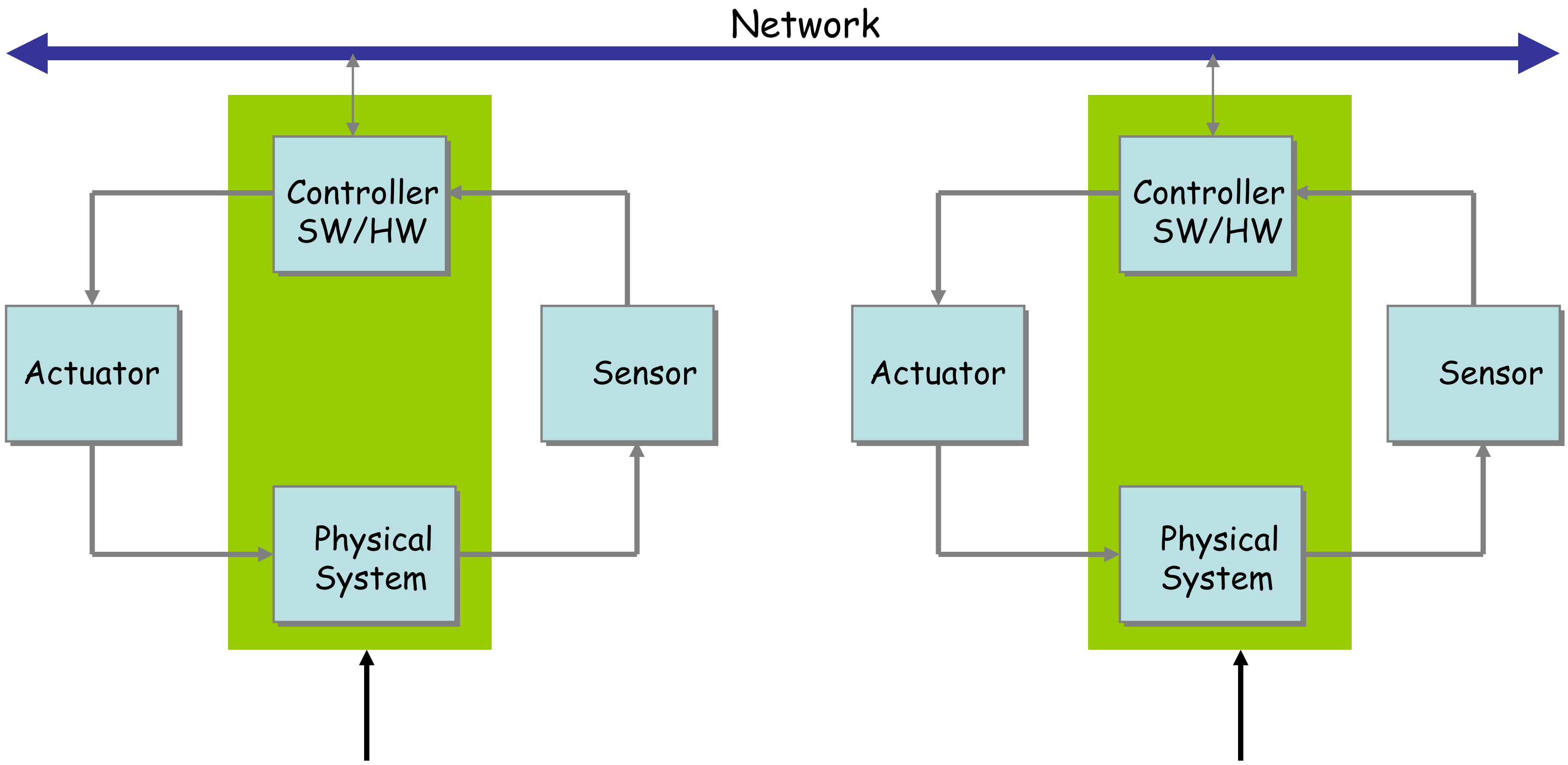


Latest BMW : 72 networked microprocessors
Boeing 777 : 1280 networked microprocessors

