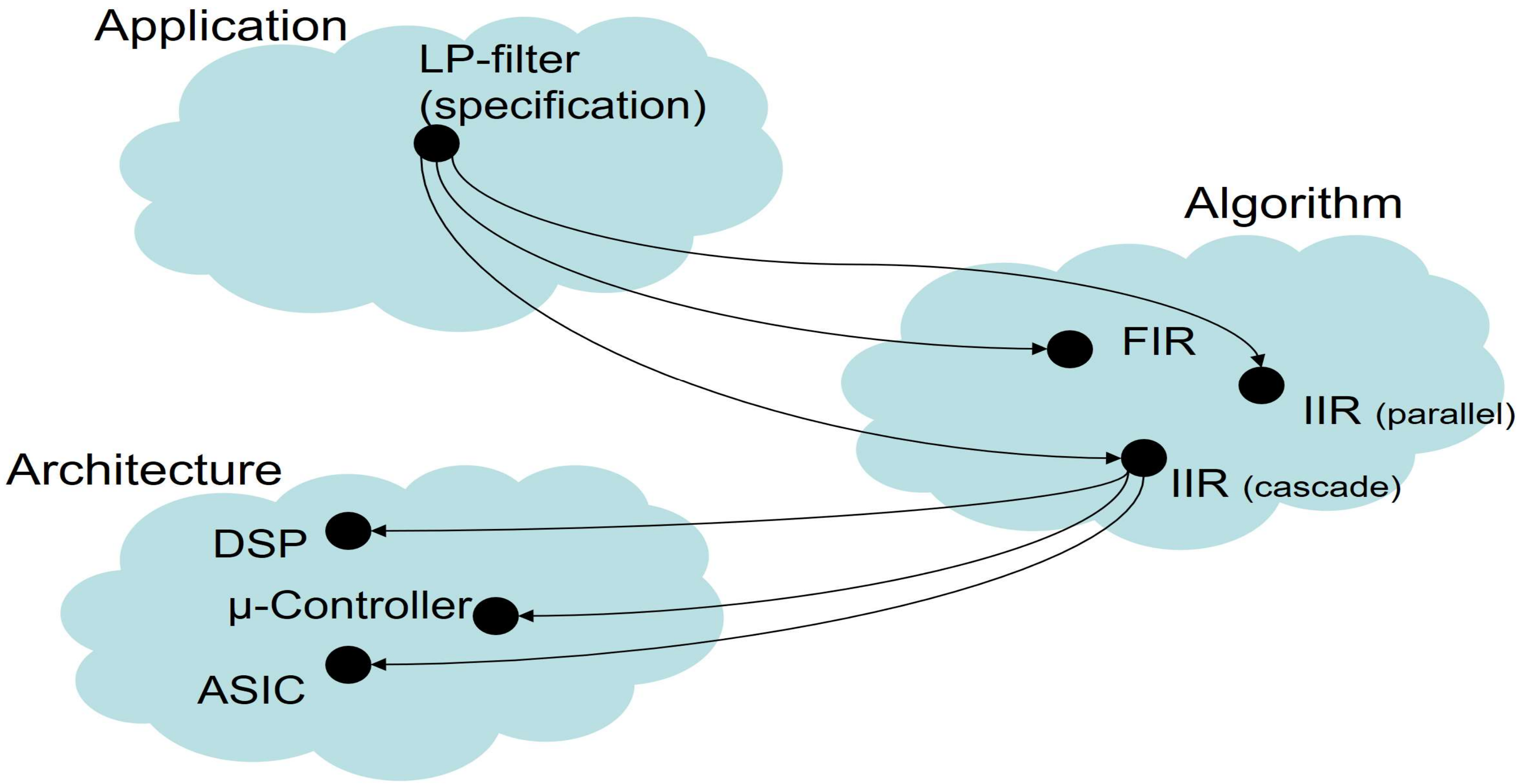
IEE 1711: Applied Signal Processing

Professor Muhammad Mahtab Alam (muhammad.alam@taltech.ee)

Lab Instructor: Julia Berdnikova



Briefly About Myself

- Tallinn University of Technology (TTU), Estonia
  - Tenure Track Professor (Telecommunication Technologies) at Thomas Johann Seebeck Department of Electronics. (April'18 – till date)
  - European Research Area-Chair (Holder) of H2020 COgnitive ELectronics (COEL) project. (Sep'16 – till date)
  - **Key Areas:** 5G and IoT -> Massive Machine Type Communication (NB-IoT), Ultra Reliable Low Latency Communication, Critical Communication, Wireless Communication, Body Area Networks.
- Research Scientist at Qatar Mobility Innovation Center, Qatar (2014 –2016)
- Charter Engineer (CEng) Status – Engineering Council United Kingdom (Mar'16)
- Assistant Prof. at University of Engineering and Technology, Pakistan (2013)
  - Lead the team of 20 members in EE Department of Swedish Engineering College
  - Accreditation from the engineering governing body (PEC)
- PhD (Signal Processing and Telecommunication) from Rennes1 University, INRIA/IRISA Lab, France (2009-2012).
  - Visiting PhD researcher – University College Cork, Ireland
- Research Assistant at CSDR-Aalborg University, Denmark (2007-2009)
  - DSP Firmware Engineer at Barco NV, Belgium (Aug'2008- Dec'2008)
- M.Sc Engineering in Applied Signal Processing and Implementation from Aalborg University (2005-2007)
- DSP Design Engineer at And-Or Logic Pvt. Ltd, Pakistan (2005)
- Streaming Networks Pvt Ltd (2004)

Outline

- Schedule and Action Plan
- Course Syllabus
- Course Evaluation and Assesment
- Course Information/Material/Practical Information/links

- Lecture 1: Applications of Digital Signal Processing
  - Digital vs Analog
  - Applications
  - DSP Methodology
  - DSP Operators
- Summary

Schedule from OiS

- Communicative Electronics (IVEM)

