

On Coding and Signal Processing for Storage Media

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Abstract

Some basic concepts of information theory, modulation, and error correcting codes are reviewed. Some recent developments in these disciplines are considered and their relevance to the design of storage systems is discussed

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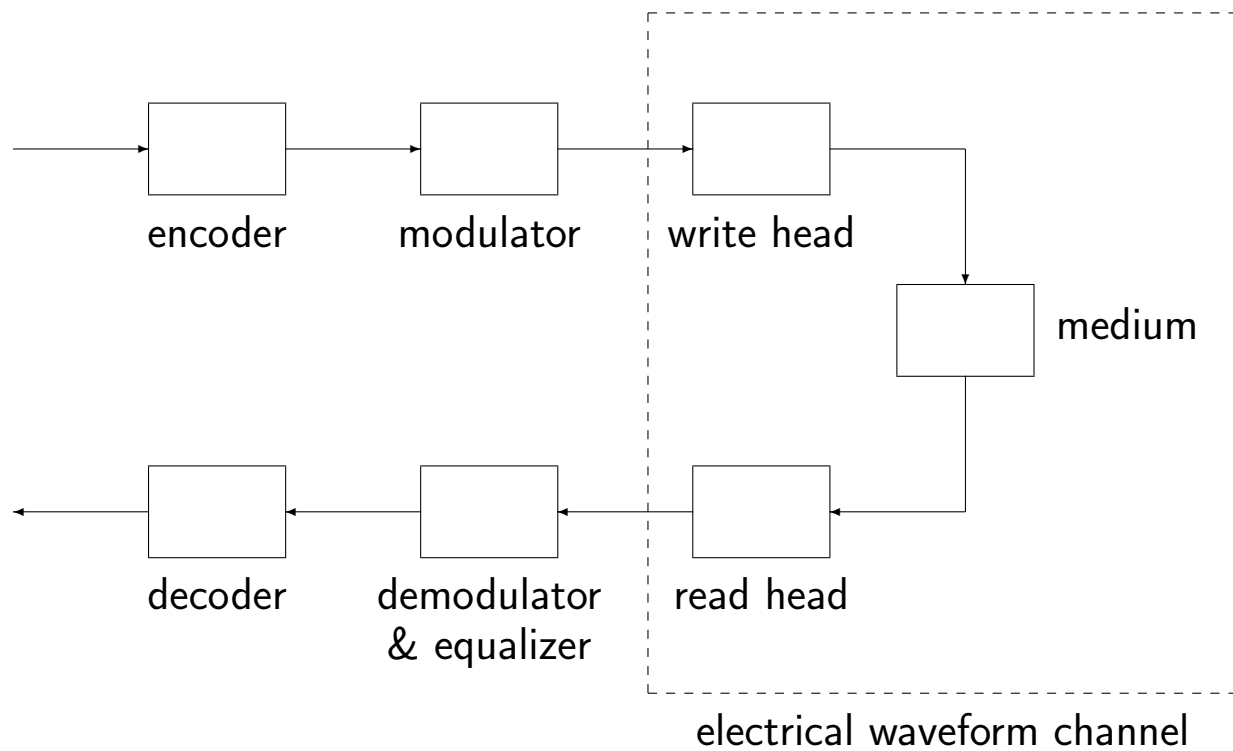


