Signals, Instruments, and Systems

School of Architecture, Civil and Environmental Engineering

EPFL, WS 2020-2021

https://disal.epfl.ch/teaching/signals_instruments_systems/

Signals, Instruments, and Systems – W1

Part I: Course Organization, Team, and Content

Team beyond this course

Distributed Intelligent Systems and Algorithms Laboratory:

https://disal.epfl.ch

- **Instructor:** Alcherio Martinoli
- **Guest lecturers**: Kagan Erünsal
- **Teaching assistants:**
  - Kagan Erünsal (Head TA, PhD student)
  - Cyrill Baumann (TA, PhD student)
  - Hugo Grall Lucas (TA, scientific assistant)
  - Anwar Quraishi (TA, PhD student)
  - Lucas Pirlet (Help TA, master student)
  - Chloé Udressy (Help TA, master student)
- **Support staff:**
  - Chiara Ercolani (PhD student)
  - Faëzeh Rahbar (PhD student)

Course Public Pages

https://disal.epfl.ch/teaching/signals_instruments_systems/

- Previous editions (5 years)
- Lecture, exercises, and course projects

Course Rationale, Content, and Prerequisites

Typical Field Instrumentation for Environmental Monitoring

Ultrasound anemometer

Laser-based disdrometer

Integrated compact weather station (temperature, humidity, anemometer disdrometer)

Data logger

Local Climate Monitoring

Features:
- Very low sampling frequency < 1Hz
- Very low power consumption: 25mW
- Solar panel
- Radio communication

Sensors:
- Air Temperature and Humidity
- Infrared Surface Temperature
- Anemometer
- Solar Radiation
- Pluviometer
- Soil moisture
- Soil pressure

Visit https://www.sensorscope.ch for further details!

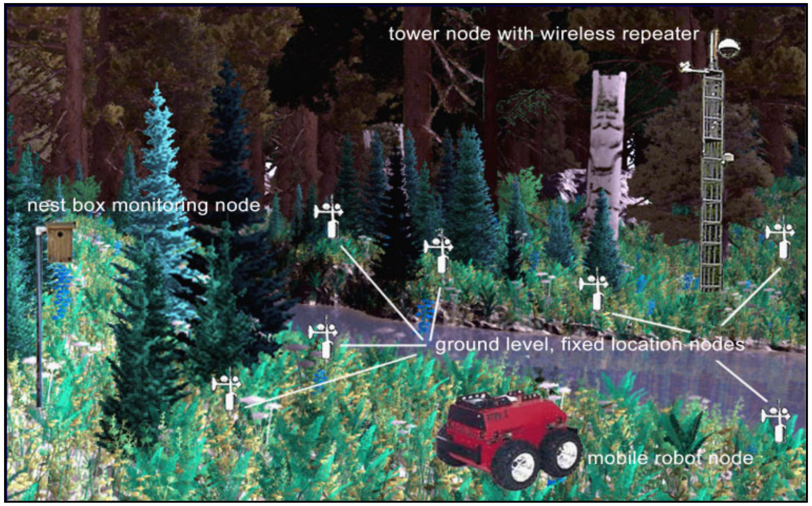
Ecosystem Monitoring

Science

- Understand response of wild populations (plants and animals) to habitats over time.
- Develop in situ observation of species and ecosystem dynamics.

Techniques

- **Data acquisition of physical and chemical properties, at various spatial and temporal scales, appropriate to the ecosystem, species and habitat.**
- **Automatic identification** of organisms (current techniques involve close-range human observation).
- Measurements over long period of time, taken *in-situ*.
- Harsh environments with extremes in temperature, moisture, obstructions, ...

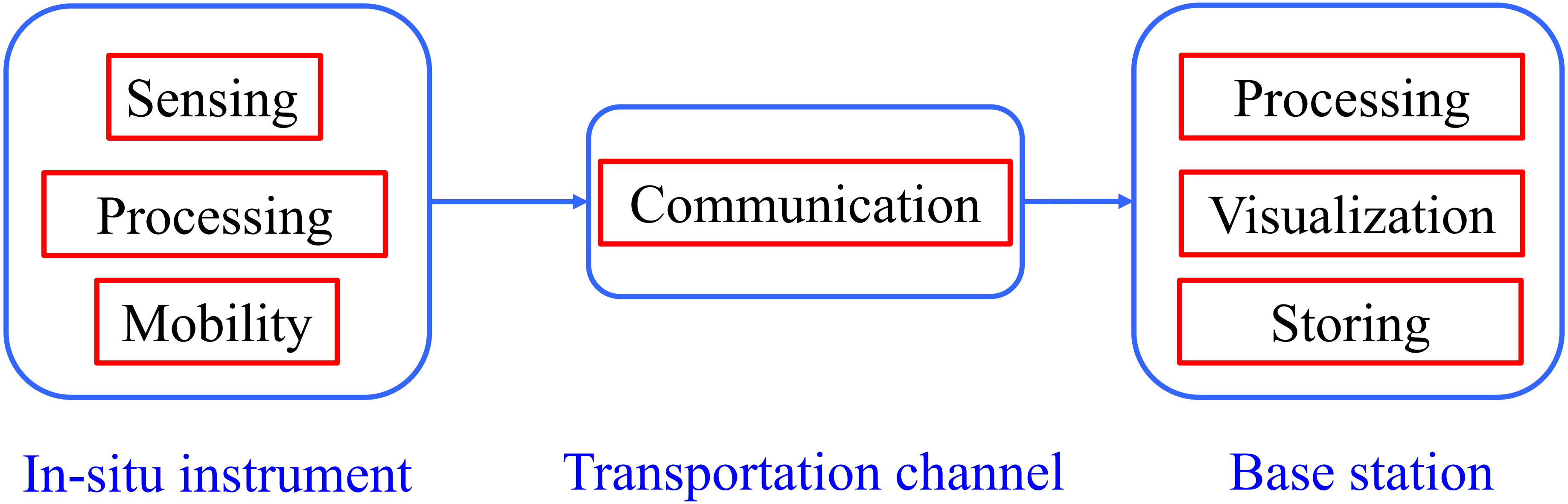


Source: D. Estrin, UCLA

Embedded Systems at the Heart of Modern Environmental Engineering

- Moving the lab to the field is “in”!
- Most of the applications require large spatial distributions (scale of the domain >> scale of a node) → sensor networks
- The underlying hardware/software technology (at the single device level) share the same principles

What These Systems Share at their Core?