IVEM21 IVEM22

IVEM21 (IVEM11/18, Electronics Engineering)

Export iCalendar file | Calendar URL | Open web link

time	lesson	C/E/OP	lecturer	room	duration	Syllabus
Monday						
10:00-11:30	Applied signal processing (*IEE1711*) **lecture**	E	professor Muhammad Mahtab Alam	U02-403	1-16	i
12:15-13:45	Cognitronics (*IEE1570*) **lecture**	E	vanemteadur Andrei Krivošei, teadur Tamás Pardy	U02-309	1-16	i
14:00-15:30	Advanced Robotics (*EEM0080*) **lecture**	E	teadur Robert Hudjakov, professor Mart Tamre	SOC-414	1-16 **odd**	i
Tuesday						
08:00-09:30	Dependability and Fault Tolerance (*IAS0530*) **lecture**	E	professor Gert Jervan	ICT-315	1-8	i
08:00-09:30	Dependability and Fault Tolerance (*IAS0530*) **exercise**	E	professor Gert Jervan	ICT-315	9-16	i
10:30-13:45	Mechatronics and Smart systems project (*UTT0110*) **practice**	E	professor Mart Tamre, insener Dhanushka Chamara Liyanage, insener Even Sekhri, dotsent Eduard Petlenkov, teadur Mairo Leier	NRG-201, NRG-202	1-16	i
14:00-16:15	Electronic System Design (*IEE1520*) **practice+exercise**	C	külalislektor Juri Mihhailov	U02-206	2-12	i
16:30-18:45	Advanced Robotics (*EEM0080*) **practice+exercise**	E	insener Dhanushka Chamara Liyanage, insener Even Sekhri	NRG-201, NRG-202	1-16	i
19:30-21:00	Embedded Systems (*IAS0330*) **practice**	C	teadur Uljana Reinsalu, doktorant-nooremteadur Madis Kerner	ICT-501	1-16	i
Wednesday						
09:30-11:45	Cognitronics (*IEE1570*) **practice**	E	doktorant Hip Kõiv	U02-204	5-15	i
10:00-13:00	Integrated Circuits and Simulations (*IEE1530*) **lecture**	E	tunnitasuline Rein Sabolotny	U02-403	1-8	i
14:00-17:00	Integrated Circuits and Simulations (*IEE1530*) **practice**	E	tunnitasuline Rein Sabolotny	U02-206	1-8	i
17:45-19:15	Entrepreneurship and Business Planning (*TMJ3300*) **lecture**	C	lektor Sirje Ustav	NRG-226	1-16 **odd**	i
Thursday						
08:00-09:30	Embedded Systems (*IAS0330*) **lecture**	C	külalisprofessor Thomas Hollstein, dotsent Kalle Tammemäe, teadur Uljana Reinsalu	ICT-315	1-16	i
10:00-12:15	Entrepreneurship and Business Planning (*TMJ3300*) **exercise**	C	tunnitasuline Pavel Prokushenkov	SOC-312	1-16	i
14:00-15:30	Applied signal processing (*IEE1711*) **practice**	E	teadur Julia Berdnikova	U02-206	1-16 **even**	i
14:00-15:30	Applied signal processing (*IEE1711*) **exercise**	E	teadur Julia Berdnikova	U02-206	1-16 **odd**	i
16:30-19:30	Prototyping (*IEP1010*) **practice**	E	lektor Andres Eek	MEK-044	1-16	i

Note:

Lecture is separate from Excerise !!

Excercise/ will start from 1st week – 31st February!

Course Syllabus

- DSP Applications, Audio processing, Image/video Processing, Digital communication systems, signal detection, estimation and modulation methods. (Transmitter, Receivers, Channel Estimation and Equalization)

- Matched filters and Time and frequency-domain analysis. Digital filters: FIR and IIR filters, linear filter design techniques. LMS, RLS and Kalman filters. Optimal filtering.

- Multirate signal processing, uppsampling, downsampling, rate conversion, poly-phase representation, filter banks. Complex envelopes, IQ channels, ambiguity functions. Beamforming and analyzing methods.

Action Plan

Action plan

Week	Sections	Topic	Activities
Week 1	Part I (Applications of signal processing in digital communication systems)	Topic 1: Applications of Signal Processing	Seminar: "Applications of Signal Processing"
Week 2		Topic 2: Digital Communication Systems (transmitter)	Seminar: "Digital Communication Systems (transmitters)"
Week 3		Topic 3: Digital Communication Systems (channel estimation and equalization)	Lecture: "Digital Communication Systems (channel estimation and equalization)"
Week 4		Topic 4: Digital Communication Systems (receiver)	Lecture: "Digital Communication Systems (receivers)"
Week 5		Topic 5: Digital Communication Systems (receiver continue …)	Lecture: "Digital Communication Systems (receivers continue …)"
Week 6	Part II (Applied signal processing and digital Filters)	Topic 6: FIR Filters	Lecture: Design of Finite Impulse Response Filters
Week 7		Topic 7: IIR Filters	Lecture: Design of Infinite Impulse Response Filters
Week 8		Topic 8: Adaptive Filter	Lecture: Adaptive filters and classes
Week 9		Topic 9: Adaptive and Kalman Filter	Lecture: Adaptive filters and classes (cont..) and Kalman Filter Introduction
Week 10		Topic 10: Kalman Filter	Lect: Kalman Filter (cont..)
Week 11	Part IIII (Applying signal processing in Software Defined Radio)	Topic 11:	Multirate signal processing (1: Downsampling)
Week 12		Topic 12:	Multirate signal processing (2: Upsampling
Week 13		Topic 13:	RF Front end Design: Bandpasss sampling design

