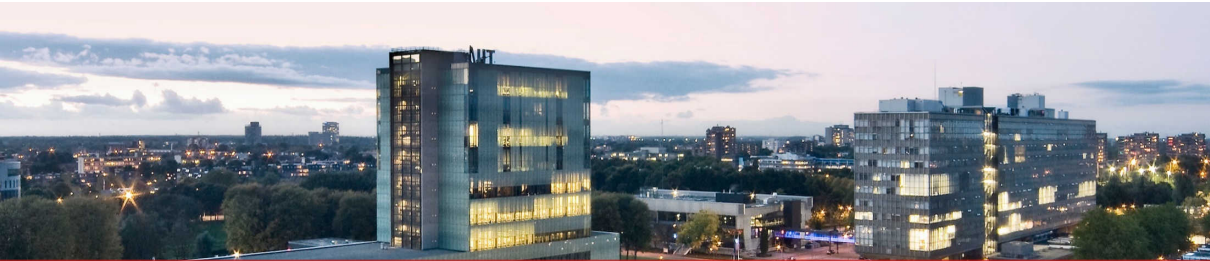


Networked Supervisory Control of Discrete-Event Systems

Aida Rashidinejad, PhD Candidate

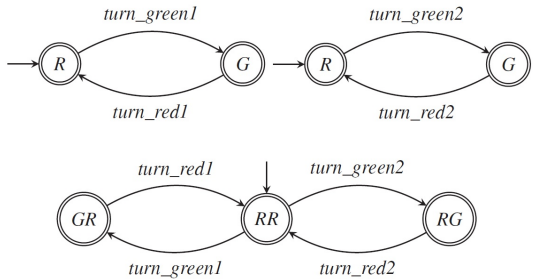
Department of Mechanical Engineering

Discrete-Event Systems

Discrete-state, event-driven systems of which the state evolution depends entirely on the occurrence of asynchronous discrete events over time.

Supervisory Control Theory

A method for synthesizing supervisors that restrict the behavior of a plant such that as much as possible of the given specifications are fulfilled.



Motivation for Control People

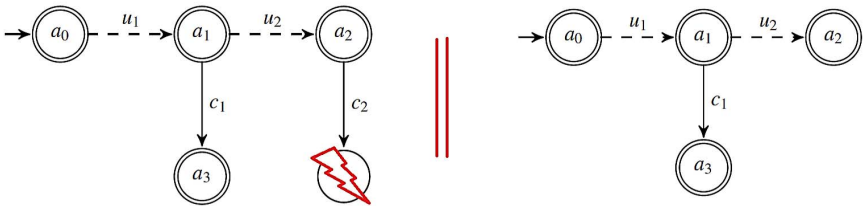
- Low-level control requirements focus on the performance of the system; how to achieve the goal.
- High-level requirements focus on making the right decision; what is the goal to achieve.

Example. Autonomous Vehicle.

- The low-level controller is responsible for steering, the speed.
- The high-level controller is responsible for lane changes, speed selection, merging into or crossing the traffic.

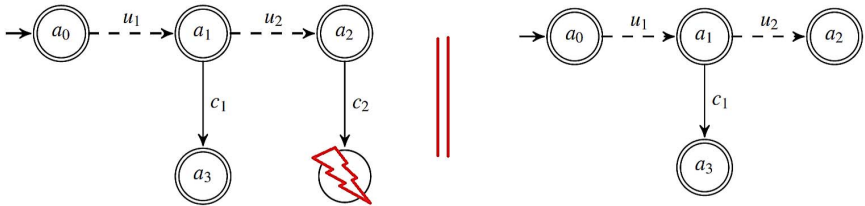
Kurt & Ozguner, *"Hybrid State System Development for Autonomous Vehicle Control in Urban Scenarios"*, IFAC, (2008)

Conventional Supervisory Control Theory



- Plant modelled as (network of) DES [single plant automaton]
- Specifications describing allowed behaviour [only nonblocking]
- Synchronous composition between plant and supervisor [supervised plant]