Networked embedded systems…



Networked embedded systems…



Physical system is continuous, software is discrete

Lesson from Ariane 5…

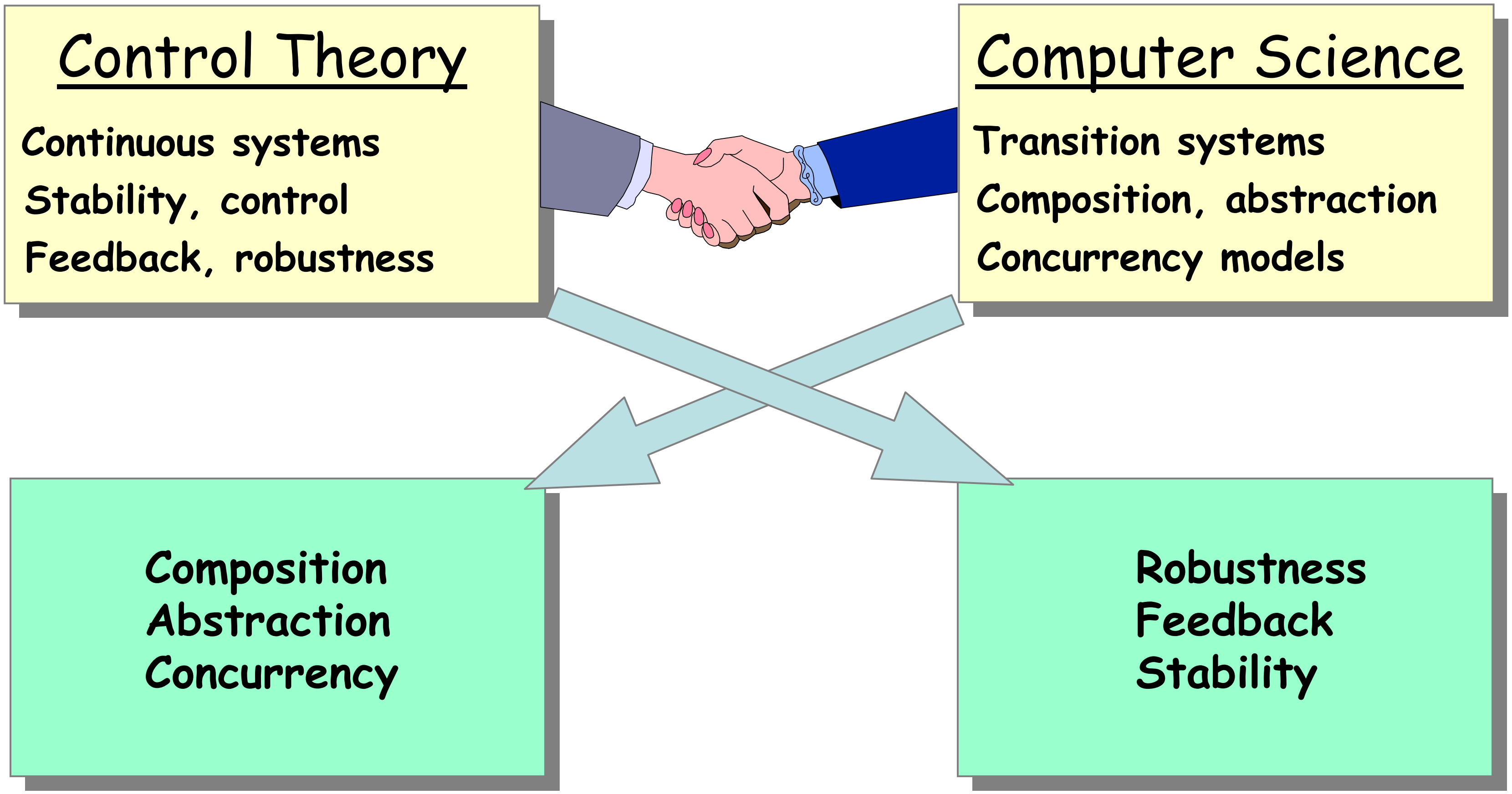
- Ariane 5, an unmanned rocket, was launched on 4th June 1996. The rocket exploded 37s after launching, due to software error.

- The program had been running for 10 years, costing $7 billions. The rocket and its cargo itself cost $500 millions.

- Post-explosion analysis singled out a software program as the cause of the accident.

•Interestingly, the same program functioned perfectly on Ariane 4, and was copied to Ariane 5 for that reason. What had changed, was the physical system around the software.

Exporting Science



Different views…

Computer science perspective

View the physics from the eyes of the software

Modeling result : Hybrid automaton

Control theory perspective

View the software from the eyes of the physics

Modeling result : Switched control systems

Hybrid behavior arises in

- Hybrid dynamics

  Hybrid model is a simplification of a larger nonlinear model
- Quantized control of continuous systems

  Input and observation sets are finite
- Logic based switching

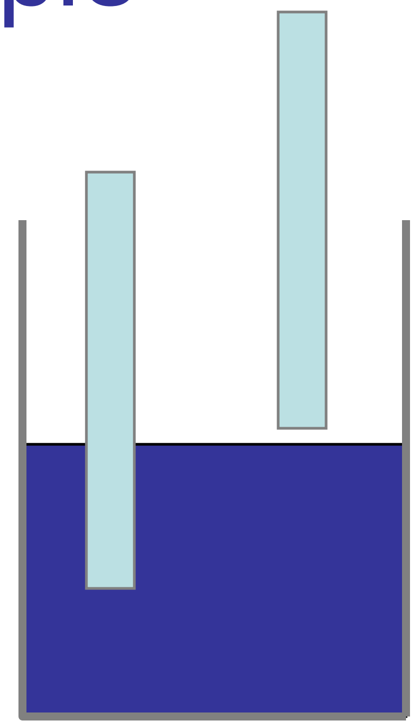
  Software is designed to supervise various dynamics/controllers
- Partial synchronization of many continuous systems

  Resource allocation for competing multi-agent systems
- Hybrid specifications of continuous systems

  Plant is continuous, but specification is discrete or hybrid...

