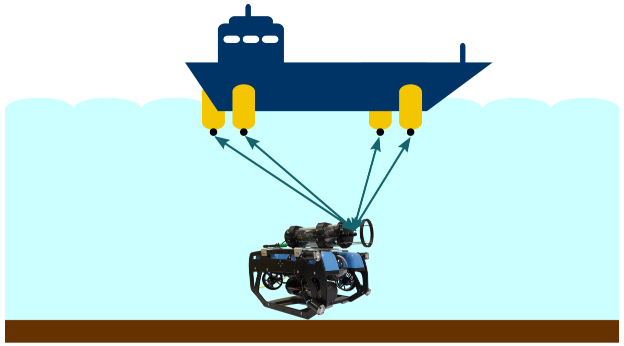
Orthogonal Codes for Acoustic Underwater Localization



Research Project by Sergej Keller

13-07-22

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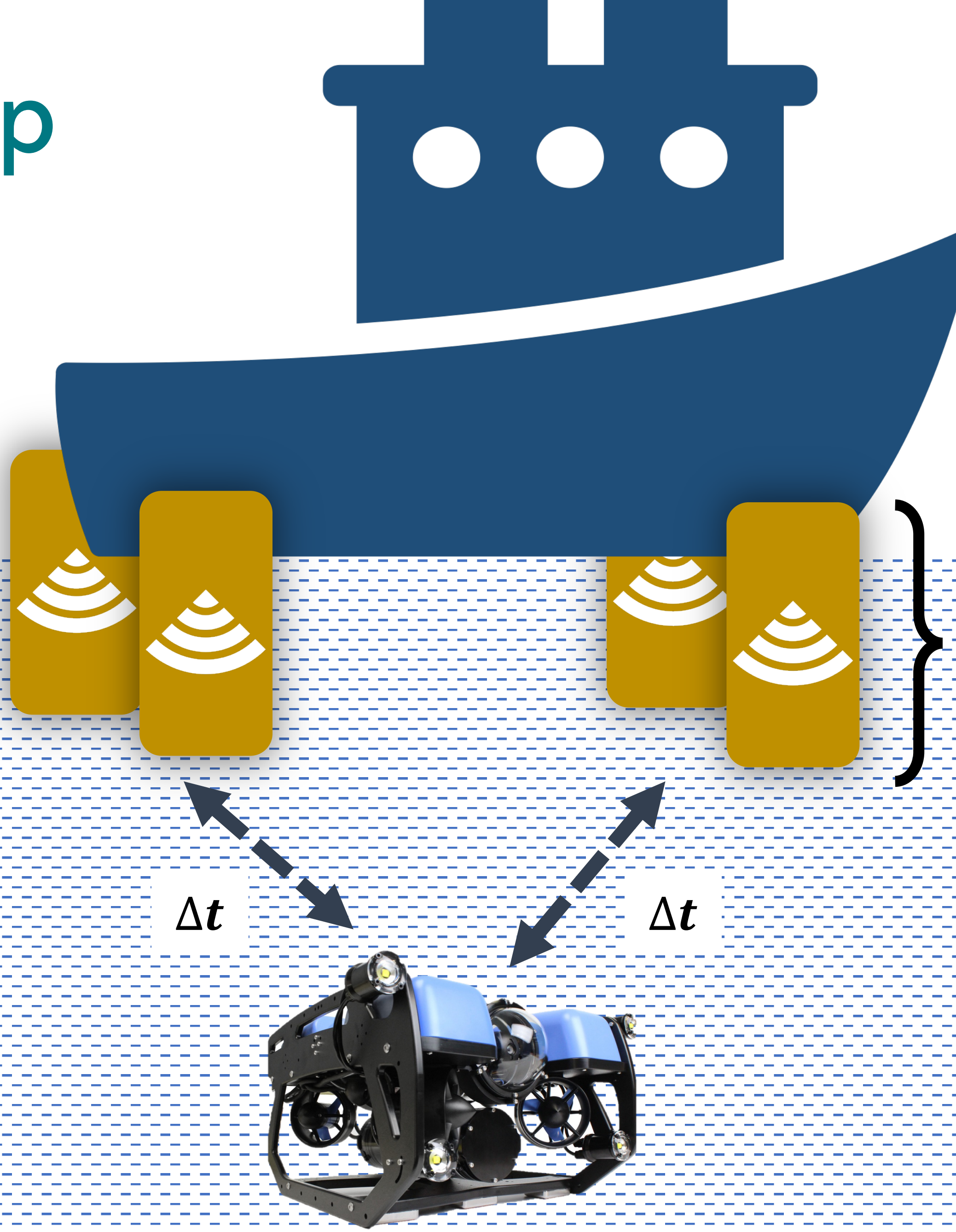
Motivation

Application Areas
- Underwater Measurement
- Subsurface Localization
- Communication of ROV’s and other UV’s

BlueROV2
- Affordable & high-performance modular underwater ROV
- Remotely Operated underwater Vehicle
- Rated for diving 100m