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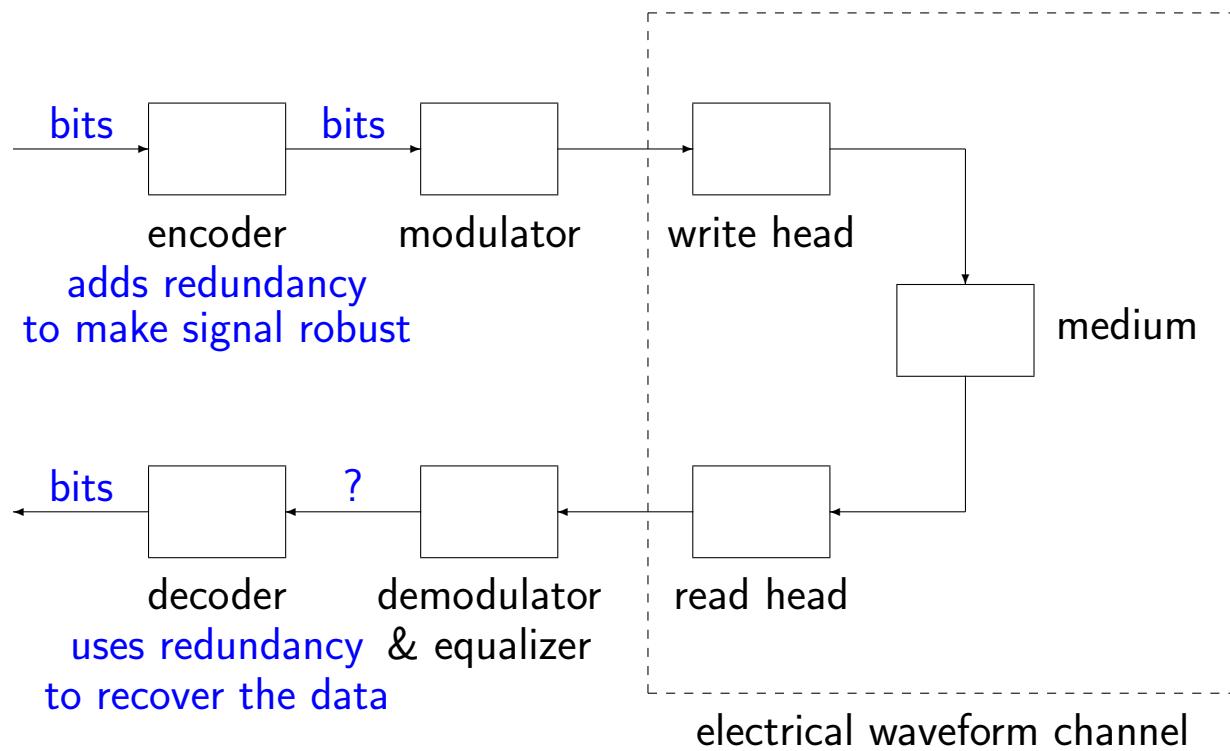
Hans-Andrea Loeliger and Dieter Arnold