Nuclear reactor example

- Without rods $\dot{T} = 0.1T - 50$
- With rod 1 $\dot{T} = 0.1T - 56$
- With rod 2 $\dot{T} = 0.1T - 60$



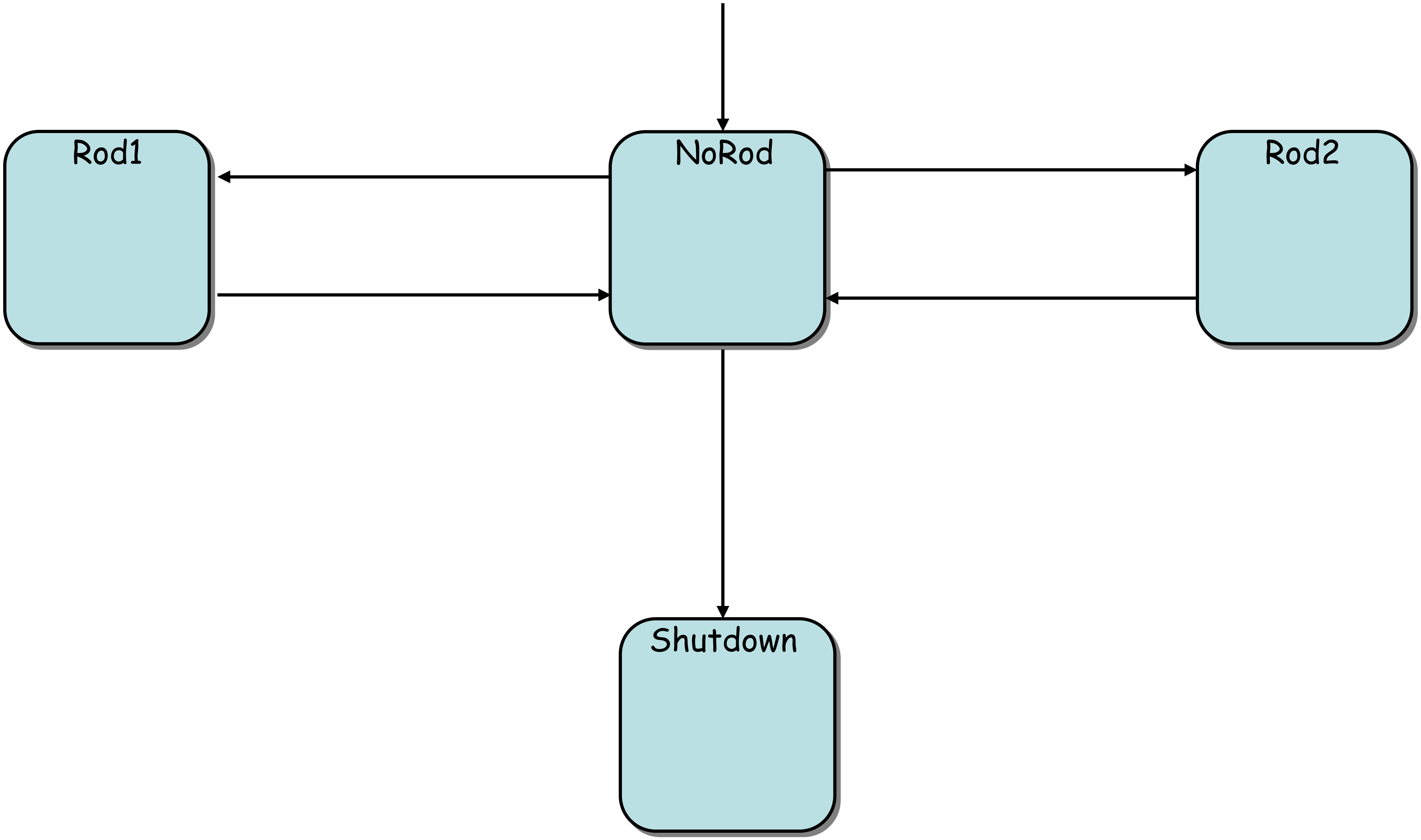
Rod 1 and 2 cannot be used simultaneously