https://bluerobotics.com/wp-content/uploads/2016/06/IMG_6544-scaled.jpg

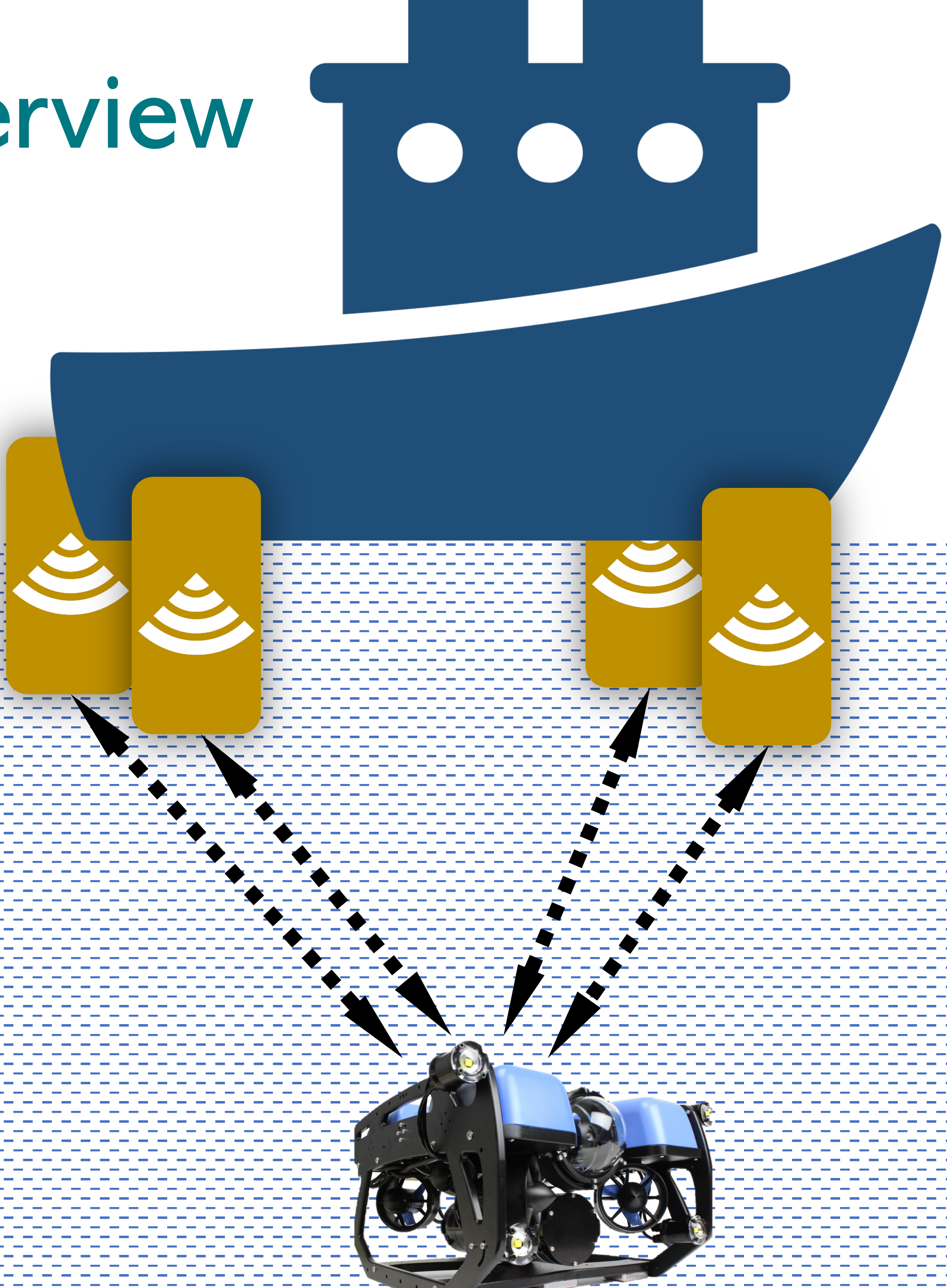
Setup



Base station
- Acoustic signals
- Multiple Anchors with known position
- In most cases deployed at surface level

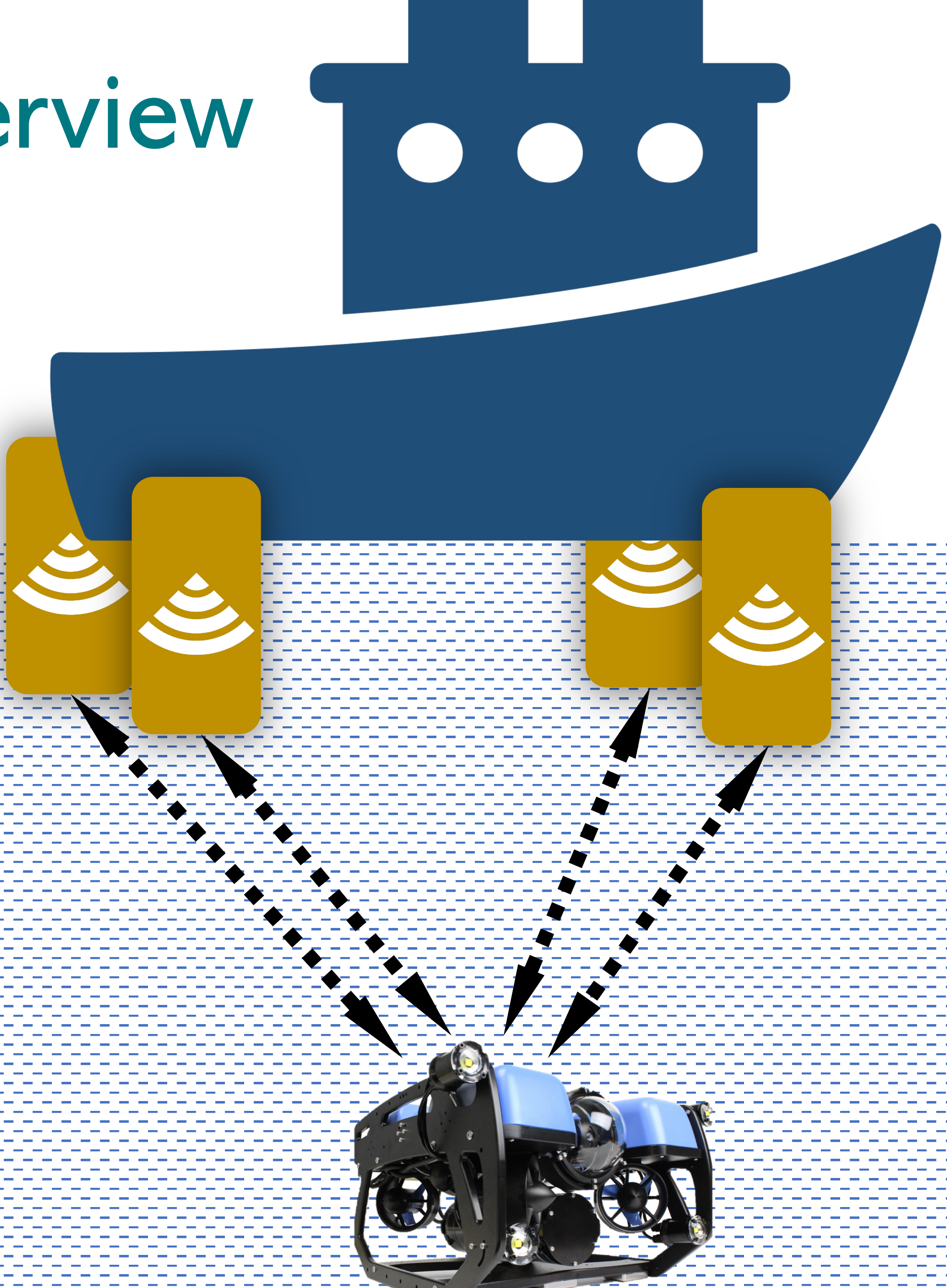
Propagation Delay
- Used for measuring distances between ROV and anchors
- Combined with multiple anchors absolute position prediction is achievable

Overview



2-way ranging (old)	one-way ranging
signal travels two times	signal travels once
signal processing at two levels	ROV receives or transmits to anchors only once
no synchronizing	synchronizing needed
two times the acoustic propagation delay	only one time the propagation delay