Evaluation

ASSESSMENT METHOD	ASSESSMENT CRITERIA
Practices (learning outcome 2-5)	The practical assignments must be presented in order to be able to take the exam. • Each student is given **five** individual assignments. Each assignment gives a maximum **5 points** and presenting all lab assignments will give a maximum of **25 points (25 %)** which will count towards the final course mark. Practical work is given maximum points if: - the assignment is done correctly, possible errors and shortcomings are corrected - the assignment is presented on time (presenting the assignment 2 weeks late will give a maximum of 3 points and presenting more than 2 week late will give a maximum of 0 points) **Penalties for late submission will count towards the final course mark** - The results of the lab assignments are presented in a report form.
Individual work (project), that is related to the learning outcomes (1-3, 5)	Assessment preconditions: The project is submitted to the supervisor on time in the way and format the supervisor requests. Deviations need to be agreed with the supervisor before the deadlines. Individual work should be **presented.** Assessment: **The individual work will be assessed** by the supervisor if all the learning outcomes are fulfilled and will give a maximum of **25 points (25 %)**
Presentation of the individual work that is related to the learning outcomes (1)	Assessment preconditions: The presentation is given on time in the way and format the supervisor requests. Deviations need to be agreed with the supervisor before the deadlines.
Written exam, that is related to the learning outcomes (1, 4)	Assessment preconditions: Both, the practices and presented individual work are assessed. Assessment: The exam will consist of at least two tasks. The student will have 90 minutes to demonstrante the fulfillment of the relevant learning outcome. According to this the supervisor evaluates if the learning outcome is fulfilled. The grade depends on the level, the work was done according to the point of view of the supervisor. The exam will give a maximum of **50 points (50 %)**

Course Materials (Books)

- Harry L. Van Trees, Detection, Estimation and modulation Theory, Part I, Wiley Inter Science.
- K. Shanmugan, A Breipohl, Random Signals, **Detection, Estimation**, and Data Analysis, J. Wiley & Sons.
- **Digital Filters**, Antoniou, McGraw Hill, can be downloaded from: http://fmipa.umri.ac.id/wp-content/uploads/2016/03/Andreas-Intoniou-Digital-signal-processing.9780071454247.31527.pdf - and 1 paper copy in the TTU library VB-25343
- Mathematical Methods and **Algorithms for Signal Processing**, Todd Moon, Addison Wesley can be downloaded from: https://www.u-cursos.cl/usuario/834c0e46b93fd72fd8408c492af56f8d/mi_blog/r/4)_Todd_Moon_Mathematical_Methods_and_Algorithms_for_Signal_Processing.pdf
- **Digital Signal Processing**, Roberts & Mullis, „Addison Wesley site needs registering“ and then can be downloaded from: https://qumildena.firebaseapp.com/aa582/digital-signal-processing-addison-wesley-series-in-electrical-engineering-by-r-a-roberts-c-t-mullis-0201163500.pdf OR

  https://pdf-2011-20.firebaseapp.com/digital-signal-processing-addison-wesley-series-in-electrical-engineering-by-r-a-roberts-c-t-mullis.pdf
- Digital Signal Processing: **A computer Based Approach**, S K Mitra, McGraw Hill
  - PDF file:https://livettu-my.sharepoint.com/personal/marika_kulmar_ttu_ee/_layouts/15/onedrive.aspx?id=%2Fpersonal%2Fmarika_kulmar_ttu_ee%2FDocuments%2FAttachments%2FDigital_Signal_Processing_-_A_Computer_Based_Approach-Mitra_s_2nd%2Epdf&parent=%2Fpersonal%2Fmarika_kulmar_ttu_ee%2FDocuments%2FAttachments&slrid=0ee2b99e-d0c2-0000-60d7-2d12ccee9bb9.
  - 2nd edition 2001. One paper copy in the TTU library 4th floor https://www.ester.ee/record=b1927471

Practical Information and useful links

- **Moodle:**
  IEE1711 Applied signal processing
  https://moodle.hitsa.ee/course/view.php?id=25187
  Self enrolment key for a student is "**yQD4YdZ"**
- Consultation Hours
  - Prior Appointment to be agreed before email: muhammad.alam@ttu.ee
  - Offcie: U02-230.

Adaptive Signal Processing:
https://www.dspalgorithms.com/www/echo/aec.php
https://www.dspalgorithms.com/www/aspt/caspt.php

Lecture 1: Signal Prcessing Applications

Analogue Vs Digital Signal Processing

Reliability:

Analogue system performance degrades due to:

- Long term drift (ageing)
- Short term drift (temperature?)
- Sensitivity to voltage instability.
- Batch-to-Batch component variation.
- High discrete component count

Interconnection failures

Introduction

Digital Systems:

- No short or long term drifts.
- Relative immunity to minor power supply variations.
- Virtually identical components.
- IC’s have > 15 year lifetime
- Development costs
- System changes at design/development stage only software changes.
- Digital system simulation is realistic.