Once a rod is removed, you cannot use it for 10 minutes

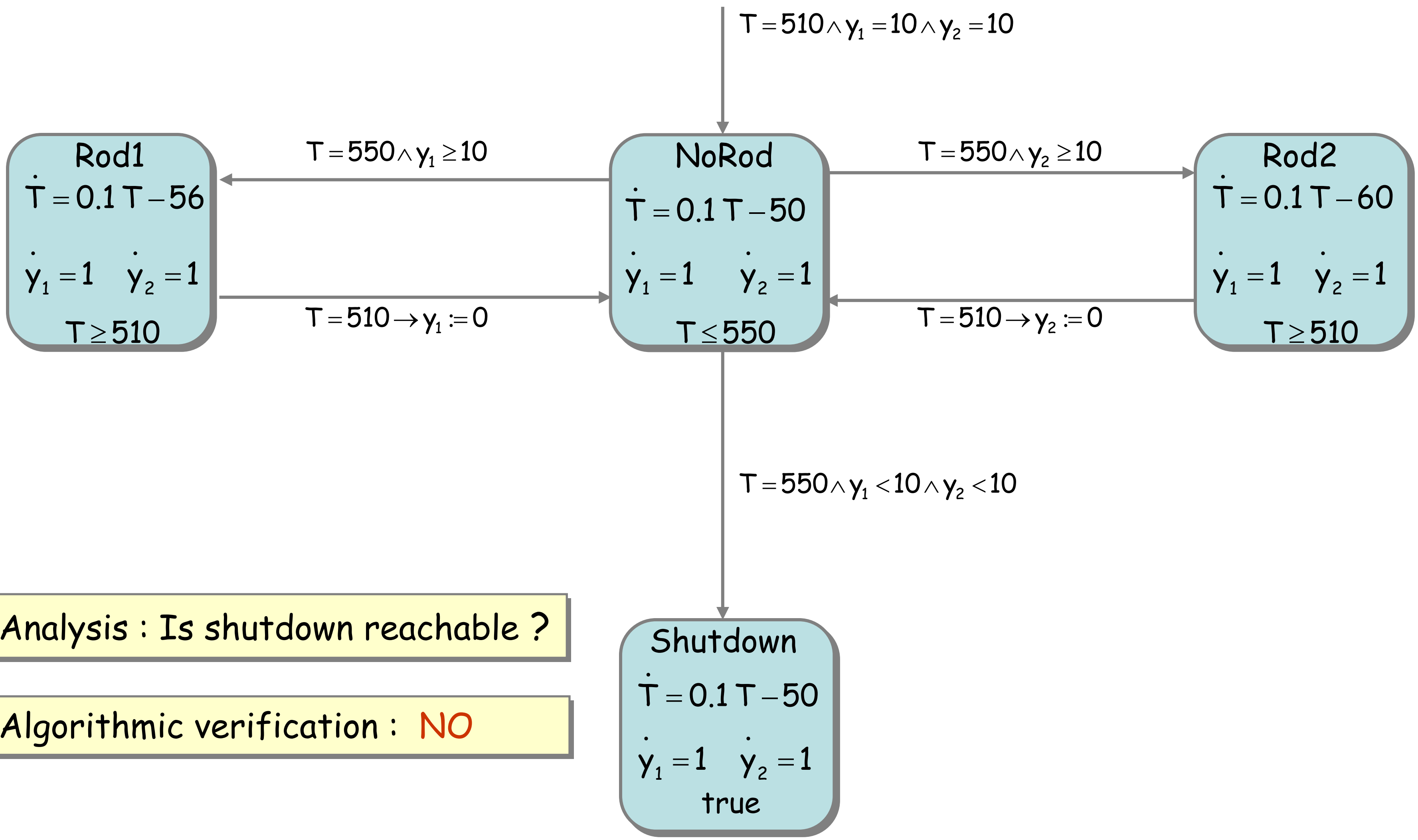
Specification : Keep temperature between 510 and 550 degrees.

If T=550 then either a rod is available or we shutdown the plant.