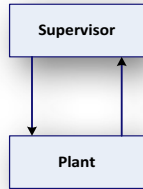
Conventional Supervisory Control Theory

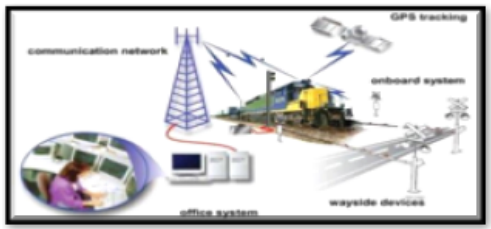


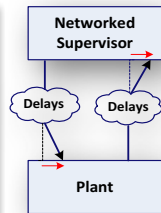
Properties of supervised plant:

- nonblockingnes
- controllability [only disable controllable events]
- maximal permissiveness [only disable when necessary]

Networked Control: Benefits & Challenges

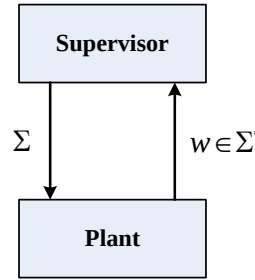






Supervisory Control in Implementation

- Avalanche effect (single event triggers multiple state changes)
- Choice (several alternatives in a state)
- Inexact synchronization
- Interleave sensitivity (observation $\neq$ execution order)
- Causality (spontaneous vs commanded execution)

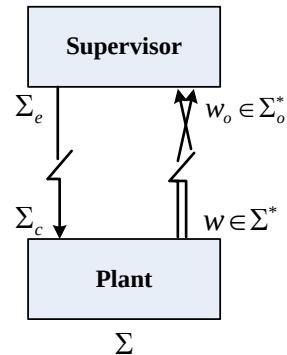


Fabian & Hellgren, *"PLC-based implementation of super-visory control for discrete event systems"*, CDC, (1998)
Bastile & Chiacchio, *"On the implementation of supervised control of discrete event systems"*, IEEE Trans. on Cont. Sys. Tech., (2007)
Zaytoon & Riera, *"Synthesis and implementation of logic controllers– a review"*, Ann. Rev. in Cont. (2017)
Balemi, *"Communication delays in connections of input/output discrete event processes"*, CDC (1992)

Supervisory Control of Discrete-Event Systems in an Asynchronous Setting

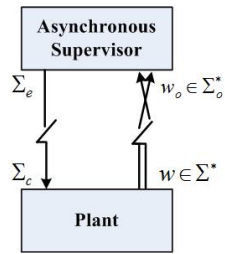
Asynchronous Supervisory Control

- A controllable event can be executed in the plant only if commanded by the supervisor.
- Uncontrollable events occur spontaneously in the plant.
- A control command may not necessarily be accepted by the plant, and in this case it remains in the channel.
- Any plant event is observable to the supervisor. The observation of an event may occur immediately or at some point in the future.
- Consecutive events that occur in the plant may be observed in any possible order



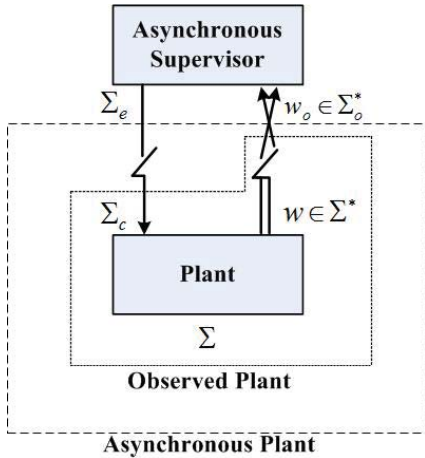
Problem Statement

Problem Statement: for a given plant G, we aim to find an asynchronous supervisor AS such that $AS||G$ is nonblocking.

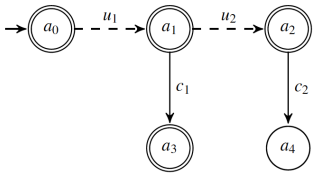


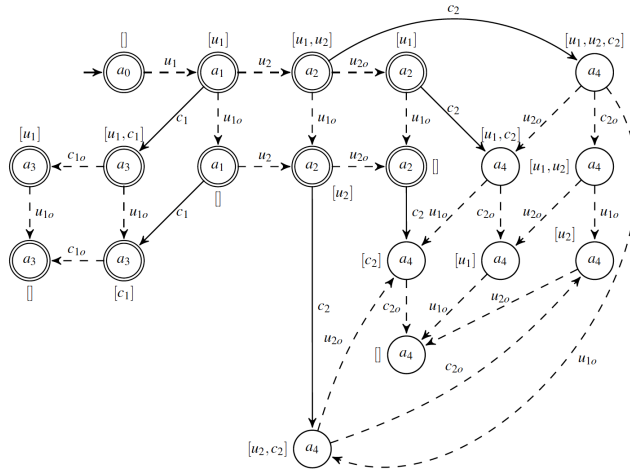
Property of the ASC Setting: for any asynchronous supervisor AS and plant G, (asynchronous) controllability is always guaranteed.

