Digitalteknik EITF65

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Lecture 1: Introduktion

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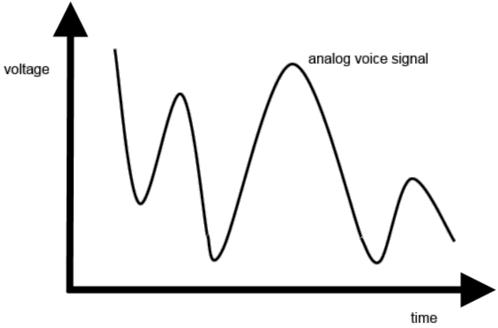
Introduction to Digital Design

- What is a digital system?
- How do we best construct digital systems?
- How can theory and a systematic approach aid us in the design process?

Signals

A *signal* is a function that conveys information about the behavior or attributes of some phenomenon. In the physical world, any quantity exhibiting variation in time or variation in space (such as an image) is potentially a signal that might provide information on the status of a physical system, or convey a message between observers, among other possibilities. (Wikipedia)



Digital vs Analog

- A digital signal is a signal that takes discrete values.
- An analog signal is any continuous signal.

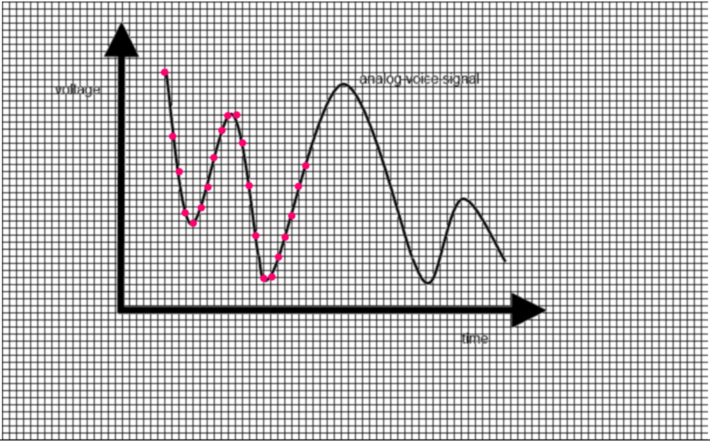
Usually, a digital signal takes discrete values in discrete time (*synchronous signals*).

We may consider time t as $t \in \mathbb{Z}$.

If time is continuous, it is called an *asynchronous* signal.

Conversions

- Analog signals can be converted to digital form (AD-converters)
- Digital signals can be converted back to analog form (DA-converters)



Example

Music on a CD

- is sampled at 44100 Hz
- uses 16 bits (2 bytes) to describe each sample
- should last for up to 74 minutes
- should have 2 different channels

$$44100 \cdot 2 \cdot (74 \cdot 60) \cdot 2 \approx 740\text{MB of data}$$

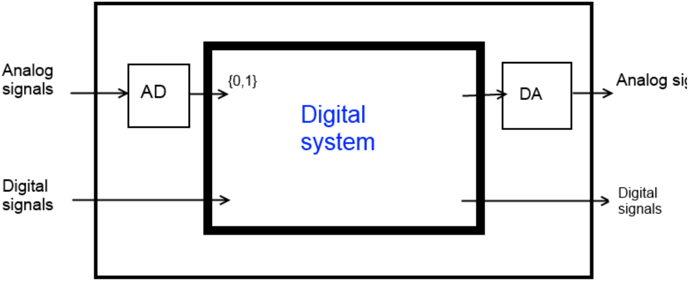
To think about: Why can a CD-ROM only hold 650MB of data?

Digital systems

The smallest alphabet size for digital signals is the binary alphabet $\{0, 1\}$.

- Digital input and digital output signals.
- Discrete time $t \in \mathbb{Z}$.
- The digital system processes/operates on input and delivers output. All in binary form.

Digital systems



Digital systems

All things we build today are digital!
Example in communication: mobile communication systems:

- NMT (1G) analog system (1981-)
- GSM (2G) digital system (1991-)
- UMTS (3G) digital system (2001-)
- LTE (4G) digital system ($\sim$ 2009-)
- 5G digital system (2020(?)-)

Why digital?

- Bandlimited analog signals can be (almost) exactly represented in digital form (Nyquist-Shannon sampling theorem).

Theorem

If a function $f(t)$ contains no frequencies higher than B hertz, it is completely determined by giving its ordinates at a series of points spaced 1/(2B) seconds apart.

Thus, we need to sample at 2B samples per second (or more).

Return to CD example

- We sample at 44100 Hz
- Human hearing range is roughly 20 - 20,000 Hz $\Rightarrow$ we need a sample rate of at least 40000 Hz. (Filter attenuation require us to have it slightly higher.)

Why digital?