Software model of nuclear reactor



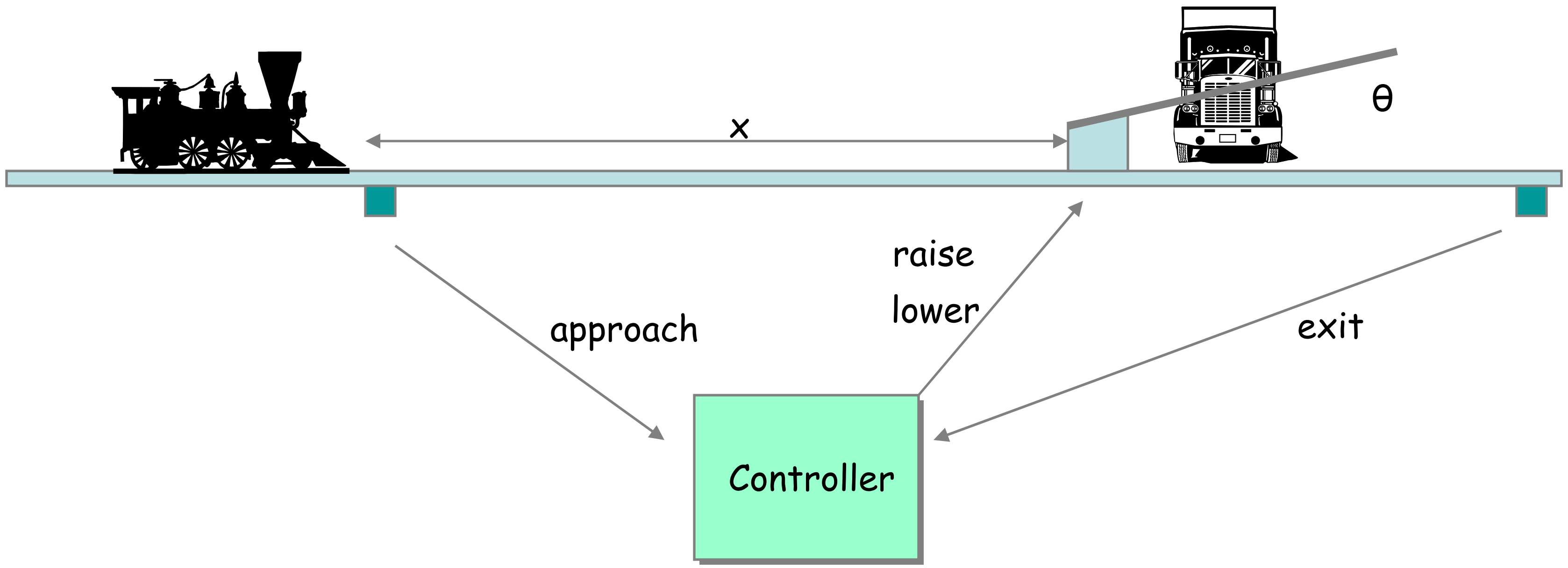
Hybrid model of nuclear reactor



Analysis : Is shutdown reachable ?

Algorithmic verification : NO

The train gate example

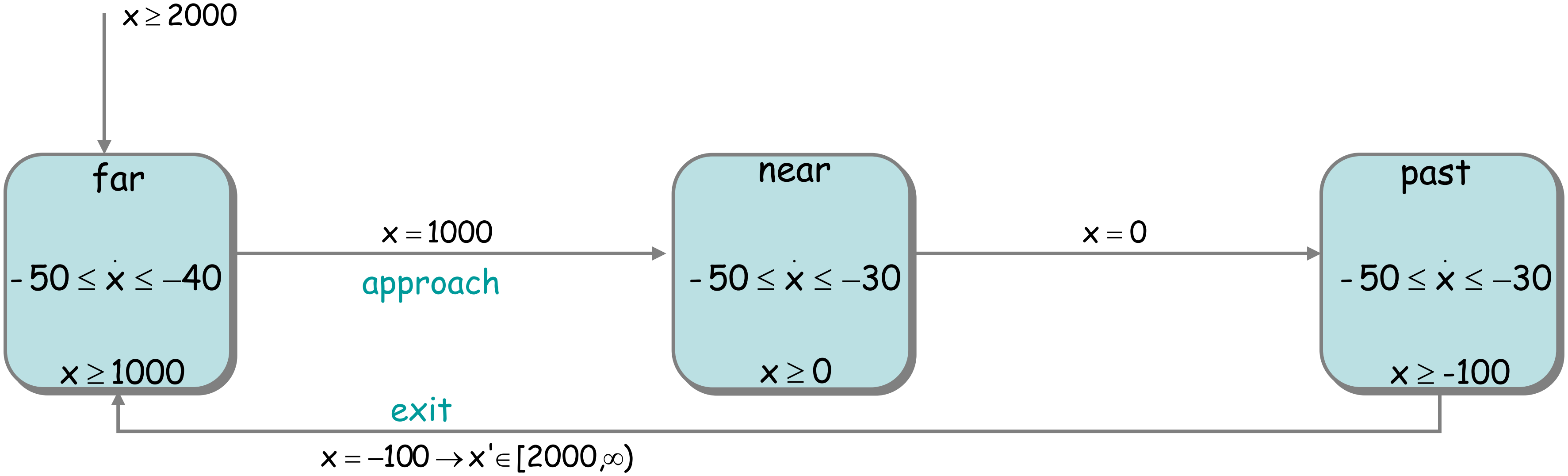


$$System = Train \,||\, Gate \,||\, Controller$$

Safety specification : If train is within 10 meters of the crossing, then gate should completely closed.