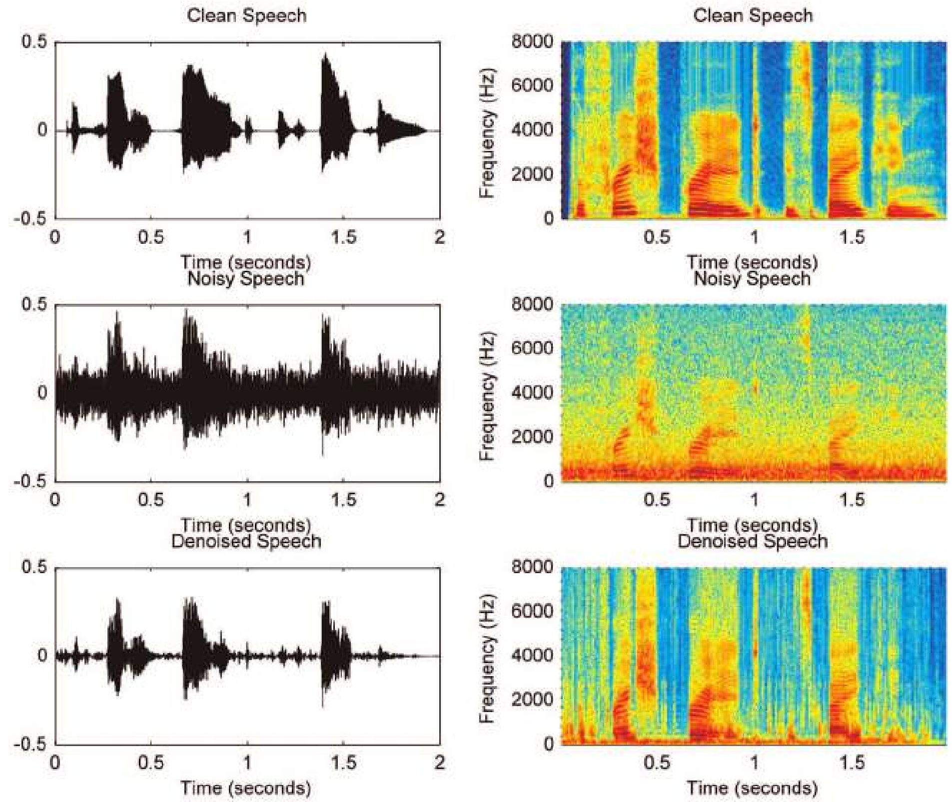
Power aspects

- Size
- Dissipation
- DSP chips available as well as ASIC/FPGA realisations

Applications (1/6)

An **audio signal** is a representation of **sound**, typically using a level of electrical voltage for analog **signals**, and a series of binary numbers for digital **signals**. **Audio signals** have frequencies in the **audio** frequency range of roughly 20 to 20,000 Hz, which corresponds to the upper and lower limits of human hearing

The **speech signal**, as it emerges from a speaker's mouth, nose and cheeks, is a one-dimensional function (air pressure) of time. Microphones convert the fluctuating air pressure into electrical **signals**, voltages or currents, in which form we usually deal with **speech signals** in **speech** processing.



The time-domain waveforms and spectrograms of a sample speech signal. The sentence was "The fresh bread is baking."

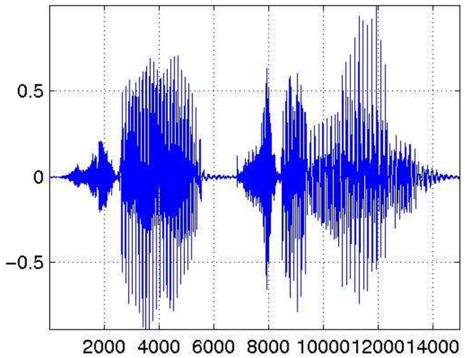
Music:

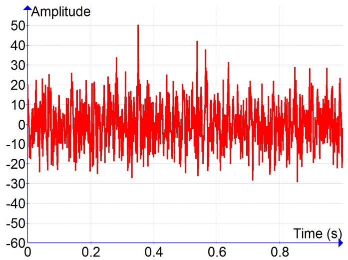
-Music recording.

- Multi-track “mixing”.

- CD and DAT.

- Filtering / Synthesis / Special effects.





Applications (2/6)

Image Processing

- Image data compression.
- Image filtering.
- Image enhancement.
- Spectral Analysis.
- Scene Analysis / Pattern recognition.

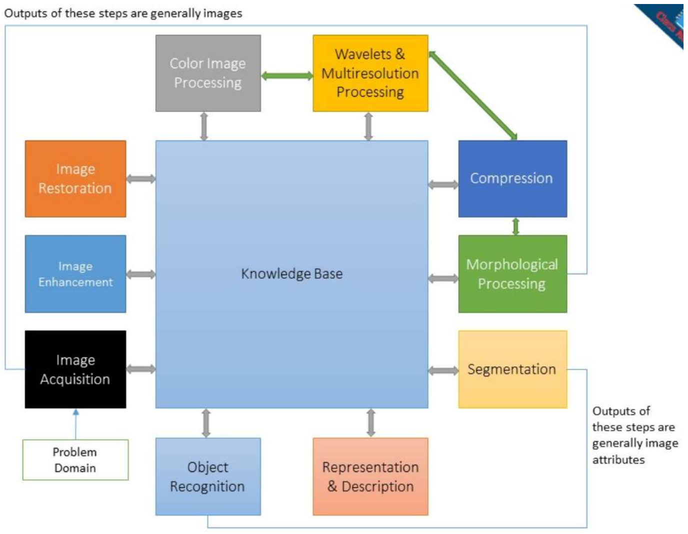
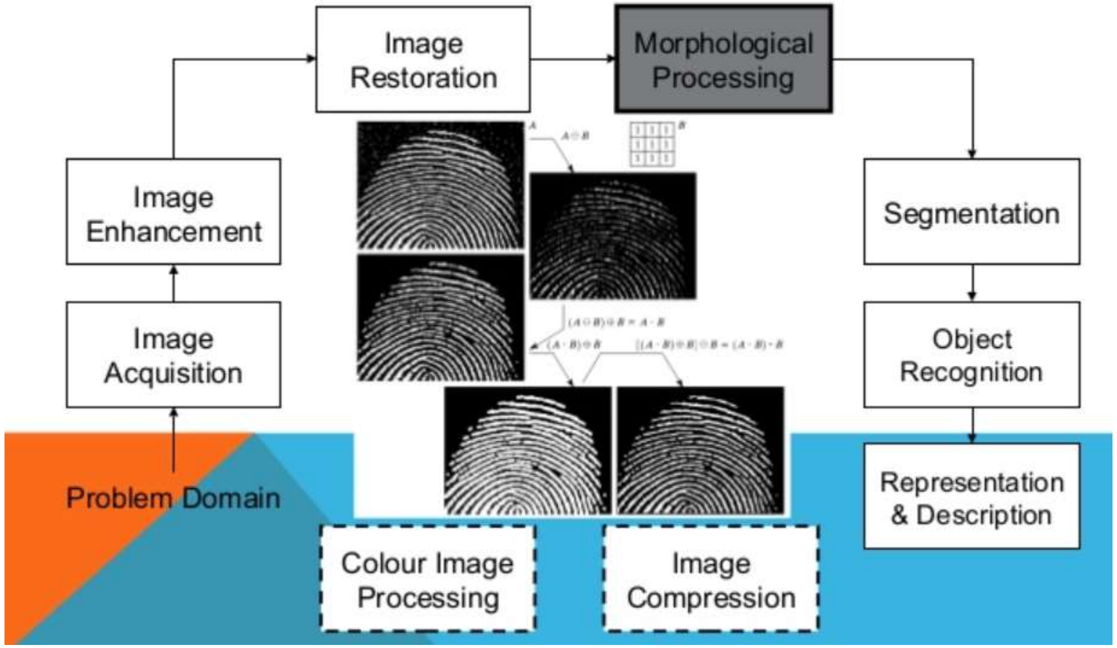