Synthesis Technique



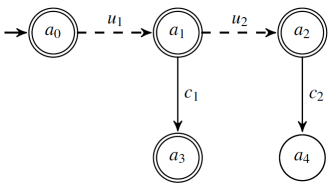
Observed plant (add observation events to plant)

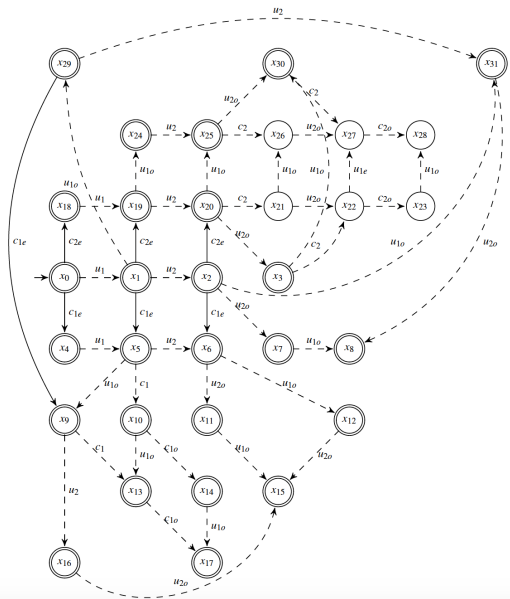




Asynchronous Plant

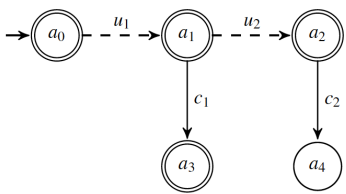
- Insert enabling events whenever appropriate (enabled in observed plant)

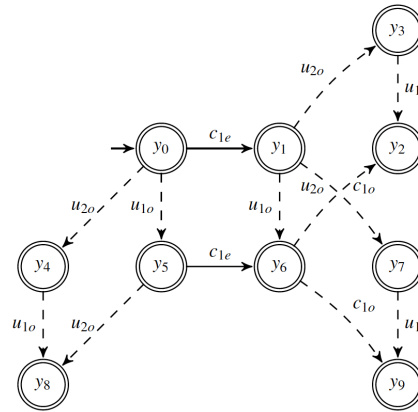




Asynchronous Supervisor

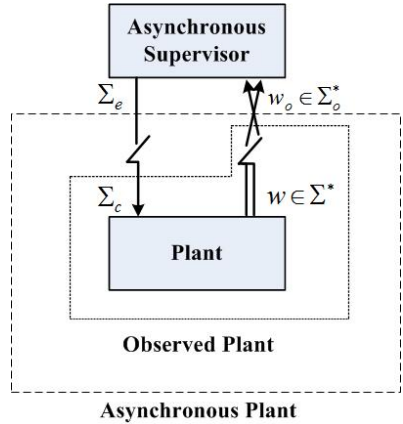
- Disable enabling events in asynchronous plant taking care that same decision is made in observationally equivalent states observed events





Conclusions

- Introduced asynchronous supervisory control setting
- Define asynchronous composition operator and asynchronous controllability
- Asynchronous controllability always holds for any asynchronously composer supervisor and plant
- Synthesis of asynchronous supervisor guaranteeing nonblockingness

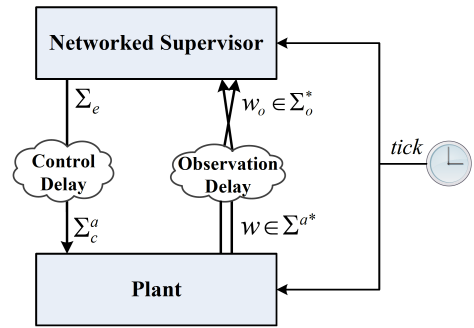


Rashidinejad & Reniers & Fabian, *"Supervisory Control of Discrete-Event Systmes in an Asynchronous Setting"*, CASE, (2019)