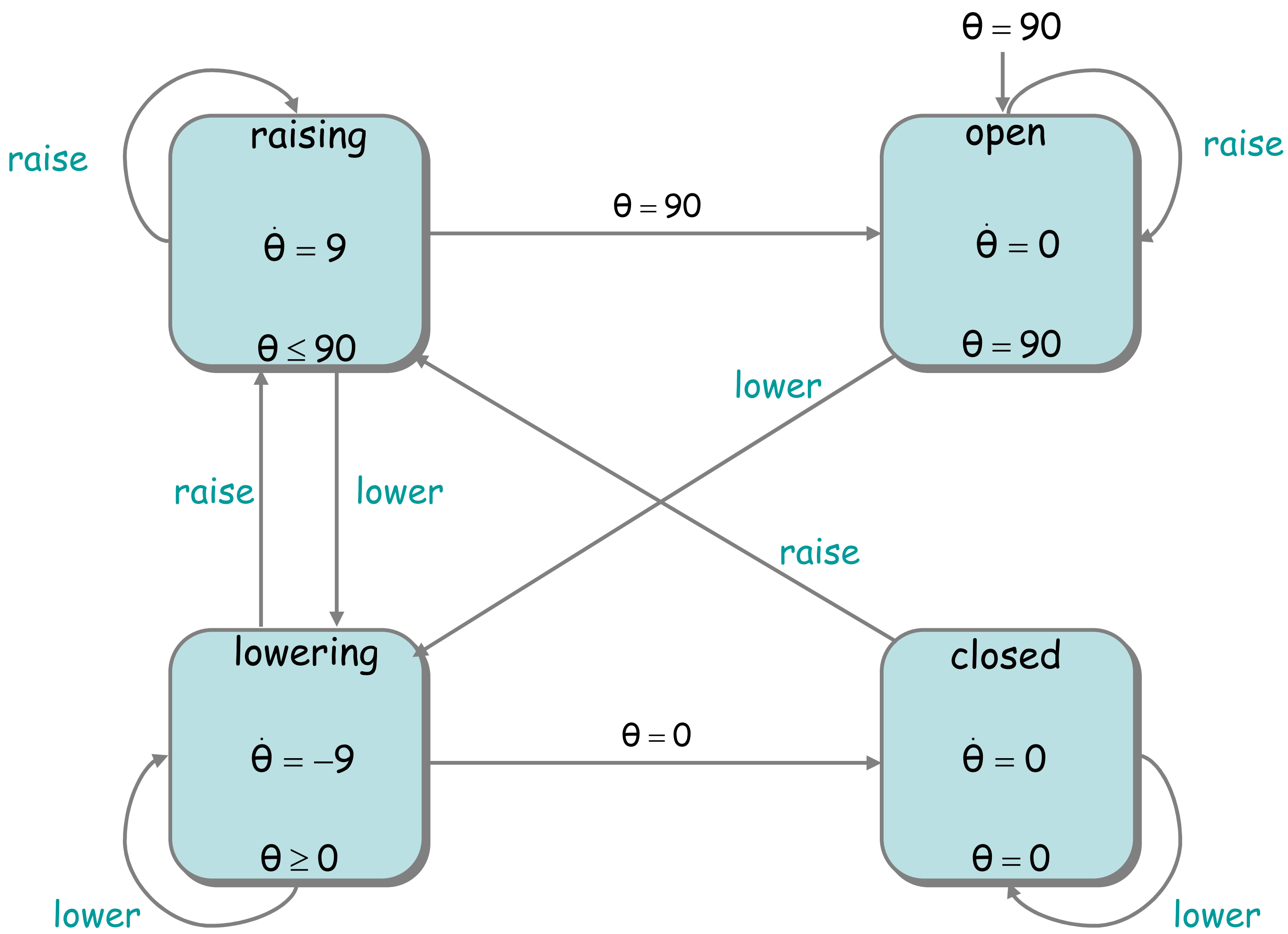
Liveness specification : Keep gate open as much as possible.