The goal of this course is to shed light on this process and blocks!

What This Course Is About

- Fundamentals of signal processing:
  - Analog/digital signals, sampling and reconstruction
  - Time/frequency domains and transforms
  - Filters, converters

- Fundamentals of embedded systems:
  - Programming skills consolidation (interpreted vs. compiled languages)
  - C for embedded and real-time systems
  - Microprocessors, microcontrollers, memory
  - Sensors and actuators
  - Basic control, communication, and estimation techniques

Severely impacted by pandemic restrictions

Prerequisites and Related Courses

- Fundamentals in compiled (C) and interpreted (Matlab, Python) language programming
- Fundamentals in probability calculus
- Fundamentals in analysis (Analysis I to IV, ODE, Fourier series and analysis, transforms)
- ICC can also help with fundamentals in signal processing (though only time domain)

Rationale (1)

- This course must allow you to become a power user of the key instruments in environmental engineering used nowadays (sensor networks, meteorological stations, data loggers, etc.) and in the near future (drones, remotely operated vehicles, robotic sensor networks, etc.)
- Being a power user means not only being an advanced user but also understand enough to collaborate with EE/CS/ME engineers to design the instruments of the future in environmental engineering; idea: complexity shifted more and more from hardware to software → a lot of domain knowledge can be transferred to the instruments at software level

Rationale (2)

- Well-balanced course: theory, algorithms, tools and practical exercises
- It should prepare you to better follow a number of master courses (especially in the new Environmental Monitoring and Modeling specialization)
- This course can be considered as an elevator to the master course "Distributed Intelligent Systems" for SIE students where various other sections and programs attend
- It should get you prepared for carrying out a design/semester/master project at DISAL

Organization of the Course

Credits and Workload

- 5 ECTS
- 1 ECTS = 30 h workload → 150 h workload total
- Rough breakdown
  - 60 h lecture (including reading, exam preparation)
  - 30 h lab (including their preparation)
  - 60 h course project (including implementation, reporting, and defense)

Grade

- Final written exam: 180 minutes
- 50% performance during semester, 50% performance during the exam (compromise US/Europe style)
- During semester: course project (50%)
- During final exam: all covered material is subject to examination, but the exam is open book (no electronic equipment allowed other than a basic, non programmable pocket calculator)

Lecture Notes & Reading

- Policy: no manuscript, but slides and your own notes
- Preliminary lecture slides in pdf format available for download before each lecture (mon evening), definitive ones after lecture (couple of days max); e-mail notification only when definitive slides are posted
- Lecture recordings available as mitigation measure for pandemic crisis
- Reading will be added on Moodle as the course progresses
- Access to Moodle: if issues contact Head TA (kagan.erunsal@epfl.ch)

Lecture Interaction Logistics

- The lecture is live-streamed
- I'll pause from time to time to ask or call for questions but you can interrupt anytime
- The interrupt must be an audio signal from on-line students (I won't be able to also monitor the chat) and an audiovisual one from the audience on-site
- I will repeat the questions of the on-site audience for the student on-line and for recording purposes

Lecture Interaction Logistics

- If the chat is absolutely needed (I hope not), students attending the course physically should participate to make it operational.
- This will involve having a at least a laptop open but muted (both loudspeakers and microphone) in class and checking regularly the chat
- Two ways to do it:
  - Forming groups of 3 students with complementary SCIPERs so that one of the three is always in the on-site audience - > the people on-site should all have a laptop and check the chat/other com channel

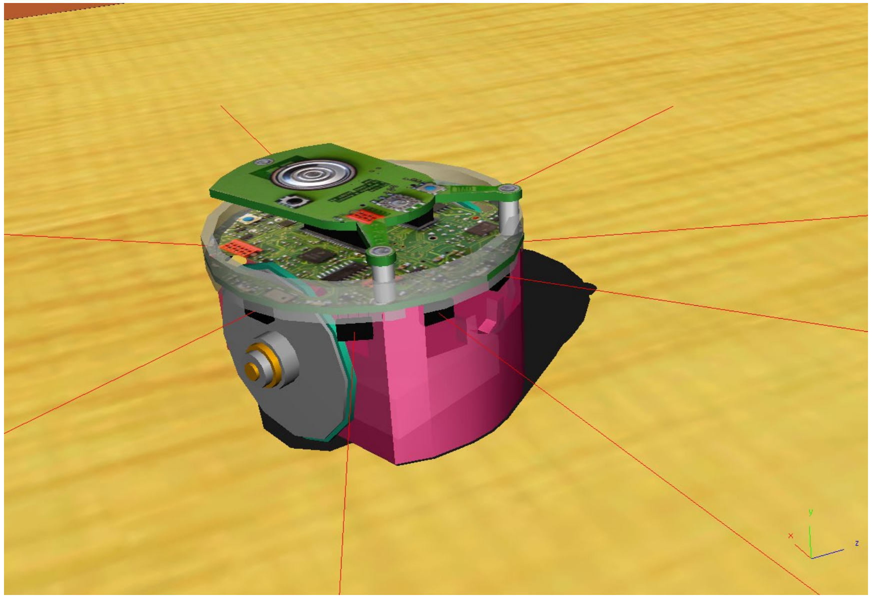
    -> too distracting for the local audience
  - Nominating a responsible student and deputy for each lecture responsible to read the chat and ask questions on behalf of the remote on-line audience.