Figure: Steps in Digital Image Processing

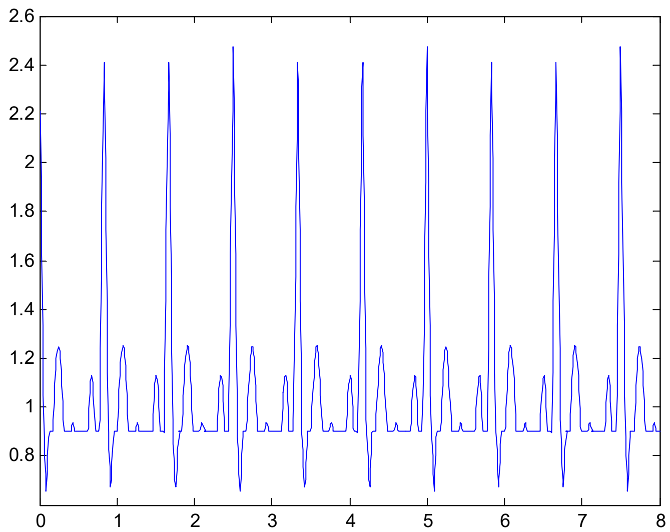
KEY STAGES IN DIGITAL IMAGE PROCESSING:
MORPHOLOGICAL PROCESSING

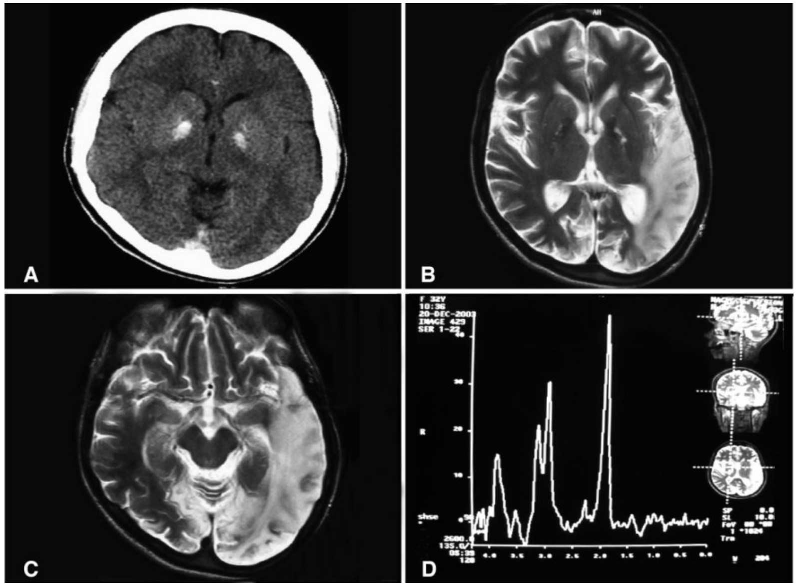


Applications (3/6)

Biomedical Signal Analysis

- Spatial image enhancement. (X-rays)
- Spectral Analysis.
- 3-D reconstruction from projections.
- Digital filtering and Data compression.