Train model



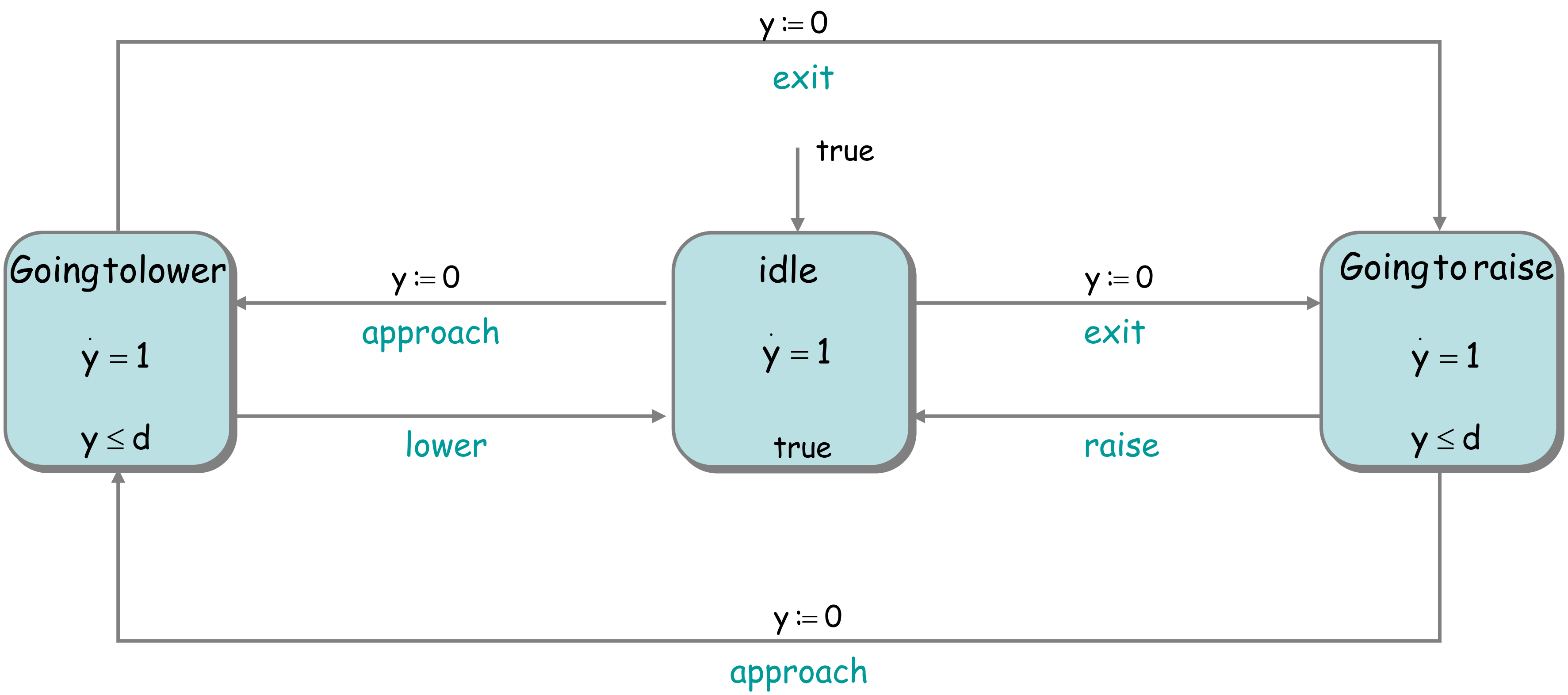
$x \geq 2000$
far
$-50 \leq \dot{x} \leq -40$
$x \geq 1000$
$x = 1000$
approach
near
$-50 \leq \dot{x} \leq -30$
$x \geq 0$
$x = 0$
past
$-50 \leq \dot{x} \leq -30$
$x \geq -100$
exit
$x = -100 \rightarrow x' \in [2000, \infty)$