Networked Supervisory Control of Timed Discrete-Event Systems

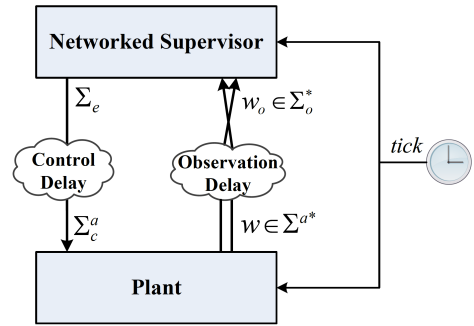
Networked Supervisory Control

- A controllable event can be executed in the plant only if commanded by the supervisor.
- Uncontrollable events occur spontaneously in the plant.
- A control command reach the plant after a constant amount of time.
- A control command may not necessarily be accepted by the plant, and in this case it remains in the channel.
- The control channel is FIFO.



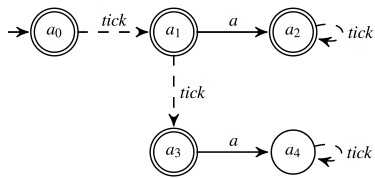
Networked Supervisory Control

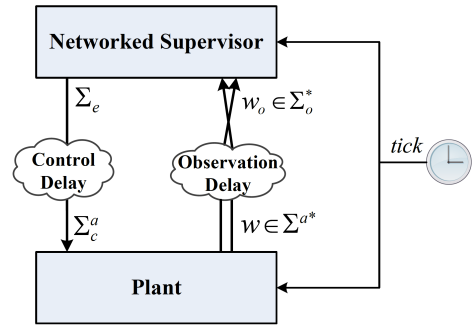
- Any event executed in the plant is observable to the supervisor.
- The observation of a plant event occurs after a constant amount of time.
- The observation channel is non-FIFO.



Networked Supervisory Control

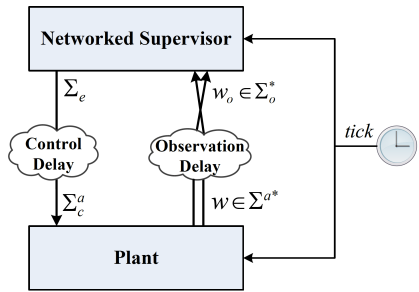
- TDES:



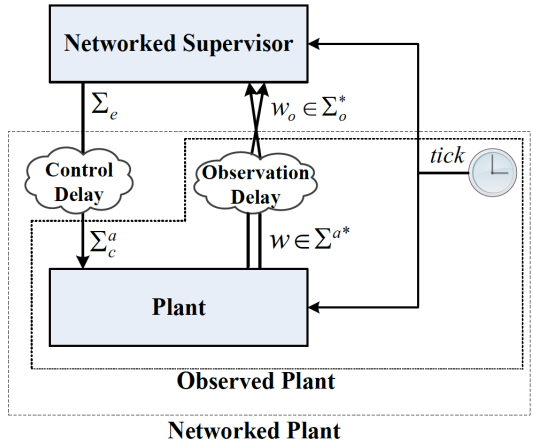


Problem Statement

Basic NSC Problem Statement: for a given plant G, the control delay N_c, and observation delay N_o, we aim to find a networked supervisor NS such that $NS|N_c, N_o|G$ is nonblocking, (time networked) controllable, time-lock free, and maximally permissive.



Synthesis Technique



Conclusions

- The assumption of synchronous interactions between the plant and supervisor is not valid anymore in a network-based control setting.
- A networked supervisory control framework is proposed in which delays are measured based on time.
- A synthesis technique is presented that results in a networked supervisor satisfying controllability, nonblockingness, time-lock freeness, and maximally permissiveness.

- Future research: from TDES to timed automata.

- Rashidinejad, Lin, Wetzels, Zhu, Reniers, Su, *"Supervisory Control of Discrete-Event Systems under Attacks: An Overview and Outlook"*, ECC (2019).

Acknowledgement

This research has received funding from the European Union's Horizon 2020 Framework Programme for Research and Innovation under grant agreement no 674875.

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

Thank you for your kind attention.

Networked Supervisory Control of Discrete-Event Systems

Aida Rashidinejad, PhD Candidate

Department of Mechanical Engineering