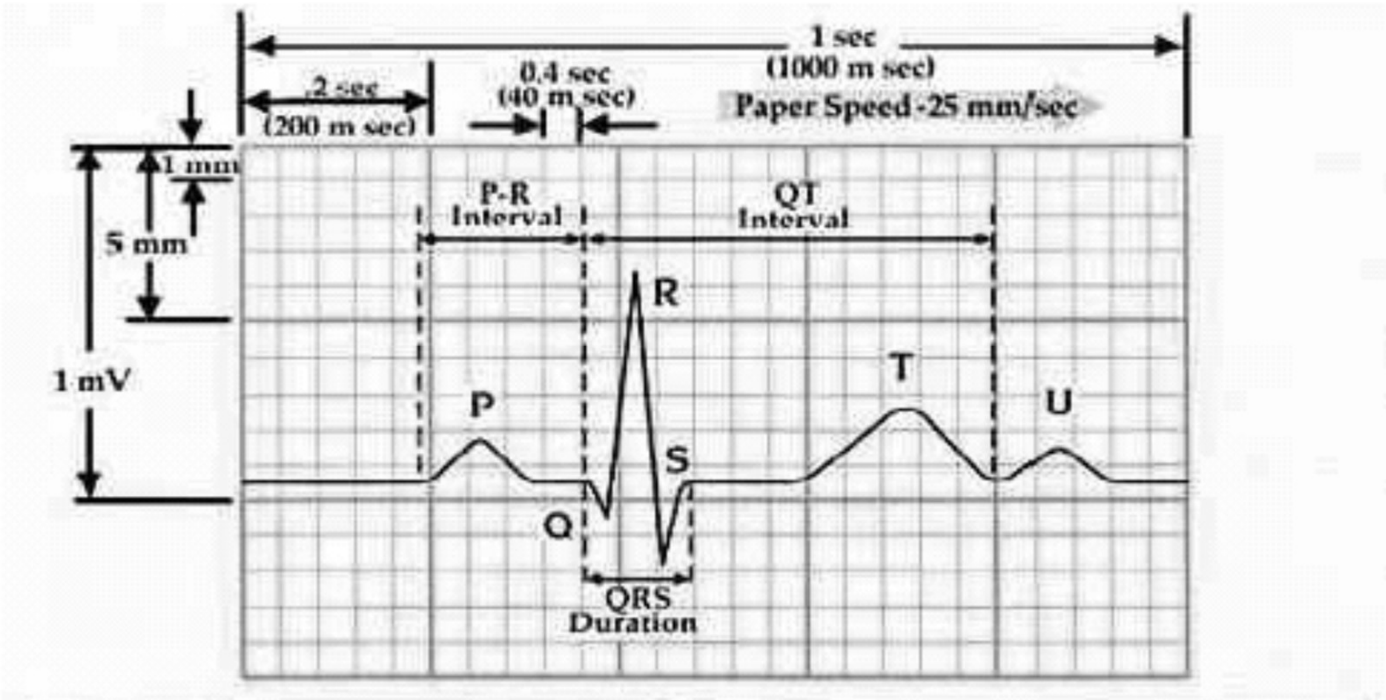




Tomography: A technique for displaying a representation of a cross section through a human body or other solid object using X-rays or ultrasound.

Applications (3/6)

- Features of ECG waveform:
  - A typical scalar electrocardiographic lead is shown in Figure, where the significant features of the waveform are the P, Q, R, S, and T waves, the duration of each wave, and certain time intervals such as the P-R, S-T, and Q-T intervals.



Applications (4/6)

Radar systems & Sonar systems: To determine the range and bearing of distant targets

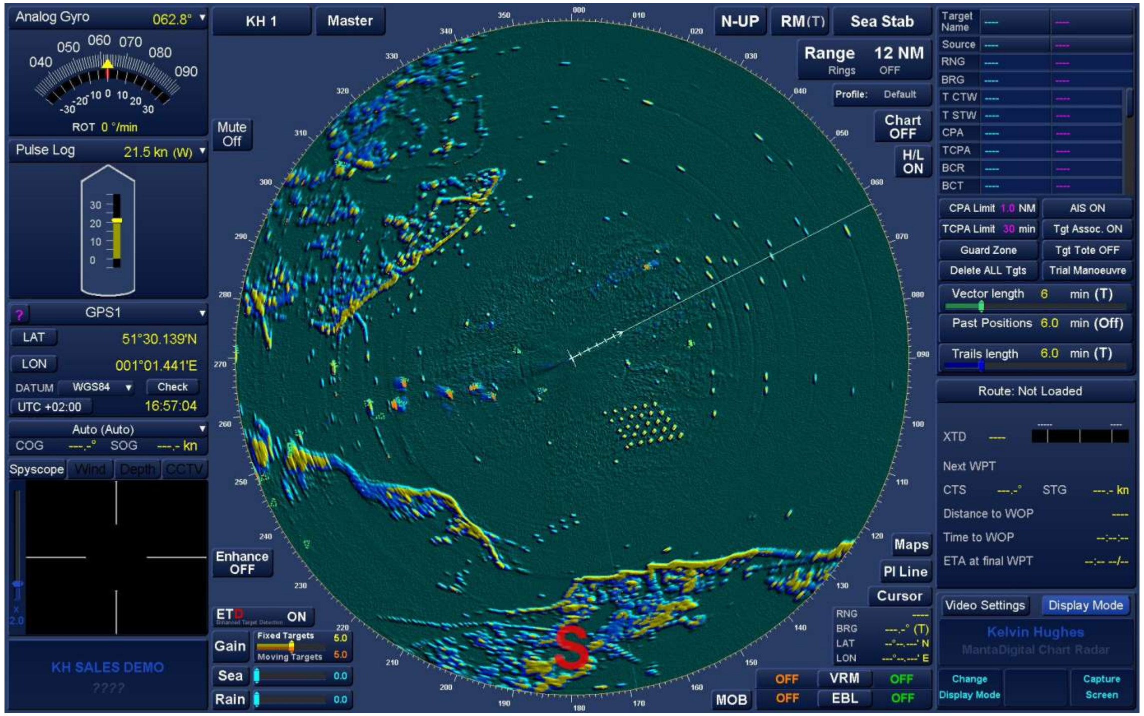
Clutter Suppression: for example, Vehicle radar receives echoes from the natural environment such as road and building. These echoes are called **clutter** which can be much higher than vehicle echo.

Doppler filters

Matched filters

Target tracking

Identification



Applications (5/6)

Seismic Signal Analysis

- Bandpass Filtering for S/N improvement.
- Predictive deconvolution to extract reverberation characteristics.
- Optimal filtering. (Wiener and Kalman.)

Applications (6/6)