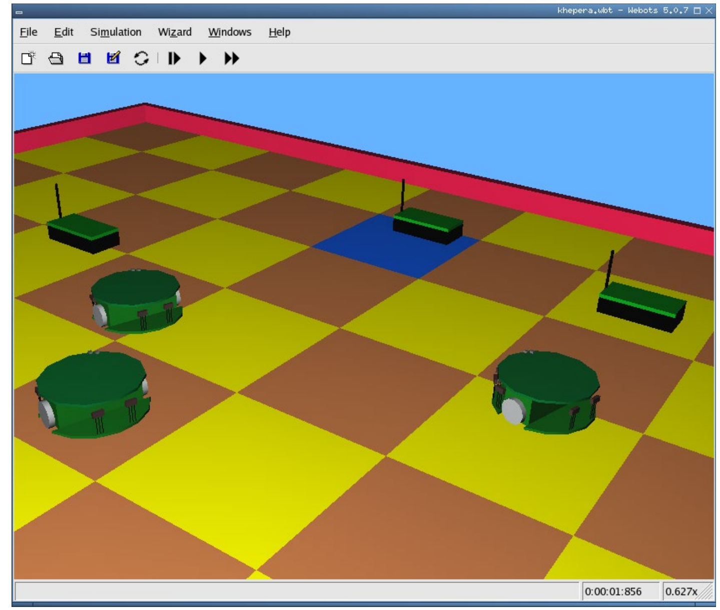
    -> Feasible, we can help in organizing it

Tools used in Exercises and Course Projects

- Matlab
- C programming tools (GCC) under Linux
- High-fidelity robotic simulator (Webots)
- ~~Real devices (desktop robots: e-puck; desktop sensor nodes: DISAL Arduino Xbee node) -~~ Not used in this edition because of pandemic restrictions.

Webots (Labs & Projects)





- High-fidelity simulation
- Discrete sensor and actuators
- Noise and nonlinear characteristics faithfully reproduced
- Different trade-offs faithfulness/computational cost

Labs (1)

- Lab session 11:15-14:00 on Thu, GR B0 01
- Mini-tutorial (5-10 min) by the main lab designer at the beginning of the lab
- 8 lab sets total
- Official solution available on Moodle after the lab session
- All software tools needed available in the classroom and to be installed on the personal computer (guidance and possibly help provided by TAs to ensure smooth operation)
- sis-ta@groupes.epfl.ch for ANY issue!

Labs (2)

- Lab assignment posted by Wednesday of the same week at latest
- Lab physical/virtual presence not compulsory but
  - We do not repeat labs
  - If you do not come to labs you will have a hard time in being efficient in the course project
- I think it is a lot of fun and really helps you understand lecture stuff
- Assistants are well prepared (2 TAs, designer and tester, and help TA)
- Dedicated feedback forms for each lab on Moodle

Suggestions for a Successful Exercise Series

From our teaching experience:

- Read the assignment in advance (i.e. before the lab), in this way you will be more efficient when the TAs are around for helping you on the toughest questions…
- Take advantage of office hours (upon appointment using the sis-ta list) if additional explanations are needed
- Do the labs seriously, do not wait for the solution distributed a couple of days later.

Course Project (1)

- Course project list distributed in Week 6, assigned in Week 7, and kick-off in Week 8
- 60 h effort, defenses last week of the semester during lecture and lab time
- Team of 2 students (ad hoc solution for numbers of students not divisible by 2)
- Short progress report (compulsory but not graded) in Week 11
- Final report to be submitted (pre-established max # of pages and format) by end of Week 13 (Dec 13)

Course Project (2)

- Final presentation probably on Zoom (8 minutes + 4 min questions)
- Each of the team members has to present
- Project office hours only during lab sessions:
  - 1 TA for each project and session
  - 3 h W8
  - 1 h W9 and W10
  - 3h W11, W12, and W13

Suggestions for a Successful Course Project

From our teaching experience:

- Exploit office hours for the course project in an efficient way (e.g., ask the toughest technical questions but do not ask the project supervisor to debug your code!)
- Plan your effort (milestones, time, constraints, etc.), coordinate your team
- Arrive at the progress report milestone with project objective understood, reading and tool familiarization over, and preliminary implementation results
- Do not copy from previous year course projects: plagiarism danger!

Final Notes

13th Iteration at ENAC

- Course moved to the fall (winter) semester, no holidays for lecture and lab sessions
- Lecture before lab session
- Overall logistic and organization similar to last semester under pandemic conditions:
  - No hardware tools, all doable on-line from home
  - No lab verification tests (computer-based mid-term tests), only project for continuous control

13th Iteration at ENAC

- C refreshing part minimized from 5 h lecture and 9 h lab to 2 h lecture and 3 h lab due to better preparation of students; we did <u>not</u> eliminate it completely since we do not know your actual level; in future editions this “C” week will be dedicated to C for embedded system programming
- 6h pure C programming replaced by 4h labs on localization/sensor fusion; same for the corresponding 4h lecture
- Course project better integrated with the last three labs; easier to <u>not</u> get lost but we will raise the expectations for the course projects
- Very difficult for us to do better without hardware tools, it does not make sense to optimize further until normal conditions will be re-established