Gate model

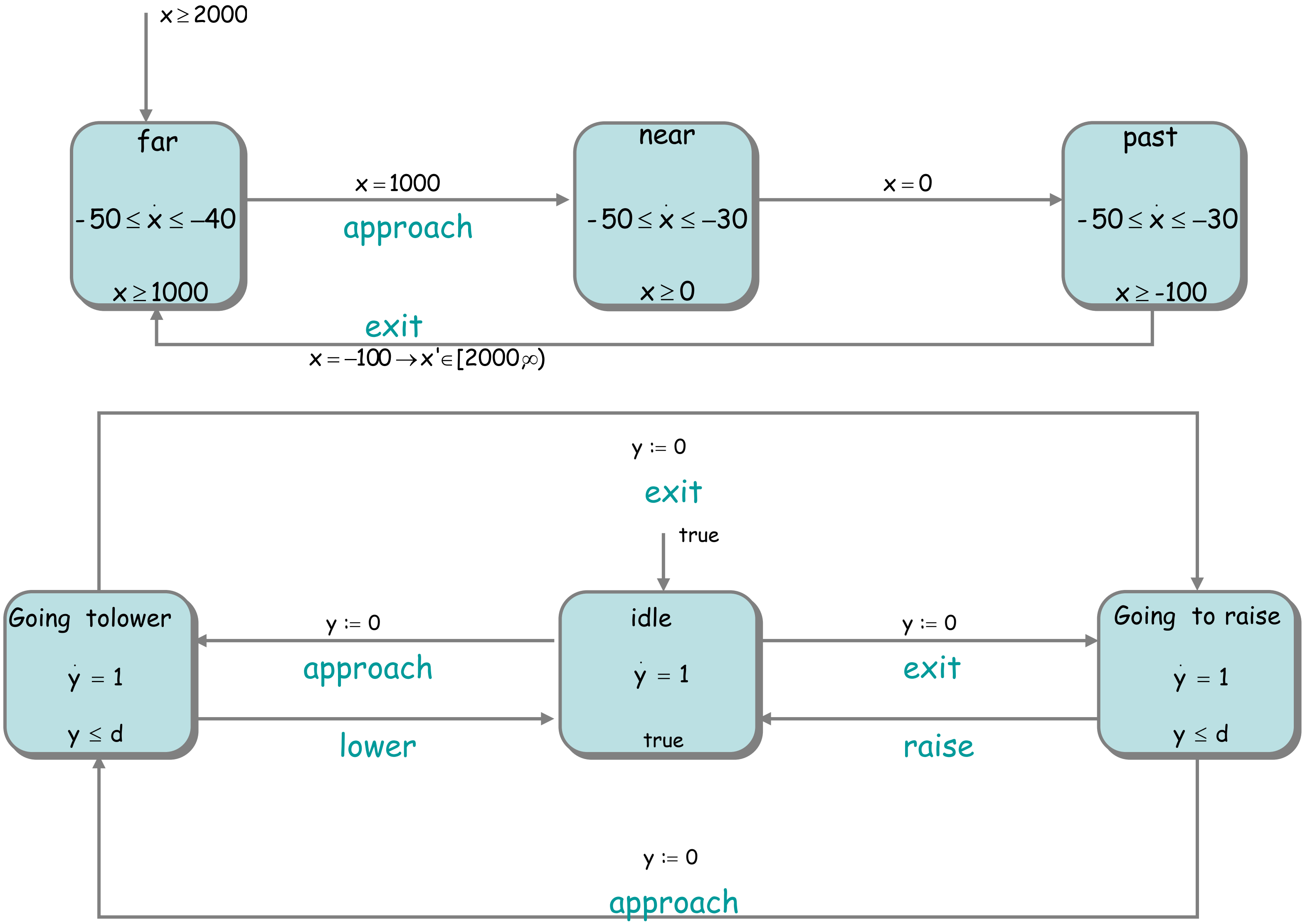


$\theta = 90$
raise
raising
$\dot{\theta} = 9$
$\theta \leq 90$
$\theta = 90$
open
$\dot{\theta} = 0$
$\theta = 90$
raise
lower
raise
lower
raise
lowering
$\dot{\theta} = -9$
$\theta \geq 0$
$\theta = 0$
closed
$\dot{\theta} = 0$
$\theta = 0$
lower
lower

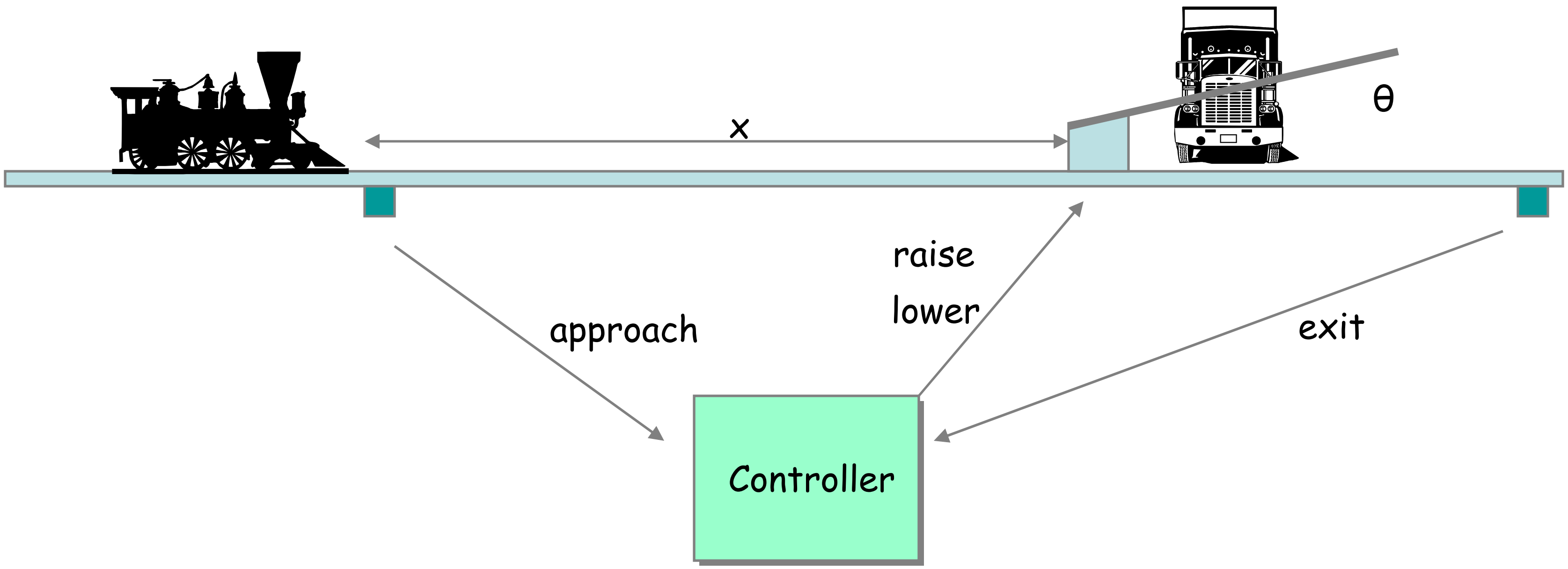
Controller model



Synchronized transitions



Verifying the controller



$$System = Train \,||\, Gate \,||\, Controller$$

Safety specification : Can we avoid the set $\theta > 0 \wedge (-10 \leq x \leq 10)$?

Parametric verification : $YES \;\; if \;\; d \leq \frac{49}{5}$