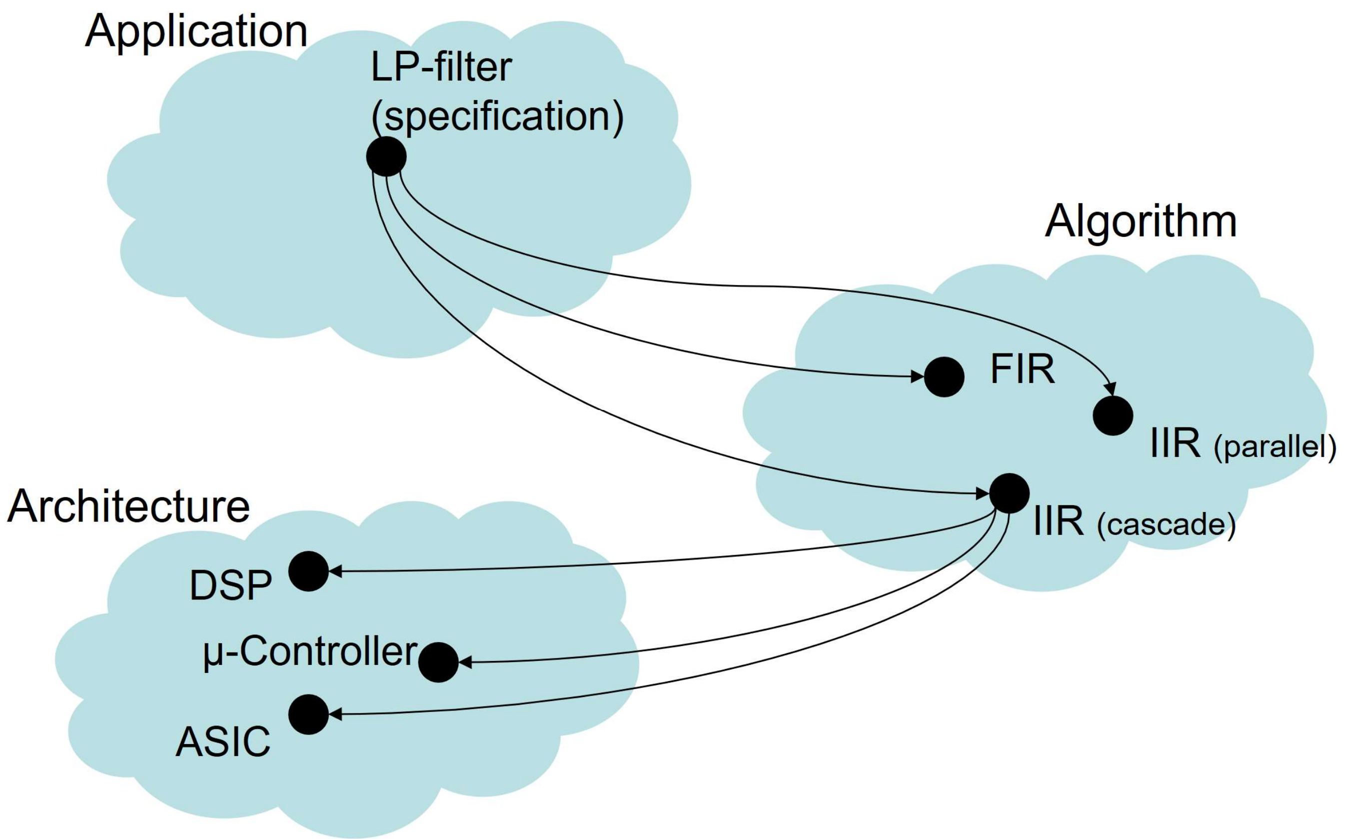
Telecommunications and Consumer Products

These are the largest and most pervasive applications of DSP and Digital Filtering

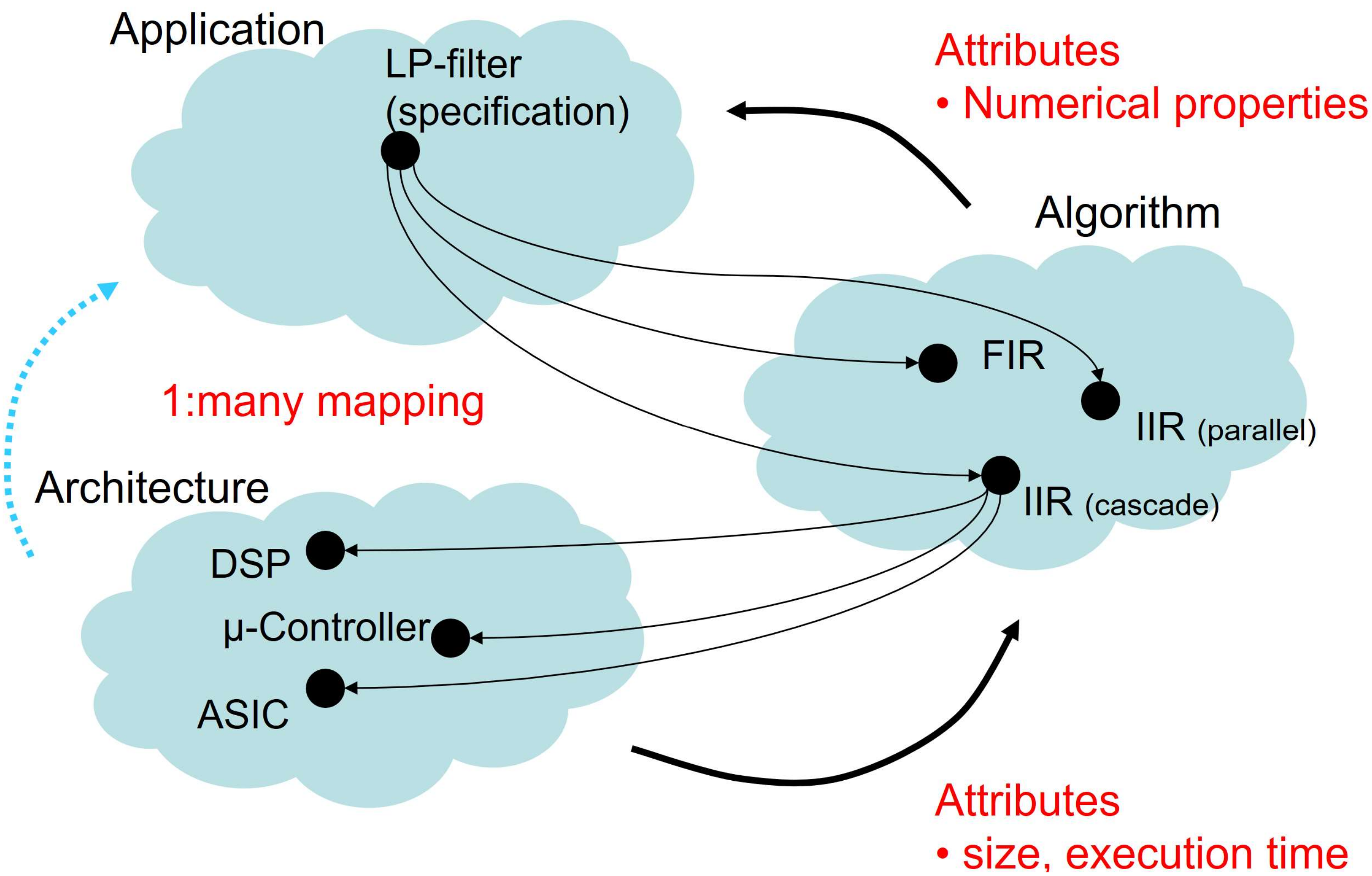
- Mobile Communications
- Digital Recording
- Digital Cameras
- Blue Tooth or similar