EPFL

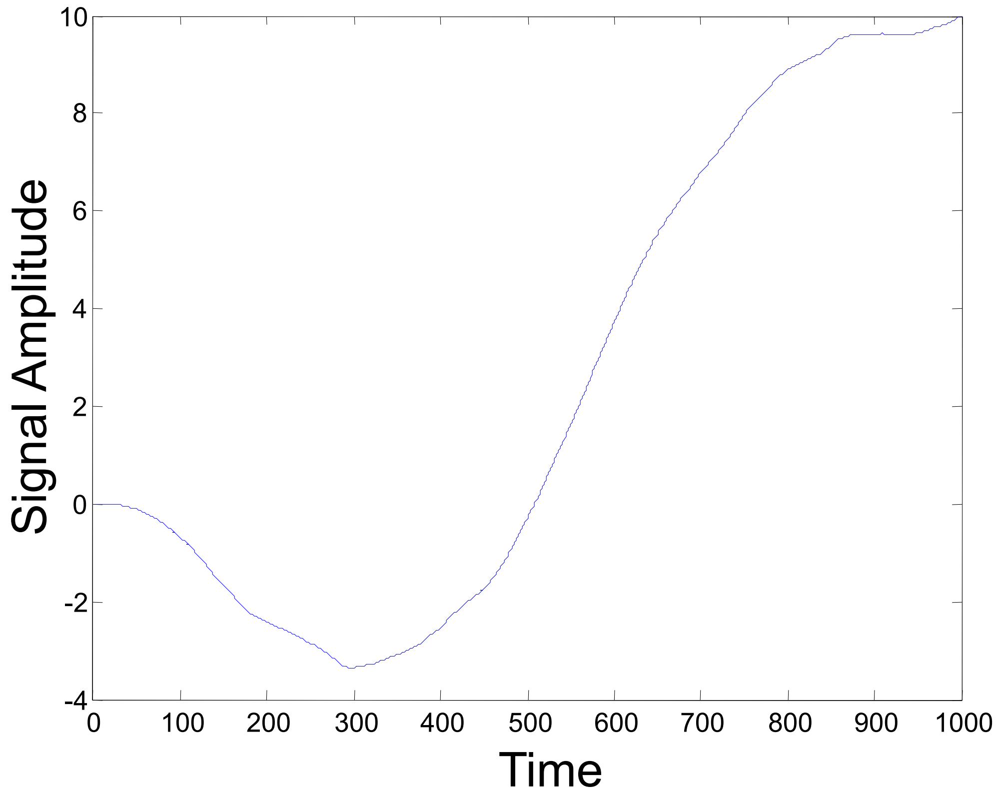
Disal

Signals, Instruments, and Systems – W1

Part II: An Introduction to Signal Processing – Analog and Digital Signals

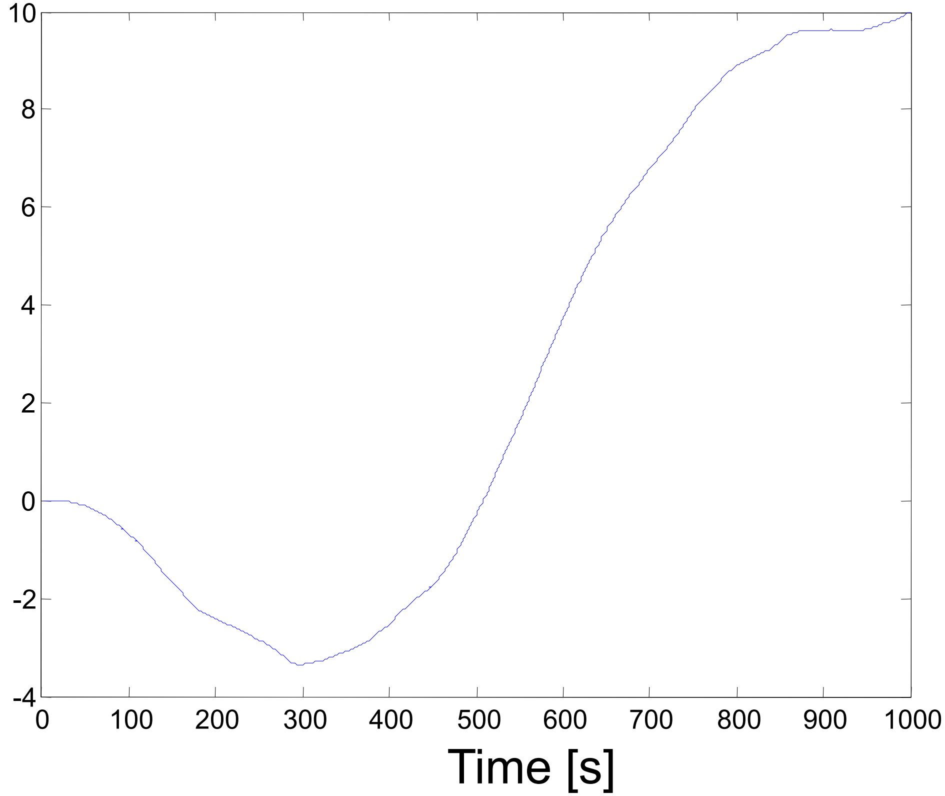
Signal – Definition

"A signal is any **time**-varying or **spatial**-varying quantity"



Signal – Definition

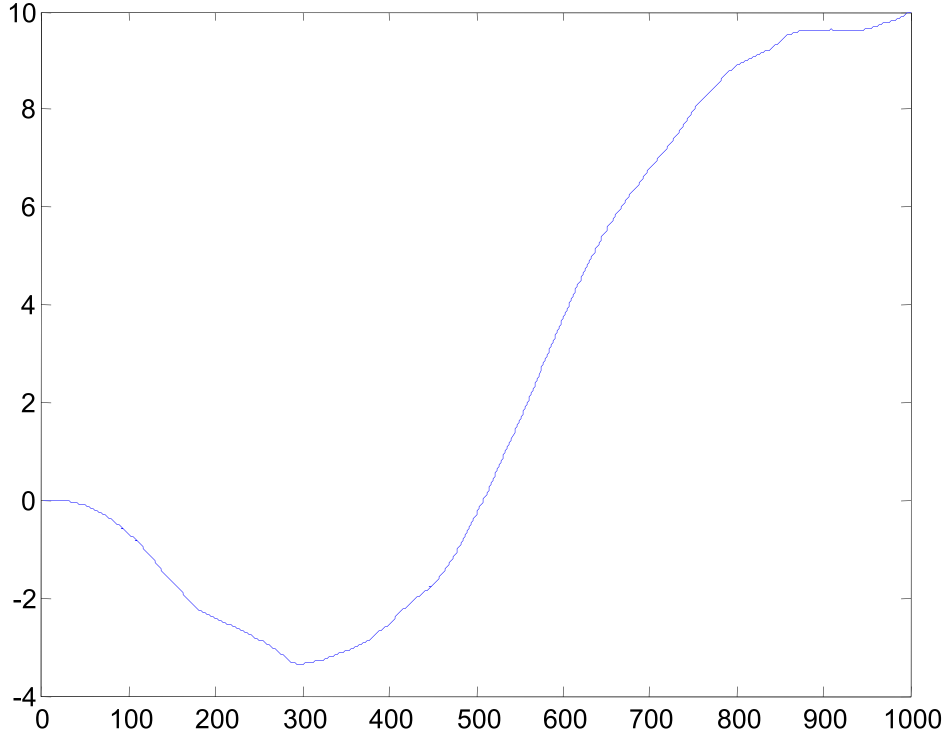
"A signal is any **time**-varying or **spatial**-varying quantity"



