

# Cyber-Physical Computation

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Renato Neves



Universidade do Minho



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Cyber-Physical Systems

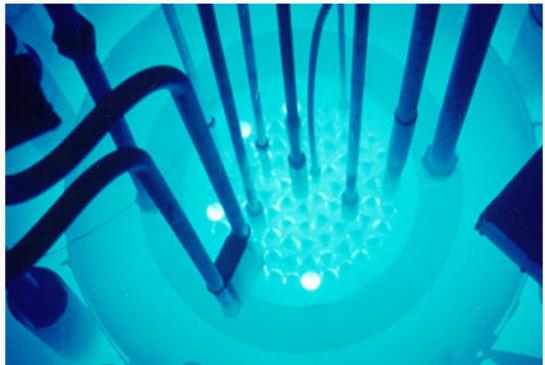
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# Cyber-Physical Systems



Digital devices that interact with their physical environment



## Another example of a cyber-physical system



SpaceX's Starship | SN8

## ...and yet some other cases

- Semi-autonomous self-driving systems
- (Crewed) spacecrafts

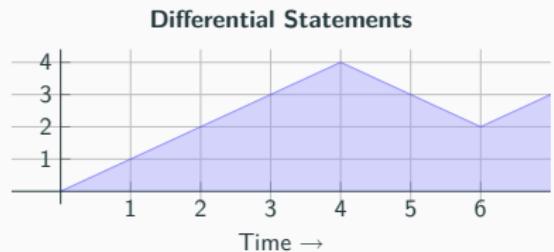
# The three ingredients of cyber-physical systems

- Concurrency
- Communication
- Hybrid interaction

# Computer Science meets Analysis



`(wait 2); x := x + 1; (wait 1) ...`

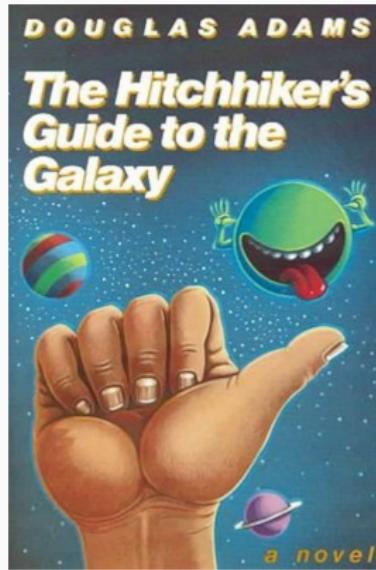


```
while (true) {
    if v ≤ 2
        then (v = 1 for 2)
    else (v = -1 for 2) }
```

# A particle and its orbital trajectory – what can go wrong?

```
x := -1; v := 0; a := 1;
while true do {
    if x <= 0 then a := 1; else a := -1;
    x' = v, v' = a   for 0.5;
}
```

# Cyber-Physical Computation



What is actually **computable** ?

# Cyber-Physical Computation

*Genesis:* David Hilbert and its  
*Entscheidungsproblem* (circa 1928)



Fuelled the appearance of first models of computation (circa 1936)

- Turing machines: state-based, part of **automata** theory
- $\lambda$ -calculus: function-based, prototypical **programming** lang

# Church-Turing Thesis

Computable if encodable as a Turing machine or (equivalently) as a  $\lambda$ -term



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# Contents of the course pt. I

We will study diverse models of cyber-physical computation

- (timed) automata,
- a hybrid while-language,
- $\lambda$ -calculus extended with computational effects (**monads!**)

# Contents of the course pt. I

We will study diverse models of cyber-physical computation

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and often make detours through the **mathematical foundations** of  
automata and programming language theory . . .

## Contents of the module pt. II

We will get acquainted with diverse tools

- **Uppaal** verification of real-timed systems modelled by (networks of) timed automata
- **Lince** agile analysis of cyber-physical systems modelled by a hybrid while-language
- **Haskell** a platform to study  $\lambda$ -calculus with effects

# How deep will we go into the rabbit hole?

Our learning path will intersect theory and practice,  
from the very basics to the state-of-the-art —  
we will face current limitations and see what  
challenges lie ahead



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# Assessment

Two individual assignments (about the modelling and analysis of cyber-physical systems)

## Materials and Contacts

Relevant class material and announcements posted on the website

<https://lmf.di.uminho.pt/CyPhyComp2425/>

e-mail: nevrenato@di.uminho.pt

office hours: wednesday afternoon (please send an email the day before if you wish to meet)

- Edward A Lee, *Cyber-physical systems-are computing foundations adequate*, Position paper for NSF workshop on cyber-physical systems: research motivation, techniques and roadmap, vol. 2, Austin, TX, 2006, pp. 1–9.
- Ragunathan Rajkumar, Insup Lee, Lui Sha, and John Stankovic, *Cyber-physical systems: the next computing revolution*, Proceedings of the 47th design automation conference, 2010, pp. 731–736.