# Synchronous Languages—Lecture 01

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*Introduction*





## Overview

About this Class
- About this class and related classes
- Practicalities
- Literature

Introduction to System Design
- Embedded and reactive systems
- Advanced design languages



- Why are these slides in English? And not—for example—in German (which is the spoken language in class)?
- Almost all of the publications in this field and most of the manuals and code documentations are in English. So being able to read English makes a vast amount of information accessible that would not be available otherwise.
- Becoming acquainted with the English terminology is also a prerequisite to writing English documents—which in turn is a prerequisite to make your results globally available.
- In short, English is the *lingua franca* of modern computer science—and you should try to practice it whenever you produce technical documentation!



## Virtual Lecture

- This class is held live, to allow for interaction.
- Slides are available on-line before lecture.
- For those who cannot participate live and for later reference, the audio and the shared screen (**not** the list of participants) will be recorded.

# Your Privacy

- Seeing your faces would allow some "class atmosphere," and it would help me to judge how well things come across.
- However, it's up to you whether you switch on your camera or not.
- In any case, it is **forbidden** by law to make photos/recordings of participants.
- Similarly, seeing your real name may help you to find buddies, and it would allow me to give you credit for contributions to the class.
- However, it's up to you whether you participate with your actual name or with some alias.





# Interaction protocol

1. Per default, have your microphone muted.
2. If you want to ask something/respond to a question, raise your hand—either on video, or by using "raise hand" feature in zoom.
3. To take your comment, I will not mention your name (to preserve anonimity), but will prompt you to unmute your microphone (a msg box will pop up on your screen)
4. After you made your comment, lower your hand (if you used the zoom feature), and mute your mike again.
5. If it's urgent or if I appear to overlook you for a longer time, you may also just speak up.





# Aim of this Lecture

After this lecture, you should have an idea on . . .

- . . . what this class and related classes are about
- . . . whether this class is for you
- . . . what is expected of you should you decide to participate





# What this class will be about

- Synchronous Languages and the Synchrony Hypothesis: Separate design of control from timing constraints
- Esterel: a textual, synchronous language
  - Formal semantics
  - Code and hardware synthesis for Esterel programs
  - Analysis, constructiveness
  - Reactive processing (Kiel Esterel Processor)
- Other synchronous languages:
  - Lustre
  - Scade
  - Statecharts, expecially SyncCharts (the graphical counterpart to Esterel) and SCCharts (Sequentially Constructive Charts)
  - Blech
- Optionally: further concurrent models of computation

# Related classes

- Embedded RT Systems (WS 20/21)
  - Modeling dynamic behaviors
  - Design of Embedded Systems
  - Analysis and verification
  - Lego Mindstorms
- Graph Drawing (WS 21/22)
  - Explains algorithms behind, *e. g.*, SCCharts browser
  - Force-directed approaches
  - Layer-based / Sugiyama
  - Tree drawing
  - Pragmatics and Human-Computer Interaction





# What you should learn in this course

1. You should know what synchronous languages are
2. You should know about their theoretical foundation of synchronous languages
3. You should have a detailed knowledge about Esterel and SCCharts, including their semantics
4. You should be aware of possibilities and problems in code/hardware generation from synchronous languages





# People

Lectures:
Reinhard von Hanxleden
`rvh@...` Tel.: 880-7281

Recitations (*Übungen*):
Alexander Schulz-Rosengarten
`als@...` Tel.: 880-7526

Corrections:
Frank Steffahn
`stu120505@...`

- Office hours: by appointment—or just contact us after class

## The Class Homepage

- https://ilearn.ps.informatik.uni-kiel.de/public/courses/200
- Contents:
  - Lecture slides (with/without notes, with/without animation)
  - Homework assignments
  - Further links



- I will try to make the lecture slides available before class—but may not always succeed ...
- Further links for example on
  - Papers related to this class
  - Tools needed for the homework...