$$T = f(t)$$

Signal – Definition

"A signal is any **time**-varying or **spatial**-varying quantity"



$$h = f(x)$$

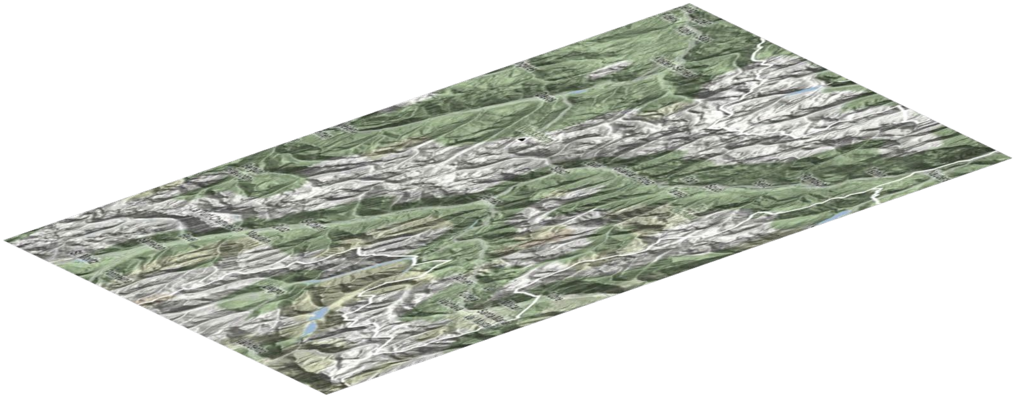
Signal – Definition

"A signal is any **time**-varying or **spatial**-varying quantity"

Signal – Definition

"A signal is any **time**-varying or **spatial**-varying quantity"

$$h = f(x, y)$$

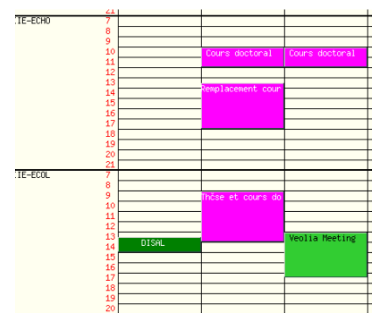


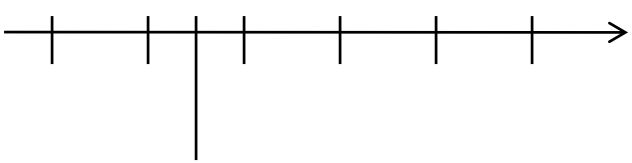
Signal – Definition

"A signal is any **time**-varying or **spatial**-varying quantity"