Thanks to Pascal Vontobel and Alek Kavčič

Generic Storage Channel

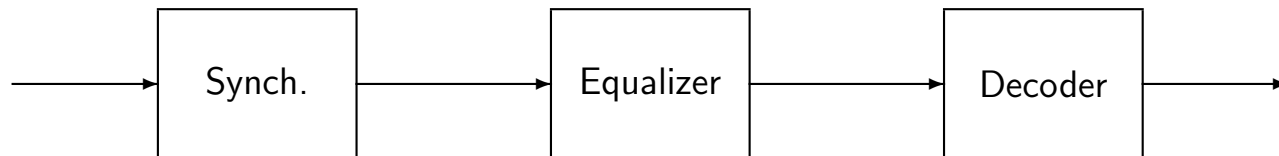


Generic Storage Channel



Turbo Coding & Turbo Signal Processing— A Breakthrough in Communications

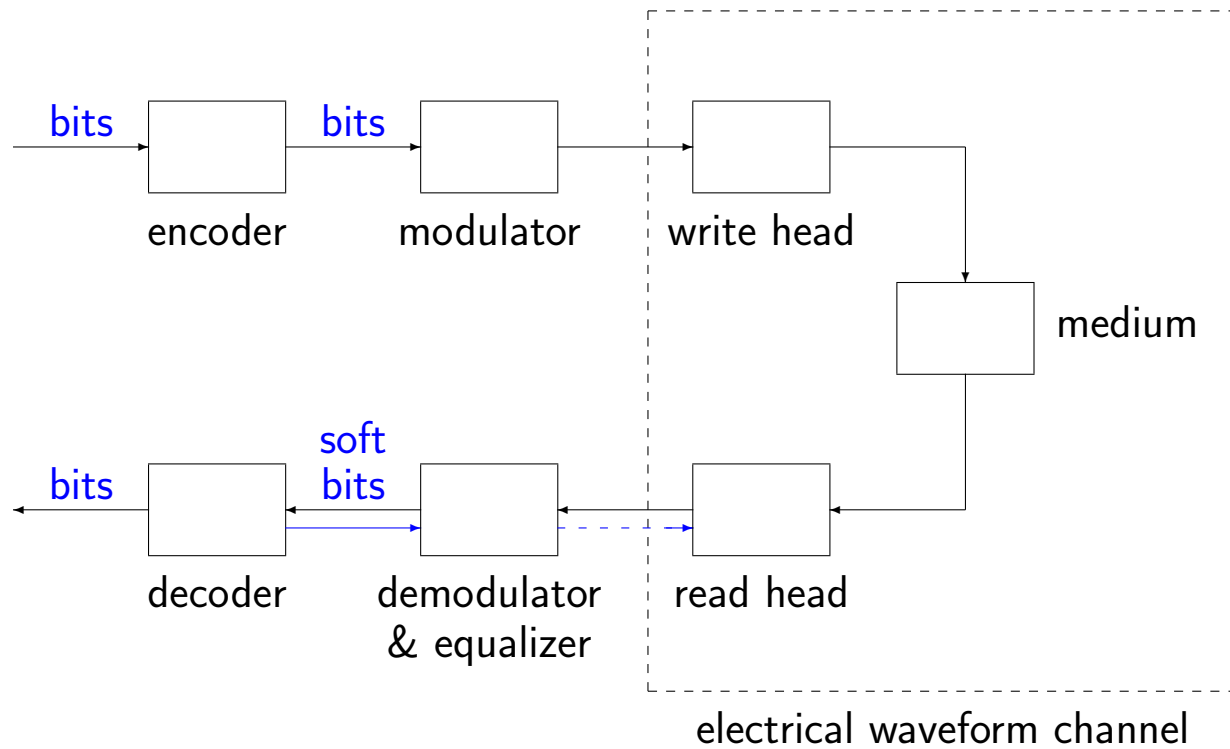
Traditional Receiver:



Much higher performance with iterative (“turbo”) processing:



Iterative Joint Decoding and Equalization



Channel Capacity

Claude Shannon proved in 1948:

- Every communication channel has a well defined **capacity** C (bits/second or bits per channel use or bits/meter or ...).
- Arbitrary reliable communication is possible for any rate $R < C$ by suitable **coding/modulation**.
- Reliable communication is impossible for $R > C$.

Example:

The capacity of the “additive white Gaussian noise channel” with bandwidth W is

$$C = W \log(1 + \text{SNR}) \quad [\text{bits/second}]$$

Is Shannon's Theory Relevant in Practice?

- In 1948, channel capacity was only a theoretical promise far away from reality.
 - Today, practical coding/modulation schemes (turbo codes, low-density parity check codes, iterative joint decoding & equalization & ...) are known that virtually achieve the channel capacity for a wide variety of communication channels.
- ⇒ The channel designer should aim for channel capacity and not worry about bit error rates or coding / signal processing!