Bit stream representing the signal gives us nice features

- Processing/Communication without errors. See course *EITN70 Channel Coding for Reliable Communication*.
- Compress data. See course *EITN45 Information Theory*.
- Encrypt data. See course *EDIN01 Cryptography*.
- Operate on and manipulate digital signals. See course EITA50/EITF75 Digital Signal Processing.
- Digital electronics are cheap. (Modern processor has around 2 billion transistors and costs around $100). See e.g., *ETIN20 Digital IC design* and *EITF35 Introduction to Structured VLSI Design*

So, we need to learn how to operate on discrete values.
This course: Build circuits that take (a sequence of) discrete values as input and output (a sequence of) discrete values.

Why analog then?

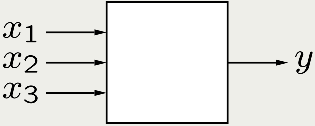
- The world is analogue. 0 and 1 is made up.
- Air pressure, voltage, current, polarization of magnets, etc is continuous.
- Digital circuits are contructed using analogue circuits.
- Digital transmission is realized using analogue signals.

Majority Function

Example

Let $y(x_1, x_2, x_3)$ be the majority function,

$$y(x_1,x_2,x_3) = \begin{cases} 0, & x_1 + x_2 + x_3 \in \{0,1\} \\ 1, & x_1 + x_2 + x_3 \in \{2,3\} \end{cases}$$



$x_1 x_2 x_3$	y
0 0 0	0
0 0 1	0
0 1 0	0
0 1 1	1
1 0 0	0
1 0 1	1
1 1 0	1
1 1 1	1

The lion threat

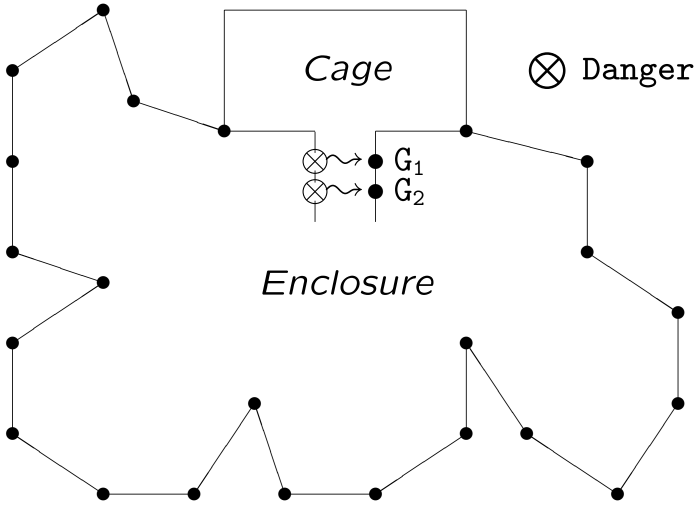
Example (Lab 1)

At a zoo there is an enclosure for lions. It consists of two parts, a cage where the lions can rest and the enclosure, which is a big open field where the lions can stroll around. The enclosure is hilly and, therefore, difficult to overview. Since the keeper wants to clean the enclosure while the lions are in the cage he needs a system where a lamp, `Danger`, tells if there is any lion in the enclosure.

At the passage between the cage and the enclosure there are two photo detectors, $\mathtt{G}_1$ and $\mathtt{G}_2$ that are parted by half a meter. The lions are about two meters long and cannot pass the passage at the same time.

Construct a circuit that solves the problem for one lion.

The lion threat (figure)



The lion threat

Example (Sequences)

- The lion walks from the cage to the enclosure:

$$(\mathtt{G}_1, \mathtt{G}_2) : 00 \rightarrow 10 \rightarrow 11 \rightarrow 01 \rightarrow 00$$

- The lion walks from the enclosure to the cage:

$$(\mathtt{G}_1, \mathtt{G}_2) : 00 \rightarrow 01 \rightarrow 11 \rightarrow 10 \rightarrow 00$$

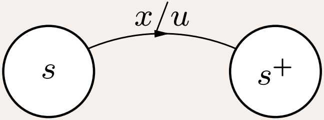
State transition graphs

Definition

A state transition graph is a graph where

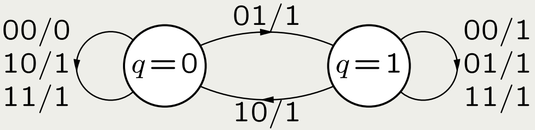
- the state is an abstract (and compact) desription of the past. It contains all relevant information about the history.
- in each state there is one branch for each input.
- in each state there is one output combination for each input.

The branches between the states are drawn as arrows labeled with the input and the output.



The lion threat

Example (Solution)



$q\,G_1\,G_2$	q^+	DANGER
0 0 0	0	0
0 0 1	1	1
0 1 0	0	1
0 1 1	0	1
1 0 0	1	1
1 0 1	1	1
1 1 0	0	1
1 1 1	1	1