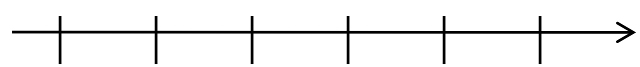
Continuous versus **Discrete**

Continuous	Discrete





$x \in R$



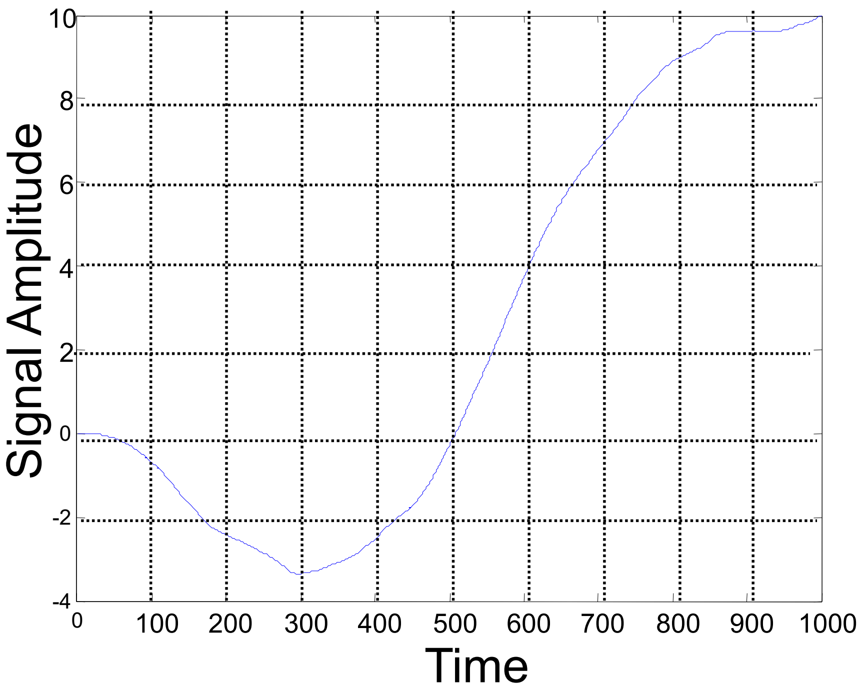
$x \in N$

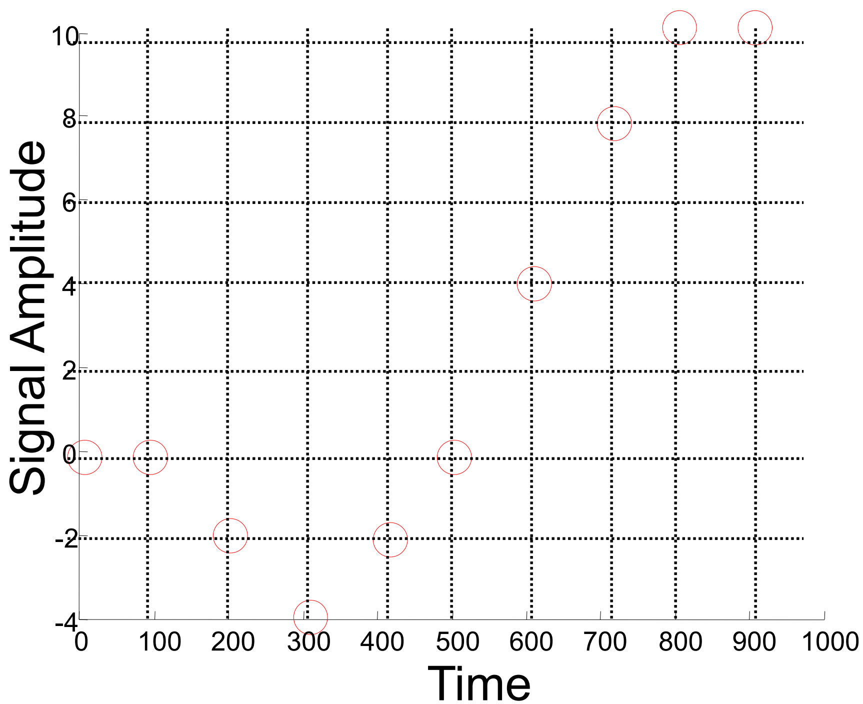
Analog versus **Digital**

Analog versus **Digital**

- An analog signal …
  – is **continuous** in time
  – has **continuous** values
- A digital signal …
  – is **discrete** in time
  – has **discrete** values

Analog – Digital





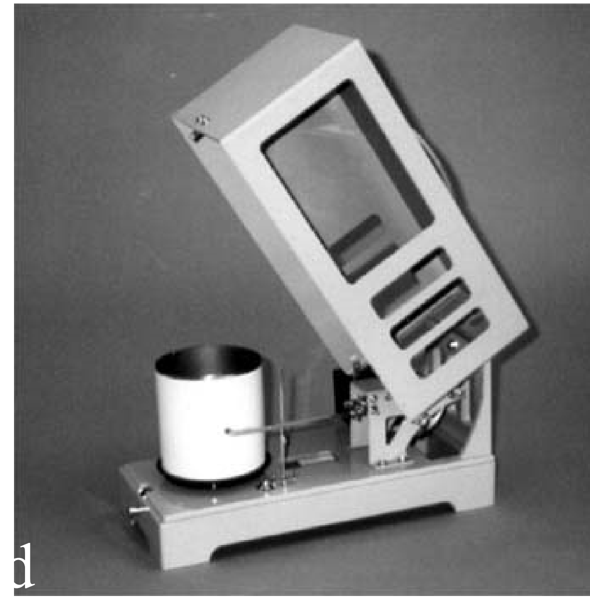
- Analog
  - Continuous
  - Real world
- Digital
  - Discrete
  - Digital world

Sensors Classification
Continuous – Discrete

	Continuous	**Discrete**
Time		
Space		
Amplitude		

Continuous: Time and Amplitude

Continuous: Time and Amplitude



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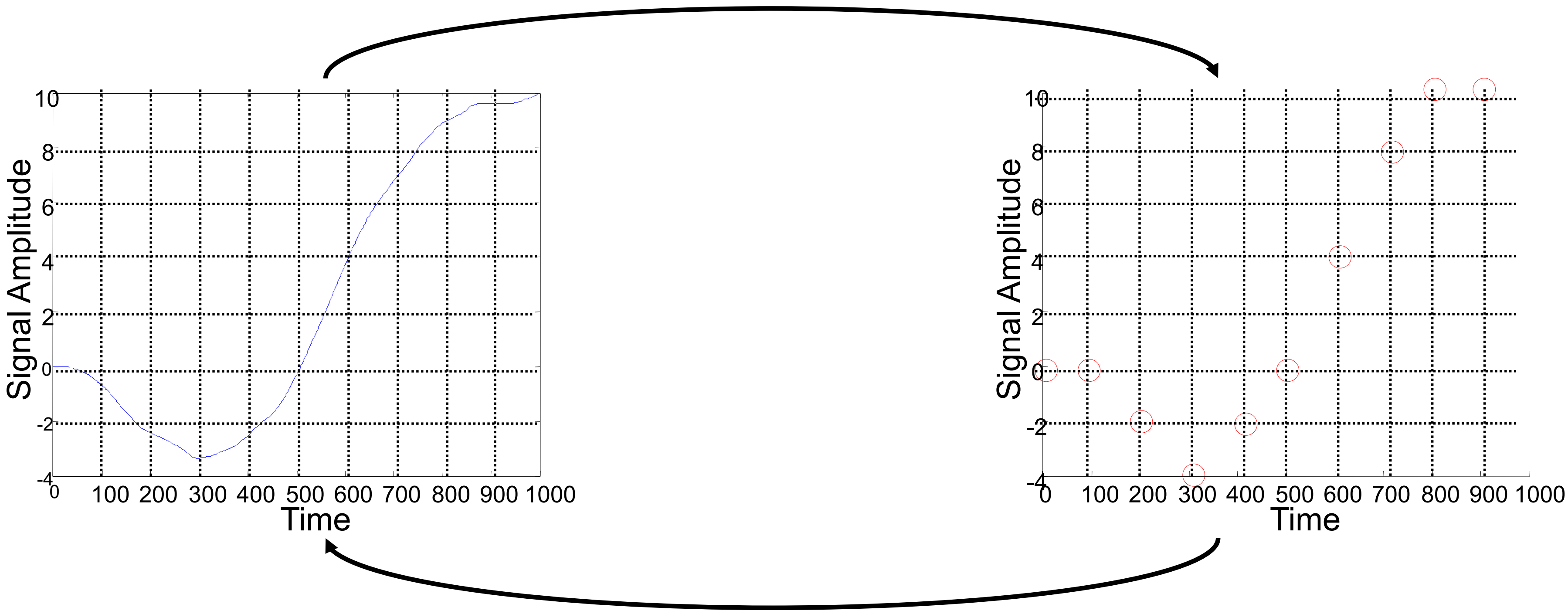
Continuous: Space and Amplitude
Discrete: Time