Overview



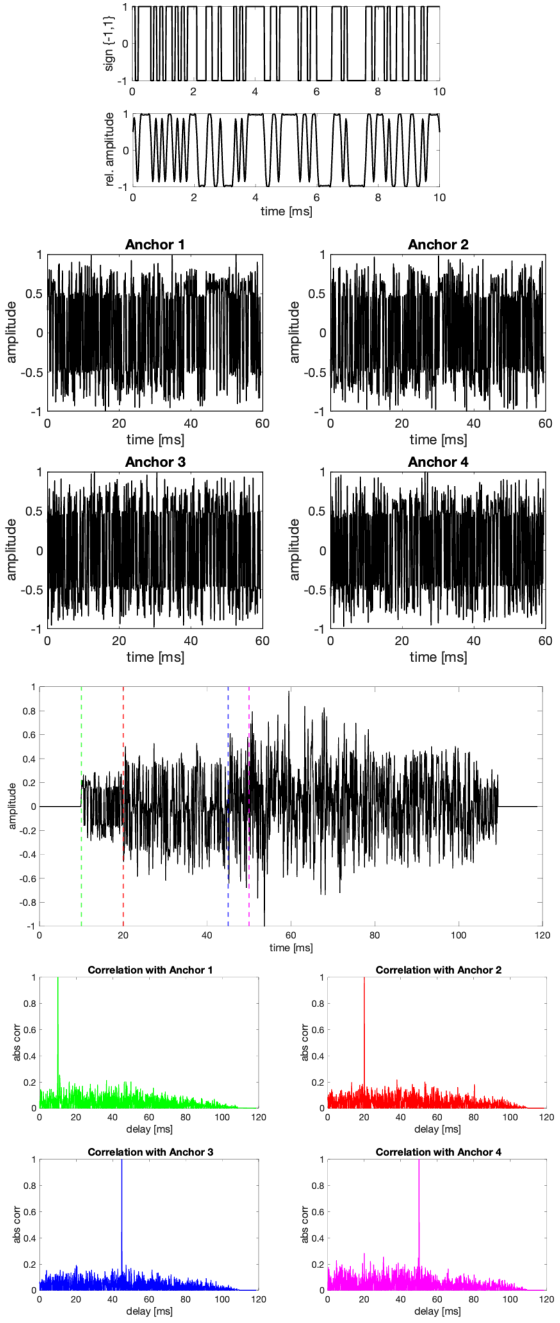
Orthogonal Codes

- Mathematical: linear combination
- Code Division Multiple Access (CDMA)
- auto-correlation properties
  → enhanced detection
- cross-correlation properties
  → improved separation from other sequences

Types of Orthogonal Codes

- Pseudorandom Binary Sequences (PRBS)
  - *Linear feedback shift registers*
  - JPL Sequences (2 x LSFR)
  - Gold Codes
  - Kasami Codes
- Walsh-functions