## Notation

The markups (the "secondary notation") used on these slides follows (mostly) the following scheme:

- Definitions, first use of a term
- Text structuring
- Examples
- Normal text
- `Code, keywords, identifiers`
- `paths, executables`
- URLs
- *MathematicalSymbols*
- *General emphasis*
- **Reeeally important stuff**





## Homeworks

- Homeworks
  - generally given at Thursday,
  - due by following Thursday (23:59 hrs),
  - should be submitted via iLearn (see class homepage)
  - discussed following Friday recitation
  - First recitation: next Tuesday (April 14)
- Homeworks shall be submitted by groups
  - Ideal group size: 2 students
  - **Each group member should be able to present submissions**
- Questions
  - may be asked at any time, on anything ...
  - ... however, questions on the homework are better asked **before** the deadline and before submitting the homework!

## Grading (*Scheinkriterien*)

- Can get bonus points for outstanding solutions
- Can also get point deductions for late submissions, multiple submissions, etc.
- Will receive regular feedback on accumulated score
- For all participants, there will be one final exam





## Final Exam

- Tentative date: **Tue, July 7** (Must be within July 6 – 18)
- Need at least 50% to pass
- In borderline cases, also consider participation in class
- Results in exercises can improve grade, if 85% exam + 15% exercises are better than exam score

Admitted to final exam if:

- Received at least 50% of homework assignment points





## Priorities

Your grade depends on

- Final exam
- Homework submissions
- Participation in class (in borderline cases)

Advice: make up your mind on whether you want to participate in this class or not rather soon (within the next two weeks)

- Should participate 0% or 100% :-)





## Literature: Synchronous Languages

- [Halbwachs 1998]
  Nicolas Halbwachs, Synchronous programming of reactive systems, a tutorial and commented bibliography,
  *Tenth International Conference on Computer-Aided Verification*, CAV'98 Vancouver (B.C.),
  LNCS 1427, Springer Verlag, June 1998,
  `http://citeseer.ist.psu.edu/viewdoc/summary?doi=10.1.1.40.8306`
- [Benveniste+ 2003]
  Albert Benveniste, Paul Caspi, Stephen A. Edwards, Nicolas Halbwachs, Paul Le Guernic, and Robert de Simone.
  The Synchronous Languages Twelve Years Later
  IEEE, Special Issue on Embedded Systems, 2003
  `http://citeseer.ist.psu.edu/viewdoc/summary?doi=10.1.1.96.1117`

# Literature: Esterel


- [Berry 2000]
  Gérard Berry, The Foundations of Esterel,
  Proof, Language and Interaction: Essays in Honour of Robin Milner,
  G. Plotkin, C. Stirling and M. Tofte, editors,
  MIT Press, *Foundations of Computing Series*, 2000,
  `http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.53.6221`
- [Berry 1999]
  Gérard Berry, The Constructive Semantics of Esterel,
  Draft book, current version 3.0, Dec. 2002
  `http://www-sop.inria.fr/members/Gerard.Berry/Papers/EsterelConstructiveBook.zip`
- [Esterel Primer]
  Gérard Berry, The Esterel v5 Language Primer, Version v5_91, 2000
  `http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.15.8212`






# Literature: SCCharts, Blech


- [von Hanxleden et al. 2014]
  Reinhard von Hanxleden et al., SCCharts: Sequentially Constructive Statecharts for Safety-Critical Applications. In *Proc. ACM SIGPLAN Conference on Programming Language Design and Implementation (PLDI '14)*, page 372–383, Edinburgh, UK, June 2014. ACM,
  `https://rtsys.informatik.uni-kiel.de/~biblio/downloads/papers/pldi14.pdf`
- [Gretz et al. 2018]
  Friedrich Gretz, Franz-Josef Grosch, Blech, Imperative Synchronous Programming!, *Proc. Forum on Design Languages (FDL '18)*, page 5–16
  `https://doi.org/10.1109/FDL.2018.8524036`






# Overview


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Introduction to System Design
- Embedded and reactive systems
- Advanced design languages