Discrete: Time and Amplitude

Discrete: Time, Space and Amplitude

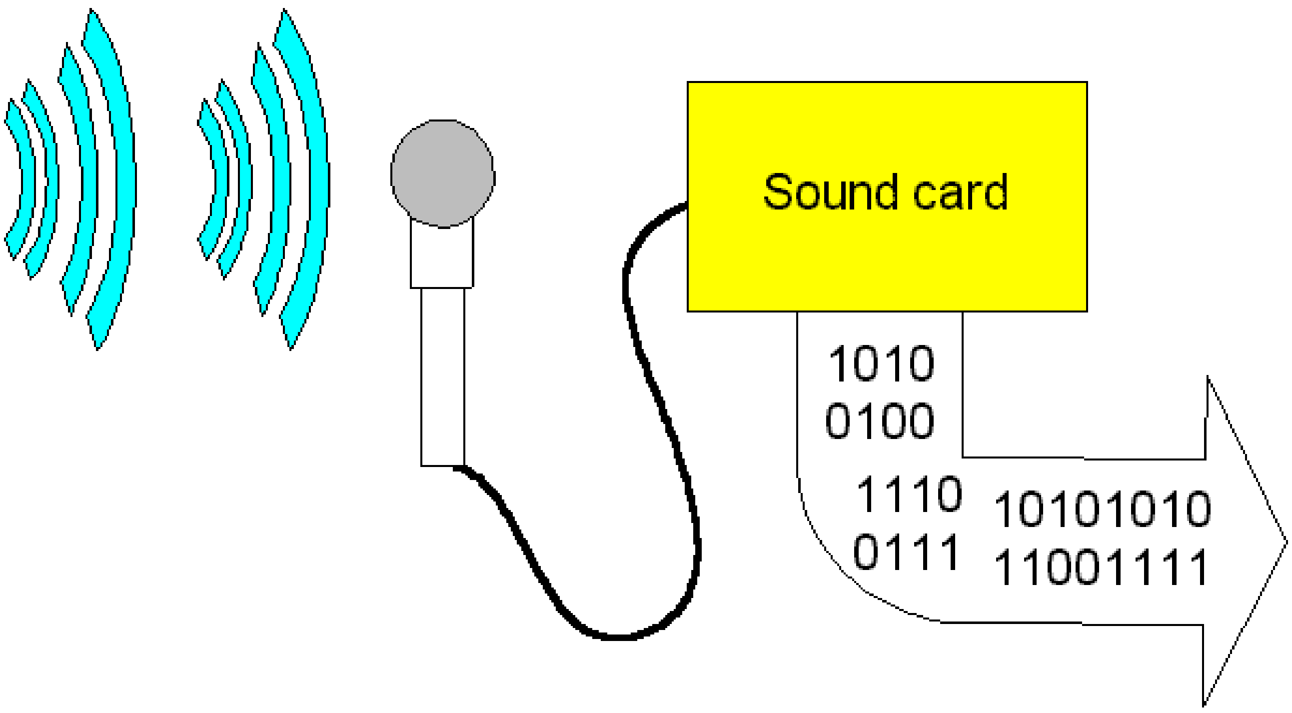
Analog-Digital-Analog Conversion



y=x(t)

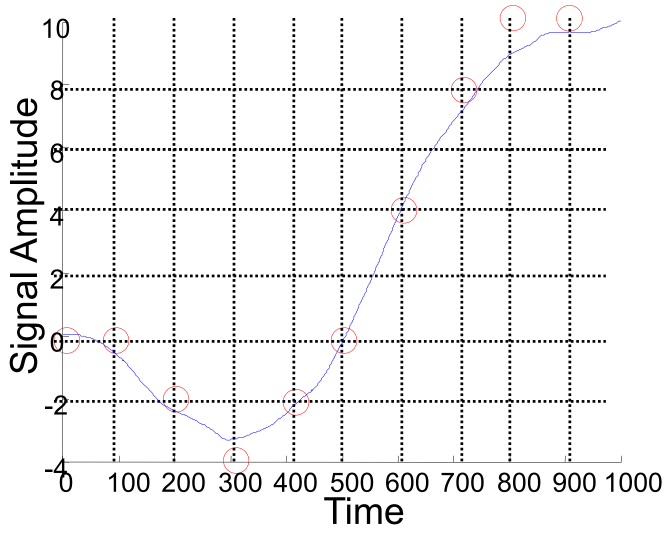
y=x[n]

Analog-Digital Conversion



Analog-Digital Converter (ADC)

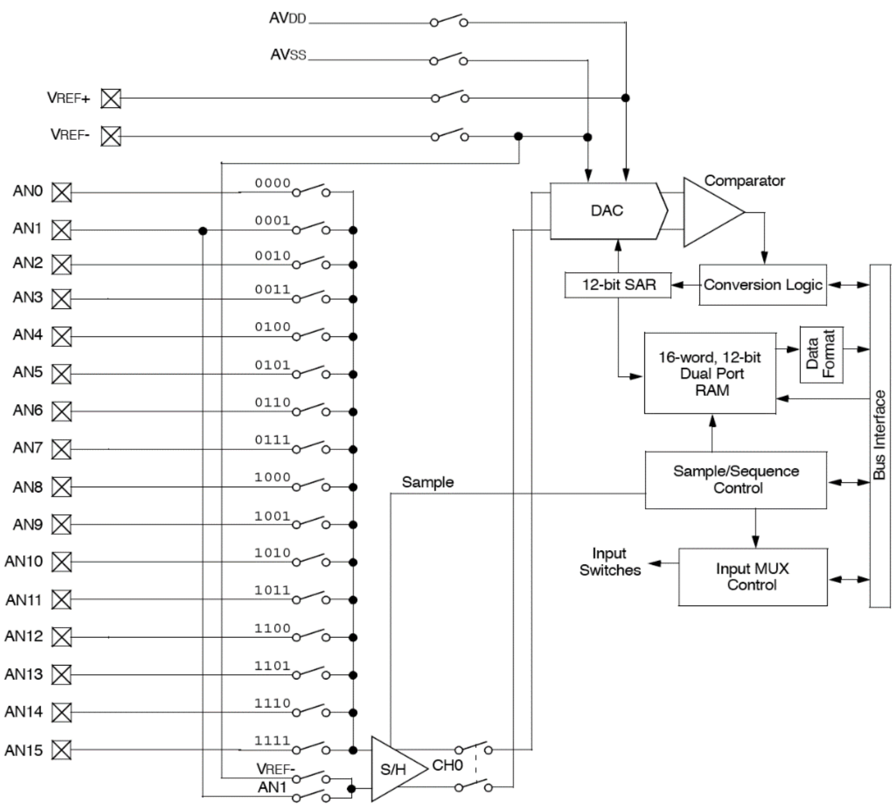
- Transforms continuous analog signal into series of values
- Two key elements
  - **Sampling** (in time)
  - **Quantization** (of values)
- Two types of converters
  - Linear ADCs
  - Non-linear ADCs