Principle – Outline



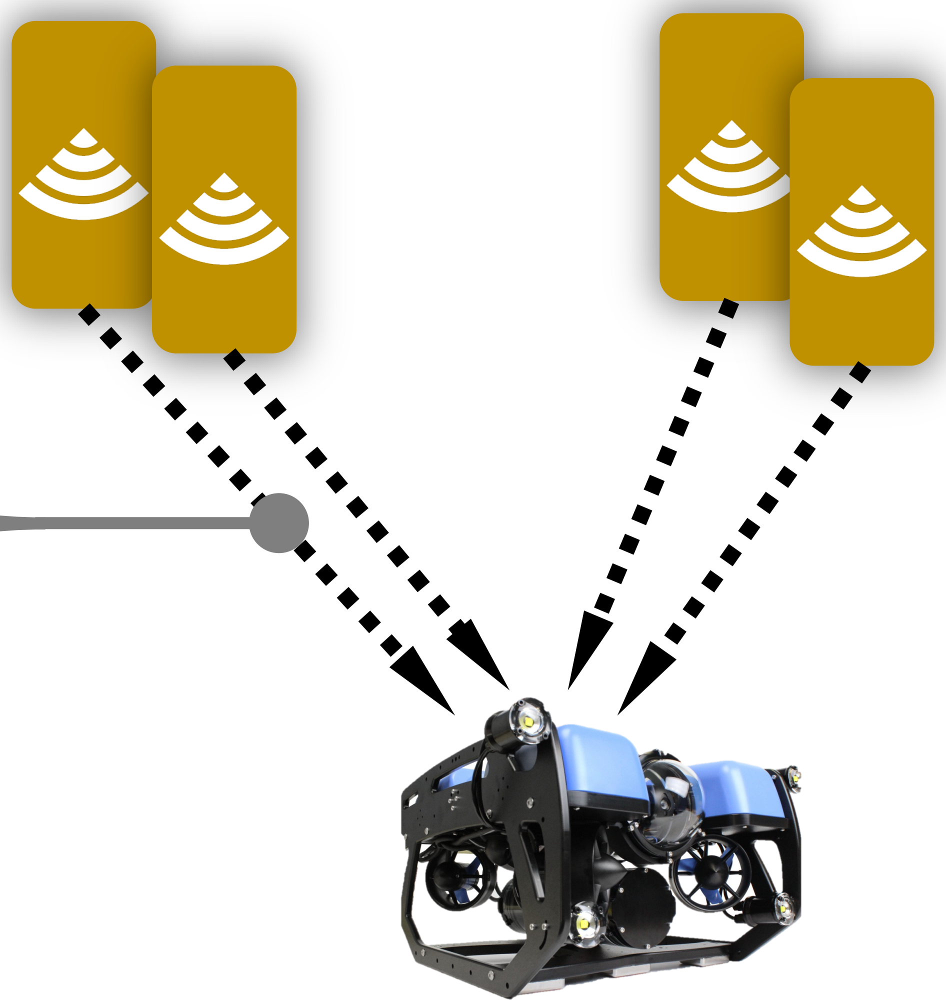
Generating orthogonal Codes

Apply Cosinus FIR

Anchors broadcasting Codes at base station

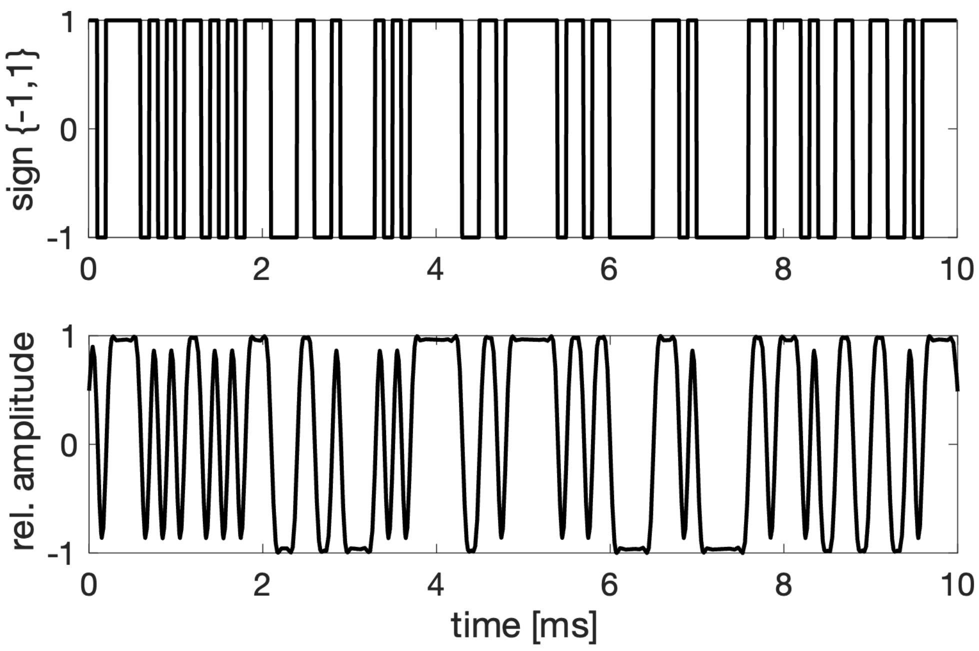
ROV receives Sum of codes

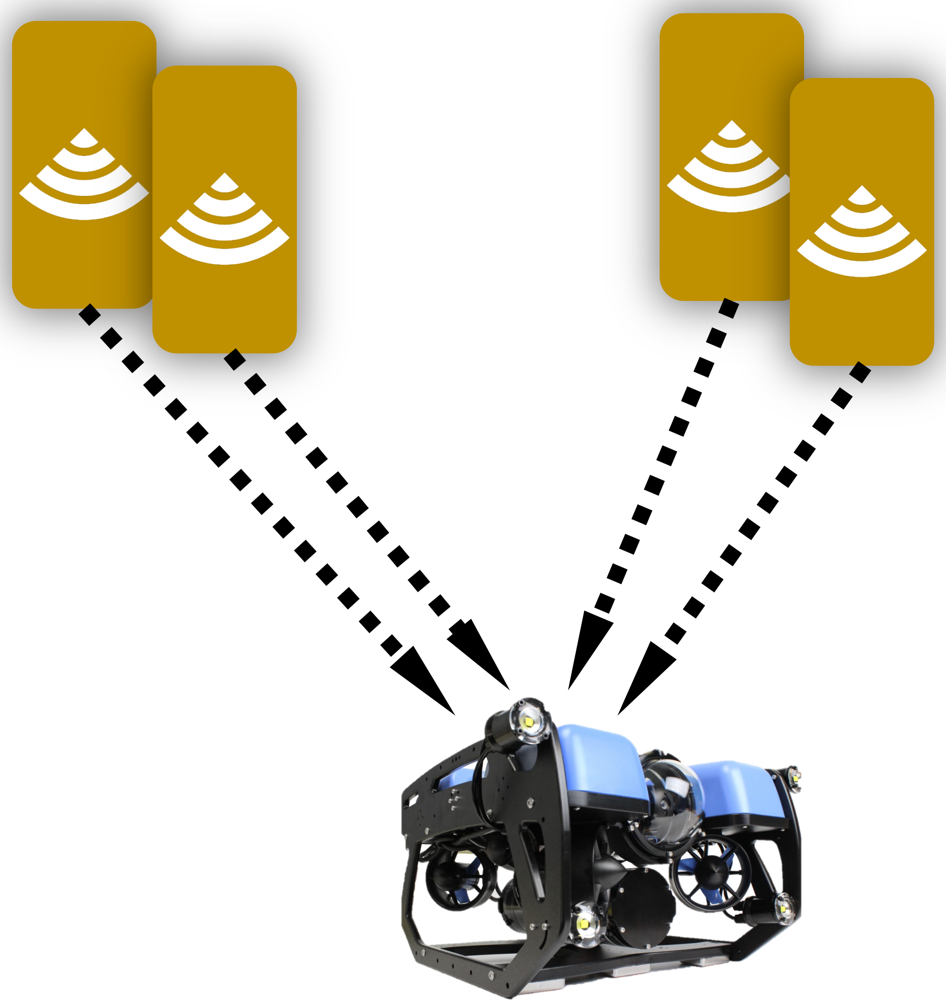
Calculate delay by max index value of cross-correlation