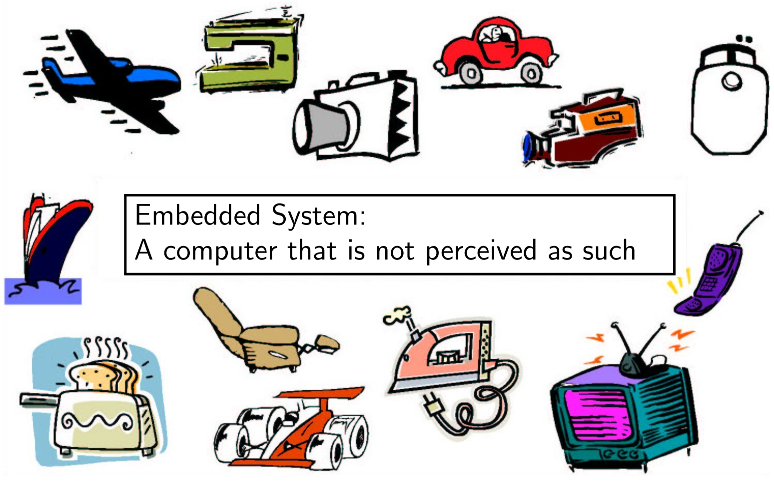





# Definition of Embedded Systems

- Embedded systems were designed for dedicated applications inside a surrounding system
- Embedded systems normally consist of hard- *and* software
- In addition to standard microprocessors, sometimes special hardware is used *e. g.* for MPEG-decoding
- Often many embedded systems form a *distributed system*
- Often many processes run in parallel on one microprocessor
- Do we need an operating system for process management?

## A Definition:








## Arguments for Embedded Systems

Increase of comfort: simplifies usage
Decrease of physical size: important for mobile devices
Increase of functionality: allows decentralized computations
Increase of safety: autopilot in aircrafts, brake-by-wire in cars
Decrease of production costs: electronic systems often cheaper
Increase of maintainability: by diagnosis devices
Optimization of control: *e. g.* dynamic control of fuel injection
Personalization: systems can be adapted for different users
Decrease of power consumption: important for mobile devices
Protection of intellectual property: difficult to copy by competitors

*Thanks to Klaus Schneider (Kaiserslautern) for providing part of this material*





## Design of Embedded Systems

Embedded systems (ES) are built for years.
What are the new challenges in their design?

- *More ESs* are included in one system
- ESs are more and more *responsible for economic success*
- ESs are more and more *responsible for design costs*
- *Product differentiation* more and more by embedded systems
- *Supervision of safety-critical systems*

Example application: cars

- Supervise and correct driving actions of driver
- Detect other cars and object in the environment
- Predict unavoidable collisions, and initiate driving actions to decrease damage
- Post-crash behavior: notify hospital and send GPS coordinates





## Problems with Embedded Systems

Are there any disadvantages? Of course:
**Many systems like cars are used for 20 years, while computer systems have much shorter lifetimes**

- Problem: supply with parts for many years
- Problem: lifetime of ESs must be long enough

**Safety-critical applications are controlled by ESs**

- Problem: computer systems do also have errors
- Problem: complex systems have many errors
- Problem: unfriendly environment (*e. g.* high/low temperature)
- Is there really a gain in safety?

# Design Problems: Design Exploration

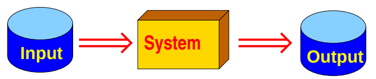
- Due to manual design, there is no time to evaluate different design variants
- In particular, the HW/SW partitioning phase cannot be repeated
- ⇝ Trend towards 'overdesign', *i. e.*, the systems are more expensive and more powerful than necessary
- ⇝ Realization independent design necessary, *i. e.*, early design phases should not fix on HW or SW solutions
- Problem: which languages to use for these descriptions?
- ⇝ One of the motivations for synchronous languages



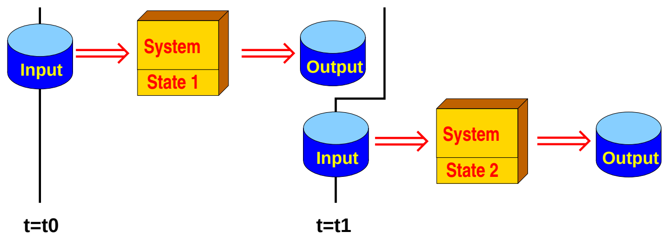


# Different Kinds of Systems

**Transformational Systems**




**Interactive/Reactive Systems**








# Interactive vs. Reactive Systems

Transformational systems:

- read inputs, compute outputs and terminate
- Example: compiler

Interactive systems:

- nonterminating
- continuous interaction
- pace is controlled by system
- Example: on-line reservation system

Reactive systems:

- nonterminating
- continuous interaction
- pace is controlled by environment
- Example: engine controller

⇒ **Reactive systems are real-time systems!**



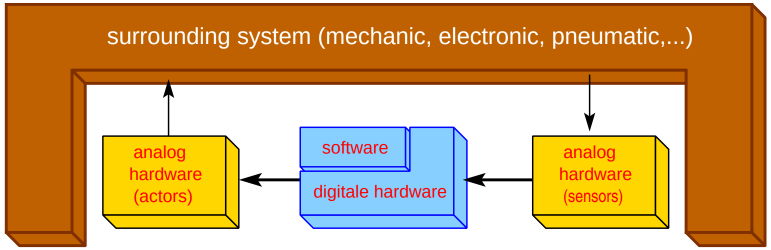


# Interactive vs. Reactive Systems

- Interactions with user/environment are basic computation steps of reactive systems
- Logical time: counts only number of interactions
- Interactions consist of micro steps (smaller computations)
- Interactions are often called macro steps
- Remark: inputs are read only once per macro step, hence, they are assumed to be constant for a macro step
- Question: when are outputs produced?
- Answer: perfect synchrony has the view that outputs are generated in zero time for a macro step

# Embedded Systems as Reactive Systems

General Schema:




Embedded systems interact directly with surrounding system and are thus often *reactive systems*





# Reactive Control Flow

Control flow on traditional (non-embedded) computing systems:

- Jumps, conditional branches, loops
- Procedure/method calls

Control flow on embedded, reactive systems: all of the above, plus

- Concurrency
- Preemption

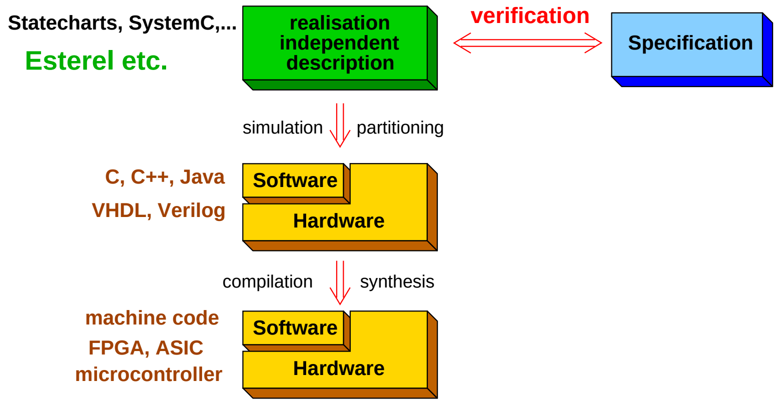
The problem: mismatch between traditional languages and reactive control flow patterns

- Non-determinism, *e. g.* due to scheduler and interrupt handler
- Processing overhead, *e. g.* due to OS involvement or need to save thread states at application level
- Timing unpredictability





# Advanced Design Flows








# Advanced Design Flows

- Early cost estimation
- Simulation of design variants
- Formal verification in early design phases
- Guarantee of real-time constraints
- Support for distributed systems (also multi-processor systems)
- Modeling of the environment, also of analog and mechanical parts

## Summary

- Embedded systems are ubiquitous today
- Distinguish transformational, interactive, reactive systems
- Synchronous languages
  - are domain independent (can describe HW and SW) and allow to work at high abstraction level
  - support reactive control flow (including concurrency and preemption)
  - have deterministic, formally founded semantics
  - support modular design due to perfect synchrony
- This class will explore the family of synchronous languages in depth