Examples of ADC Applications

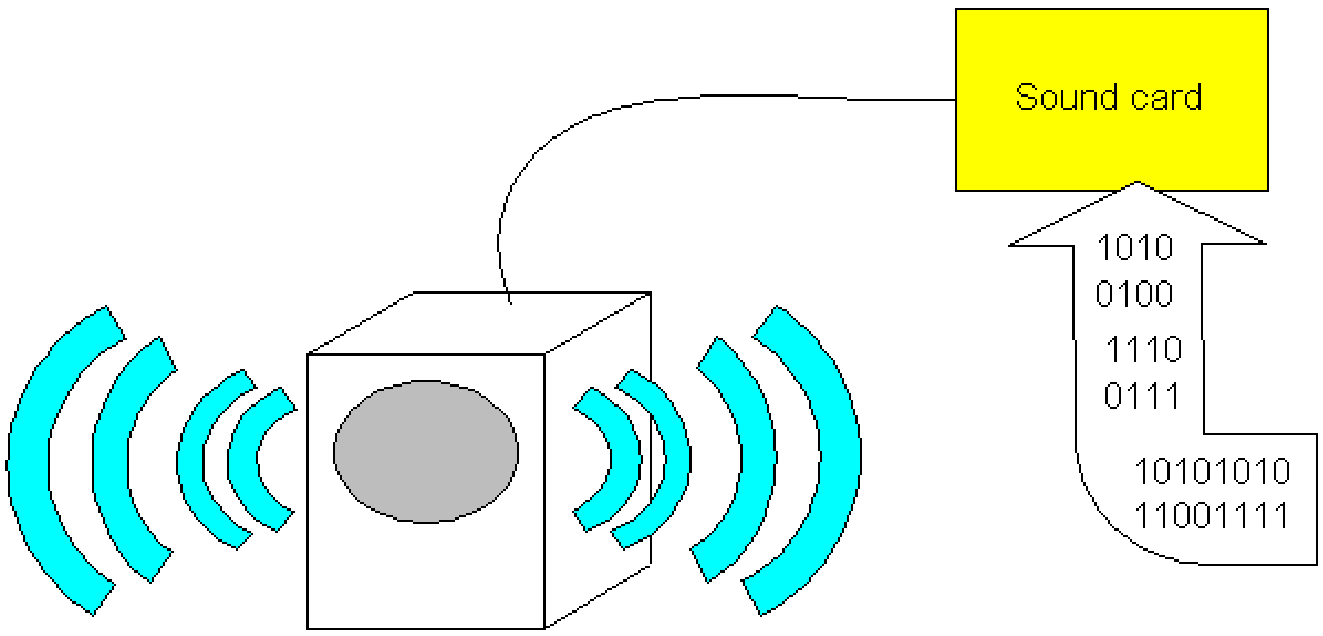
- Input line of a soundcard
- Sensor of digital camera
- Mobile phone
- Computer mouse
- …

An Example from your Course Tools



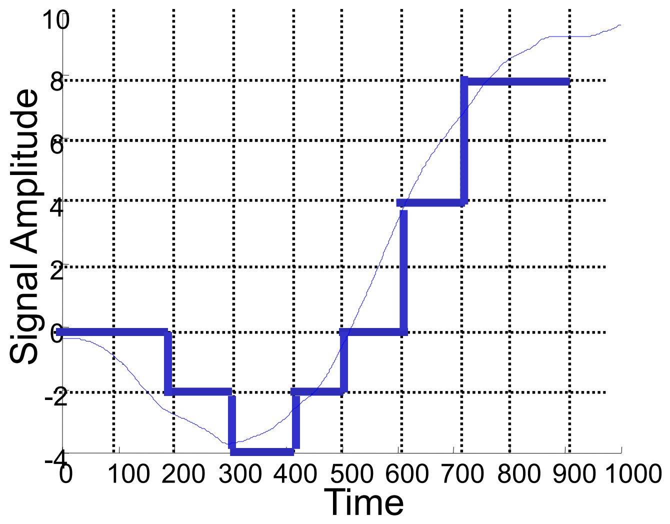
- From datasheet dsPIC on e-puck: ADC 16 channels, 12 bits, 200 ksps total capacity
- 2^{12} -1 discrete levels of resolution per channel
- Max 200k Hz sampling frequency on 1 channel -> e.g., 10 channels: 20k Hz

Digital-Analog Conversion



Digital-Analog Converter (DAC)

- Transforms a series of values into a continuous signal
- DAC outputs piecewise constant signal
- Additional filter stage to smooth signal (often carried out by the properties of the transducer/actuator itself)



Examples of DAC Applications

- Mobile phone
- MP3 player
- Graphics card (with older monitors)
- Monitors (newer systems)

Conclusion

Take Home Messages

- A signal can be a varying quantity in time and/or space
- Signals can be mono-dimensional or multi-dimensional
- Signal classification:
  - continuous vs. discrete in time
  - continuous vs. discrete in space
  - continuous vs. discrete in amplitude
- Analog signals are continuous in both time (or/and space) and amplitude; digital signals are discrete in both time (or/and space) and amplitude
- Sampling and quantization are two key elements in the transformation of analog into digital signals

Additional Literature – Week 1

Related course material

- Information, Calcul, Communication (ICC)
- Analysis IV

Books

- J. H. McClellan, R. W. Schafer, M. A. Yoder
  "DSP First: A Multimedia Approach", Prentice Hall, 1999.
- A. Oppenheim and A. S. Willsky with S. Nawab, "Signals and Systems", Prentice Hall, 1997.