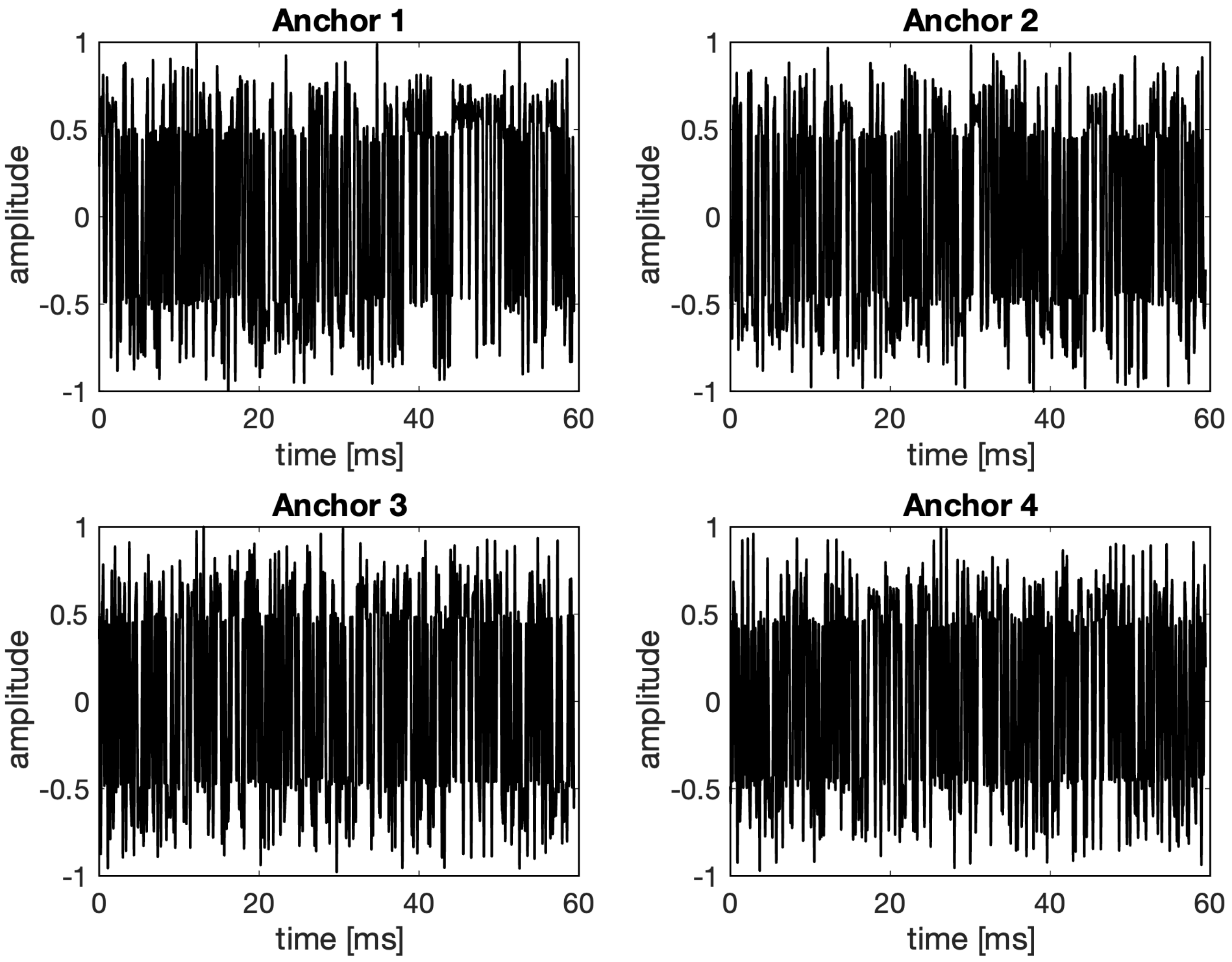
Principle – cosine FIR

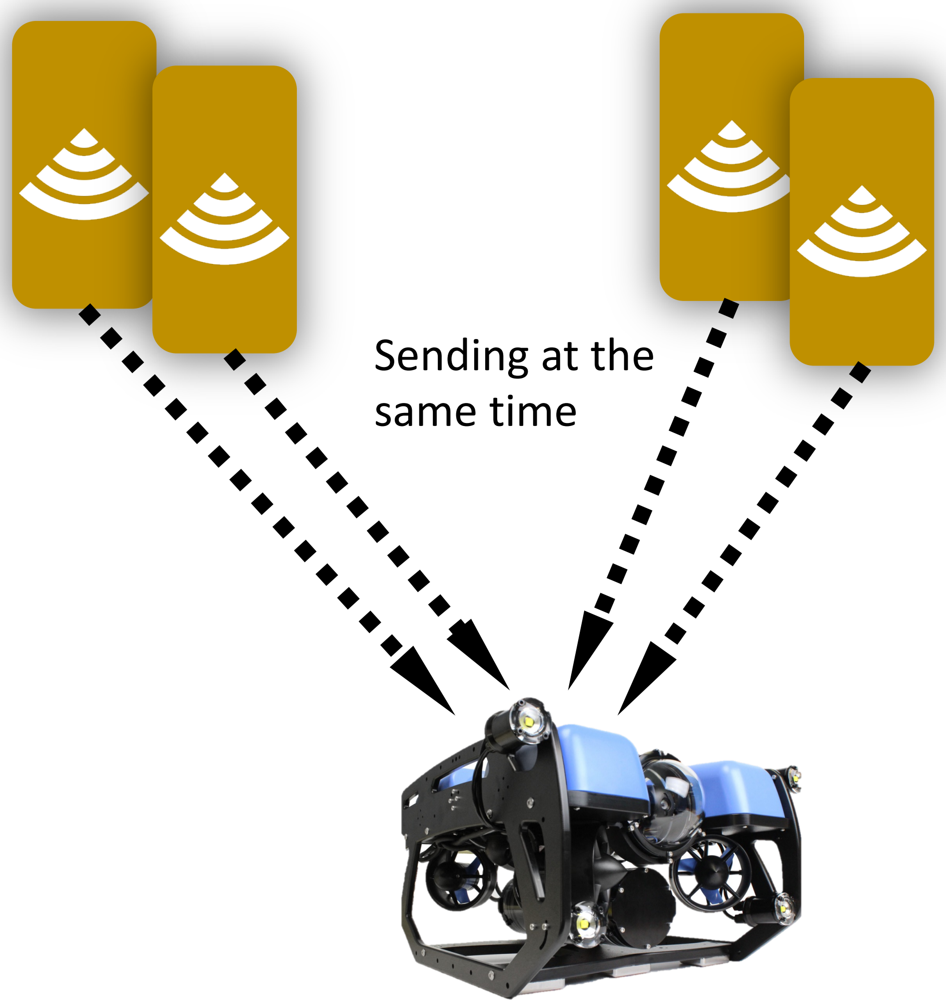
- The anchors apply the raised-cosine filter
- Used for pulse shaping of generated codes
- Impulse response is zero at $\forall nT, n > 0$
  → Eliminates intersymbol interferences (ISI)
  → filtered signal has **limited bandwidth**