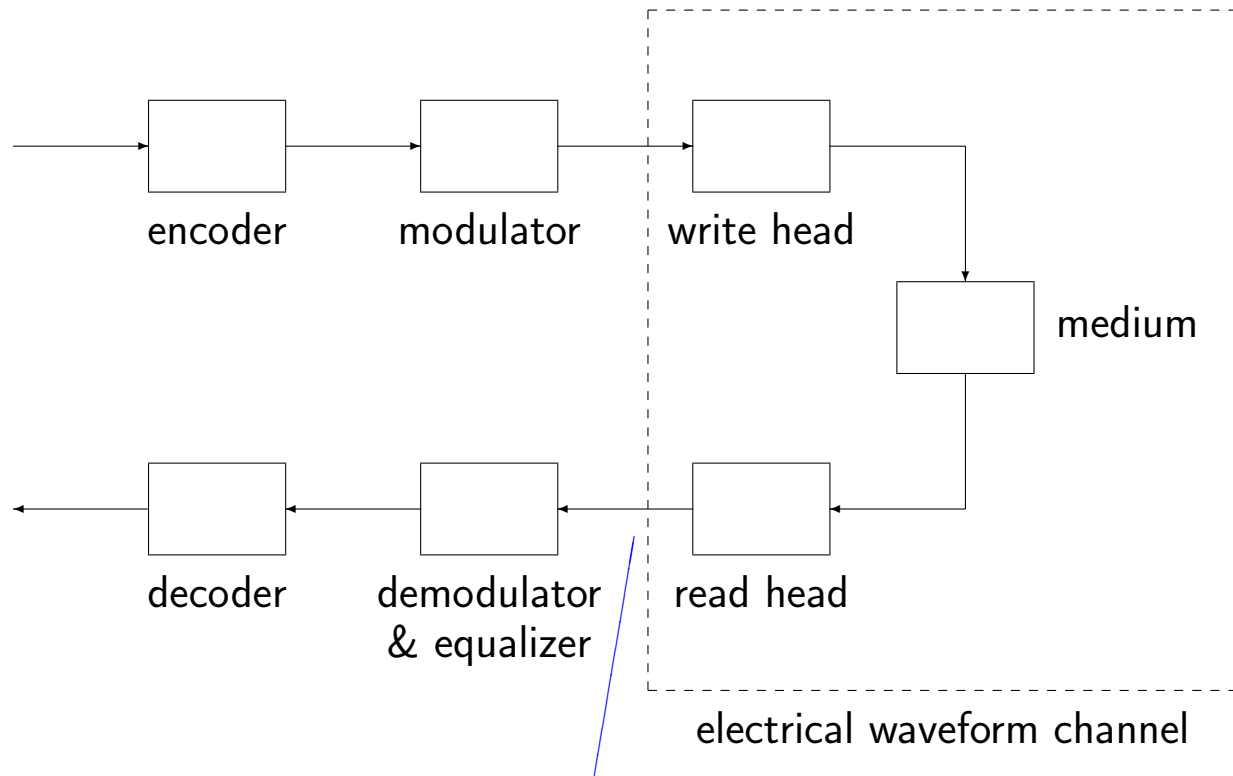
Is Shannon's Theory Relevant for Storage Channels?

Finally, *yes!*

- Until recently, the capacity of most storage channels could not be computed.
- *Now it can!* (With some qualifications)
cf. Arnold/Loeliger 2001; Kavčić 2001; ALV 2002.
- *Practical coding / modulation / signal processing schemes* that come close to the channel capacity are *within reach!* (With some qualifications).

Since these results are fairly new, substantial effort may still be required to apply them to any particular application.

Generic Storage Channel

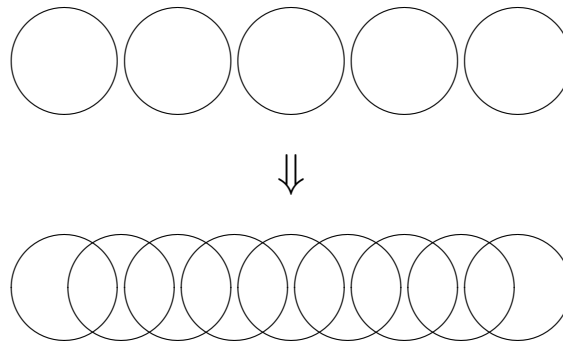


clean bits here
⇒ bad design!

How to Increase Channel Capacity

Besides by the obvious means (improving the medium, the read/write heads, servo precision, etc.), the channel capacity can also be increased by

- going to higher areal density
- using cells/pits of variable size (length/depth/width)
- cell/pit position modulation
- ...



Our Research at ETH Zürich

- Coding and modulation.
- Numerical computation of **channel capacity** of “difficult” channels from channel measurements / simulations.
- Generic techniques for **joint decoding, channel estimation, equalization, and synchronization** (“turbo signal processing”).
- Exploring the implementation of such techniques with novel nonlinear **analog circuits** (“probability gates”) for high-speed or low-power applications.

Conclusions

(subject to some qualifications)

- The “channel” write-head \rightarrow medium \rightarrow read-head should **not** be designed for any target bit error rate, but to maximize the information-theoretic **channel capacity**.
- The channel capacity (or good approximations of it) **can now be computed** numerically for **real** channels.
- Due to advances in **joint coding/signal processing** techniques, **practical schemes** that (almost) achieve the channel capacity are now **within reach**.