A3 Model Paradigm

A: Application
A: Algorithm
A: Architecture



A3 Model Paradigm



Steps in Digital Signal Processing (1/2)

- Most of the signals in our environment are analog such as raadio, sound, temperature and light.
- To processes these signals with a smart gadgets, computer, etc., we must:
  - convert the analog signals into electrical signals, e.g., using a transducer such as a microphone to convert sound into electrical signal
  - digitize these signals, or convert them from analog to digital, using an ADC (Analog to Digital Converter)

Steps in Digital Signal Processing (2/2)

- Analog input signal is filtered to be a band-limited signal by an input lowpass filter
- Signal is then sampled and quantized by an ADC
- Digital signal is processed by a digital circuit, often a computer or a digital signal processor
- Processed digital signal is then converted back to an analog signal by a DAC
- The resulting step waveform is converted to a smooth signal by a reconstruction filter called an anti-imaging filter

Why do we need DSPs?

- DSP operations require a lot of multiplying and adding operations of the form:

$$A = B*C + D$$

- This simple equation involves a multiply and an add operation
- The multiply instruction of a GPP is very slow compared with the add instruction
  - For example, Motorola 68000 microprocessor uses
    - 10 clock cycles for add
    - 74 clock cycles for multiply
- Digital signal processors can perform the multiply and the add operation in just one clock Cycle
- Most DSPs have a specialized instruction that causes them to multiply, add and save the result in a single cycle
- This instruction is called a MAC (Multiply, Add, and Accumulate)

Advantage of DSP

- Guaranteed accuracy: (accuracy is only determined by the number of bits used)
- Perfect Reproducibility: Identical performance from unit to unit
  - A digital recording can be copied or reproduced several times with no loss in signal quality

- No drift in performance with temperature and age

- Uses advances in semiconductor technology to achieve:

  (i) smaller size

  (ii) lower cost

  (iii) low power consumption

  (iv) higher operating speed

- Greater flexibility: Reprogrammable , no need to modify the hardware
- Superior performance

  ie. linear phase response can be achieved

  complex adaptive filtering becomes possible

Disadvantage of DSP

* Speed and Cost
  - DSP techniques are limited to signals with relatively low bandwidths. DSP designs can be expensive, especially when large bandwidth signals are involved.

  ADC or DACs are either to expensive or do not have sufficient resolution for wide bandwidth applications.
* DSP designs can be time consuming plus need the necessary resources (software)
* Finite word-length problems: If only a limited number of bits is used due to economic considerations serious degradation in system performance may result.
  - The use of finite precision arithmetic makes it necessary to quantize filter calculations by rounding or truncation.
  - Roundoff noise is that error in the filter output that results from rounding or truncating calculations within the filter.
  - As the name implies, this error looks like low-level noise at the filter output

DSP Key Operations

- Convolution
- Correlation
- Digital Filtering
- Discrete Transformation
- Modulation

Convolution

- Convolution is one of the most frequently used operations in DSP. Specially in digital filtering applications where two finite and causal sequences x[n] and h[n] of lengths N1 and N2 are convolved

$$y[n] = h[n] \otimes x[n] = \sum_{k=-\infty}^{\infty} h[k]x[n-k] = \sum_{k=0}^{\infty} h[k]x[n-k]$$

where, n = 0,1,…….,(M-1) and $M = N_1 + N_2 - 1$

This is a multiply and accumulate operation and DSP device manufacturers have developed signal processors that perform this action most efficiently.

Correlation and Covariance (1/3)

Auto-Correlation :

The auto-correlation of a process x(t) is defined as the mean of the product $\boldsymbol{x}(t_1)\boldsymbol{x}^*(t_2)$. This function is denoted as R(t_1, t_2) or $R_x\,(t_1, t_2)$ or $R_{xx}\,(t_1, t_2)$.

$$R_x\,(t_1, t_2) = E\{\boldsymbol{x}_1(t_1)\boldsymbol{x}^*(t_2)\}$$

$$R(t_1, t_2) = \mathrm{E}\{x(t_1)x(t_2)\} = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} x_1 x_2 f(x_1, x_2; t_1, t_2)\,dx_1 dx_2$$

Correlation and Covariance (2/3)

Auto-covariance:

Auto-covariance C (t_1, t_2) of a process $\boldsymbol{x}$(t) is the covarince of the random variables $\boldsymbol{x}(t_1)$ and $\boldsymbol{x}(t_2)$ and is defined as

$$C\ (t_1, t_2) = R(t_1, t_2) - \eta(t_1)\eta^*(t_2)$$

Here $\eta(t)$ = E{$\boldsymbol{x}$(t)} is the mean of $\boldsymbol{x}$(t)

Correlation and Covariance (3/3)

Cross-Correlation:

Cross-correlation of two processes $\boldsymbol{x}$(t) and $\boldsymbol{y}$(t) is given as

$$R_{xy}(t_1, t_2) = E\{x(t_1)y^*(t_2)\} = R_{yx}{}^*(t_2, t_1)$$

Cross-Covarience:
Cross-covarience of two processes $\boldsymbol{x}$(t) and $\boldsymbol{y}$(t) is given as

$$C_{xy}(t_1, t_2) = R_{xy}(t_1, t_2) - \eta_x(t_1)\eta^*{}_y(t_2)$$

If $C_{xy}(t_1, t_2)$=0 for every t1 and t2 then the two
Processes are uncorrelated (independent)