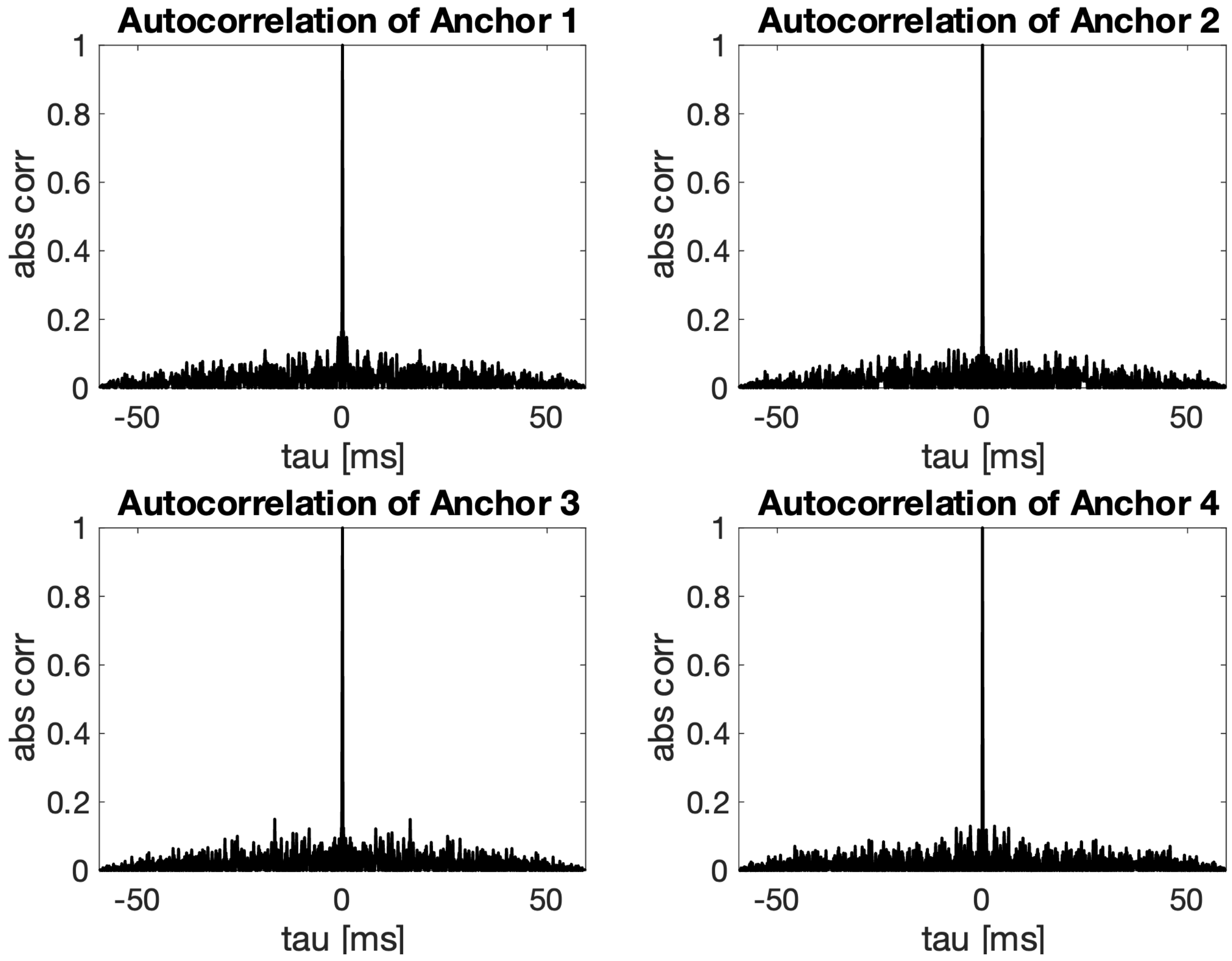


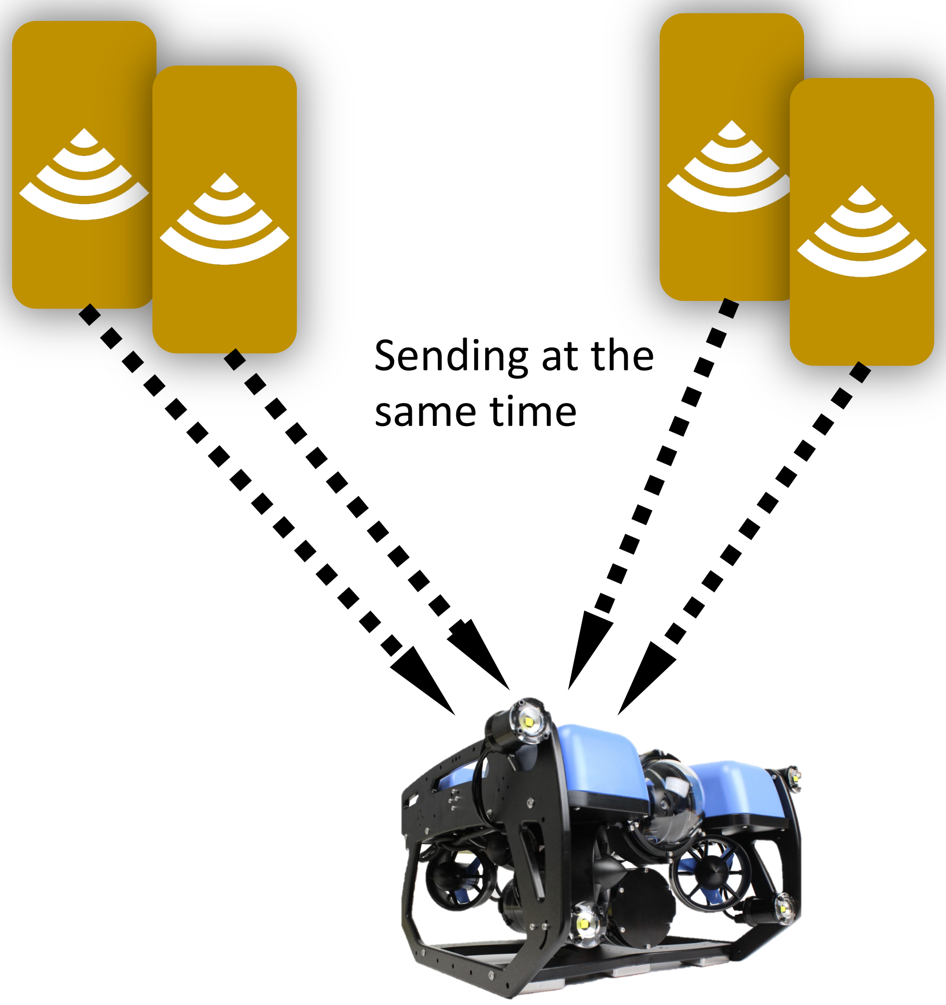
Principle – anchor codes



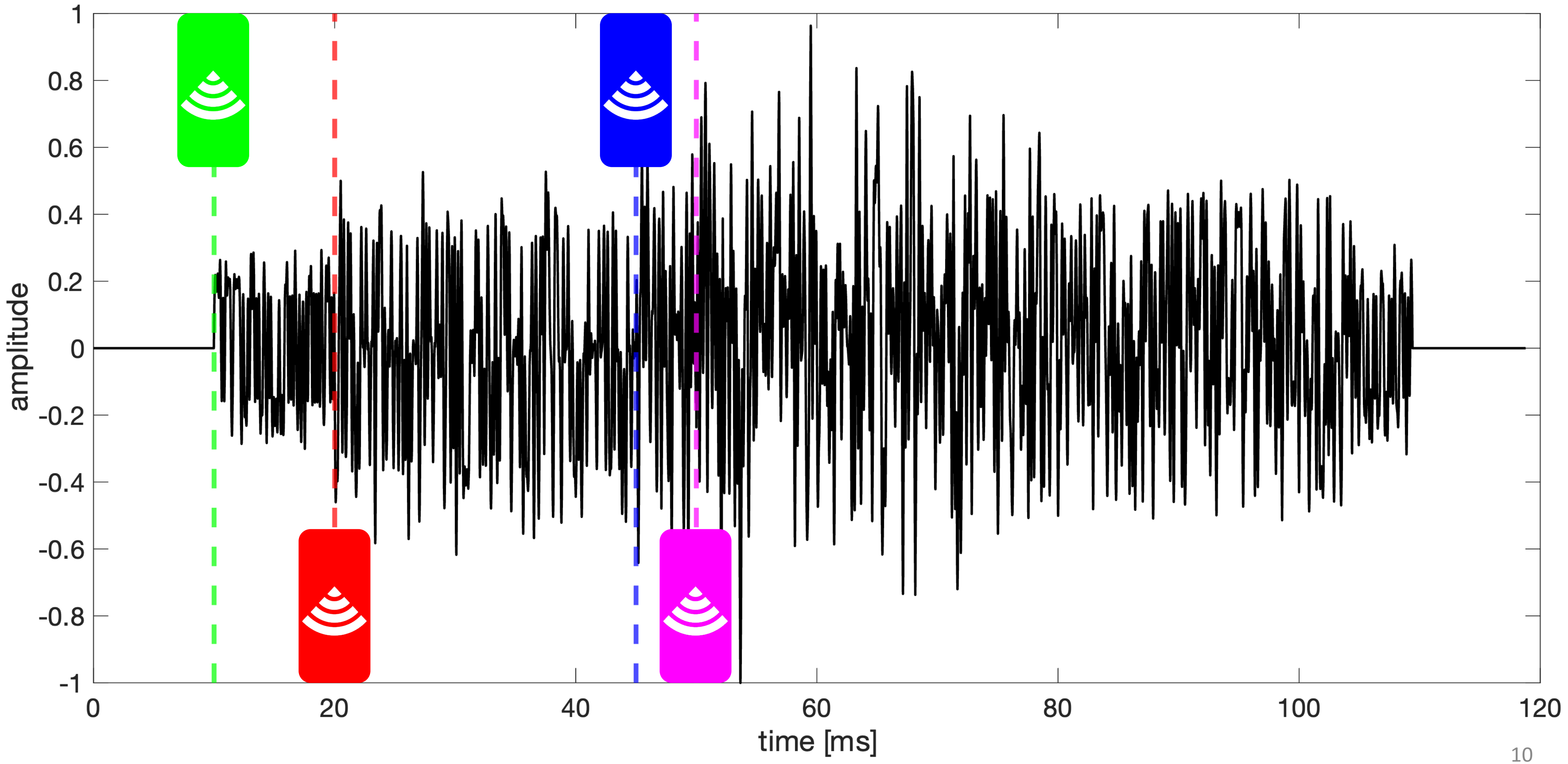


Principle – anchor codes





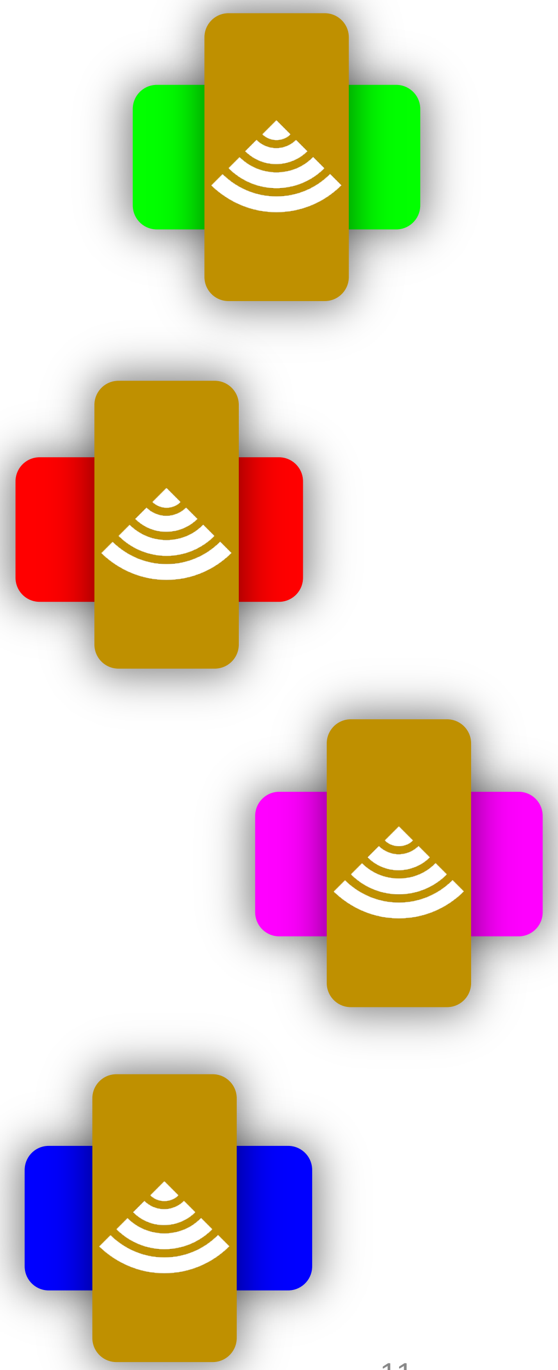
Principle – sum of codes



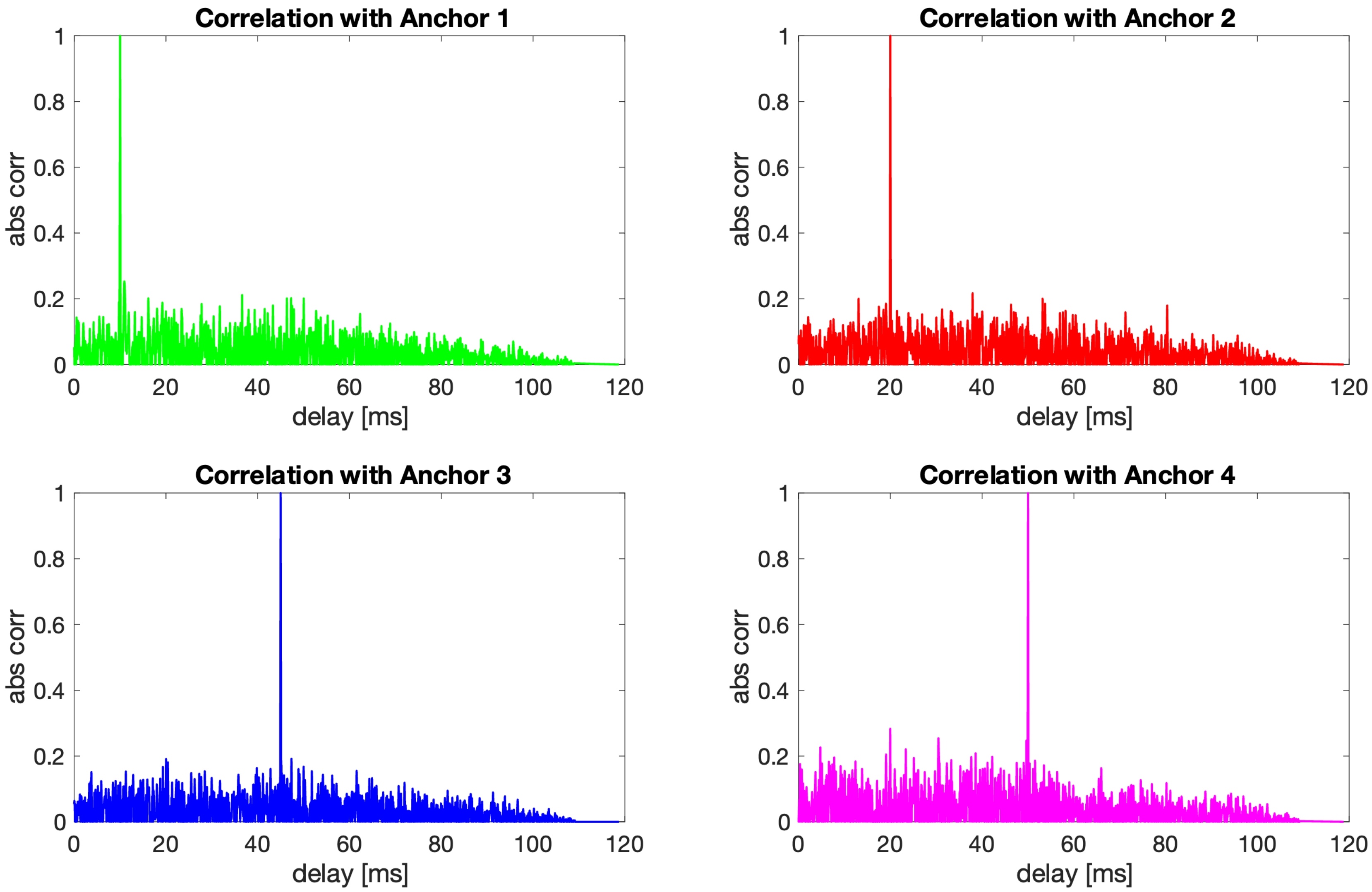
Principle – math of correlation

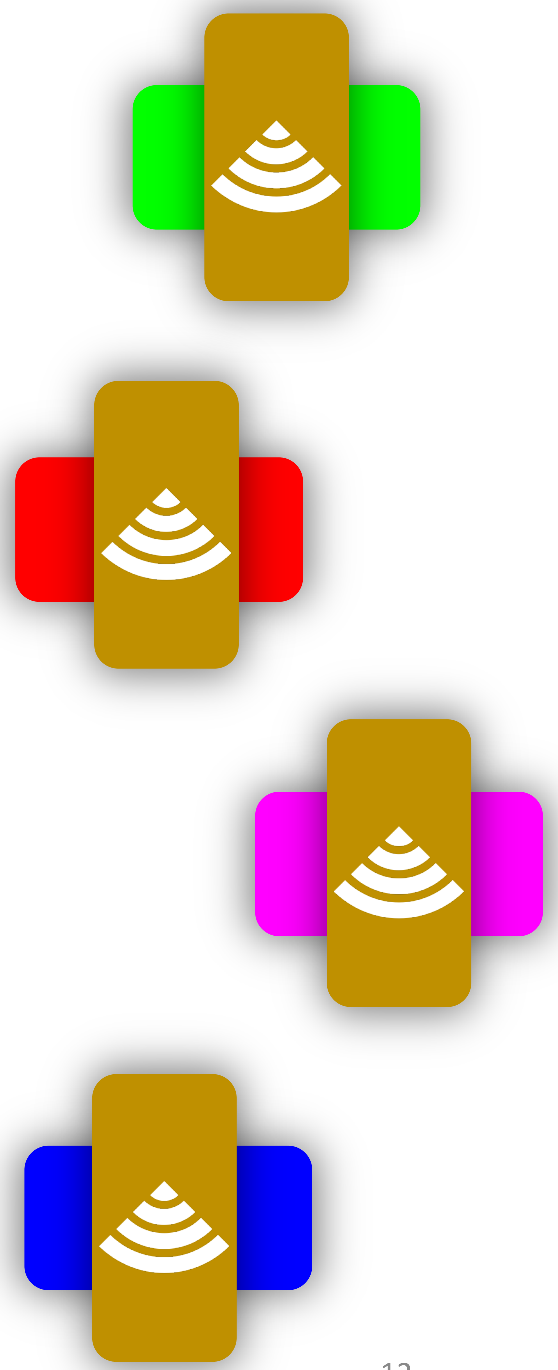
$$(A \otimes A_{recv})(\tau) = \int A(t) \cdot A_{recv}(t+\tau)dt$$

$$\Delta t = \underset{\tau \in [0,\infty]}{\arg\max} (A \otimes A_{recv})(\tau)$$

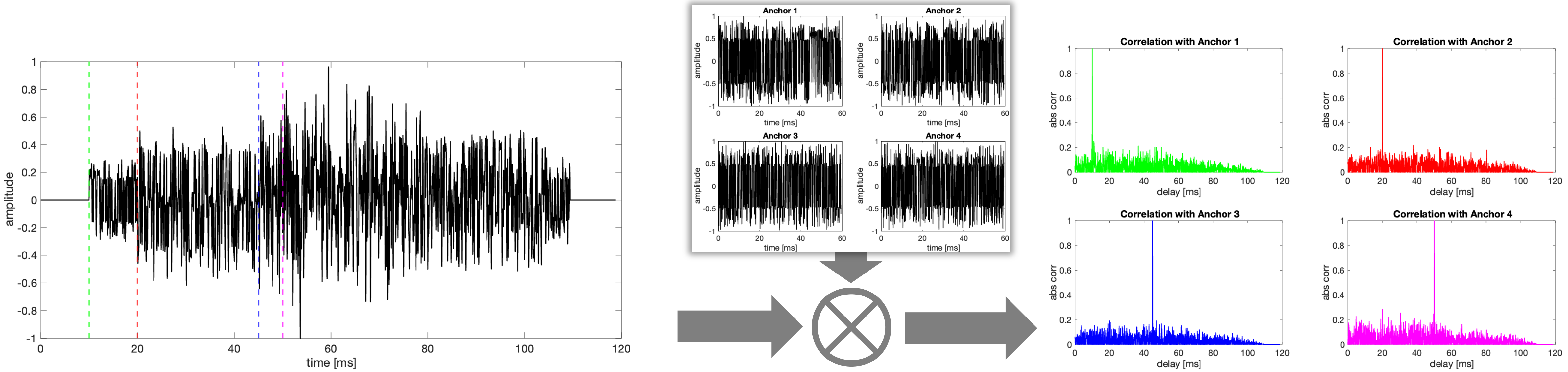


Principle – cross-correlation plots





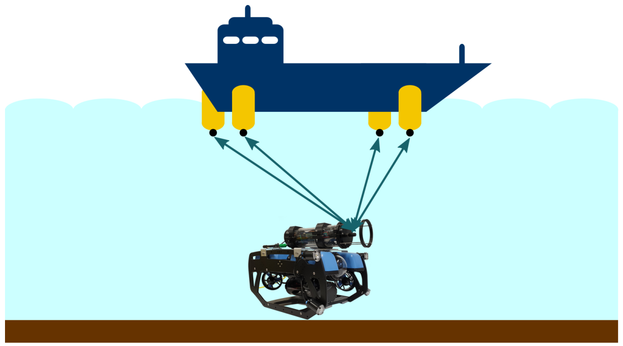
Principle – correlation



The maximum of the resulting correlation coefficients shows the time delay (TDOA – Time Difference of Arrival)

- **Questions**:
  - How can the relation between noise and peak be maximized?
  - How do certain parameters change this relation?
  - Can alternative PN Codes be used & are they even better?

Project Goals



- Research Study on orthogonal (random) codes, modulation & processing
  - Applying different orthogonal code concepts
  - Tweaking available parameters und collecting results
- Running different scenarios on available MATLAB simulation
- Development and Implementation of a localization system in Python
- Evaluation & Comparison of implemented Algorithms
- Real world evaluation
- Documentation of project

Roadmap

Phase I
06-22 to 7-22

- Initial familiarization
- Superficial Research on orthogonal code types
- Cross-correlation & orthogonality
- Motivational presentation

Phase II
07-09 to 09-22

- Analysis of relation between parameters
- Localization algorithms
- Selecting and testing different orthogonal codes
- Researching and Implementation in Python
- MATLAB Simulation

Phase III
09-22 to 12-22

- Documentation of Code and Research (LaTeX)
- Optimization of Scripts
- Correct mistakes in Code and Docs
- Final Evaluation
- Final presentation