



EXCELLABUST
EXCELLING LABUST IN MARINE ROBOTICS

Human robot interaction languages

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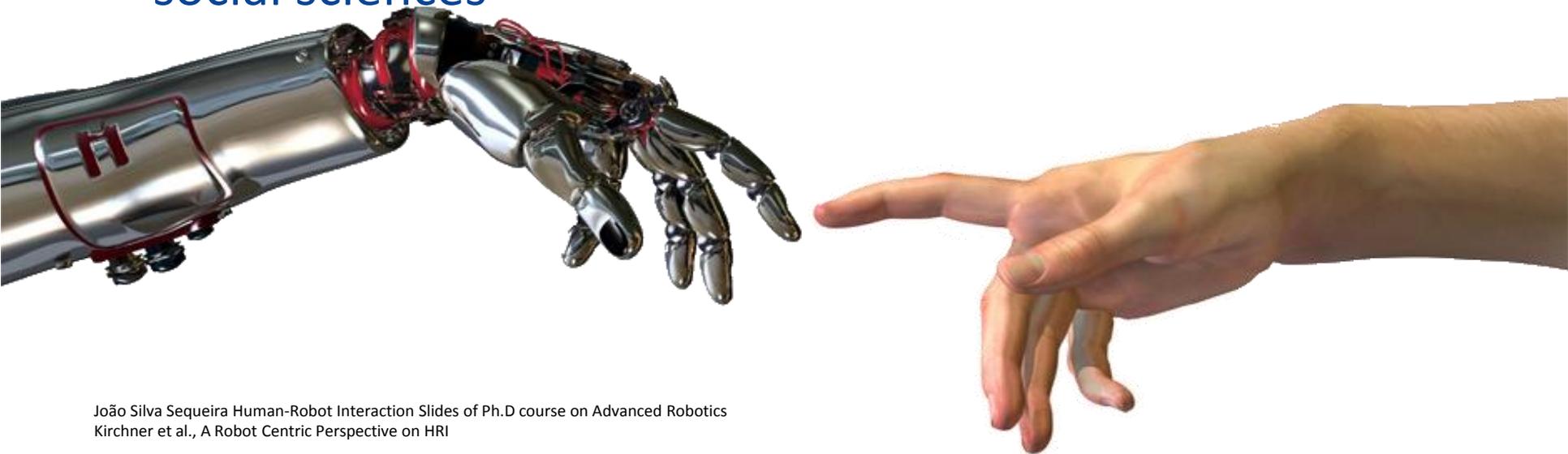


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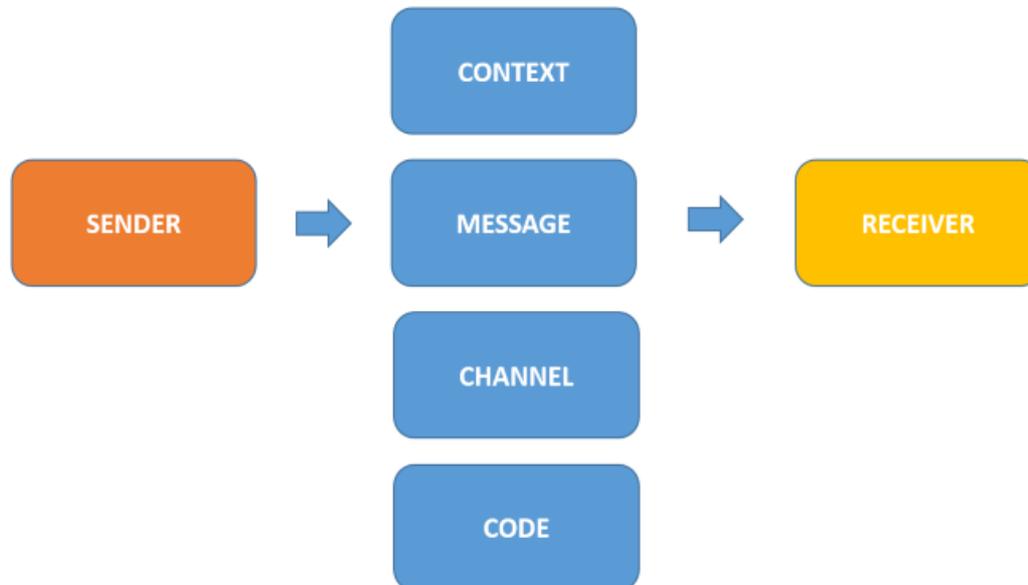
Human-robot interaction

- Robotics and HRI strictly correlated
- Rationale: usually you look at human to human relations and try to extrapolate HRI
- A multidisciplinary field with contributions from human-computer interaction, artificial intelligence, robotics, natural language processing (understanding), design and social sciences



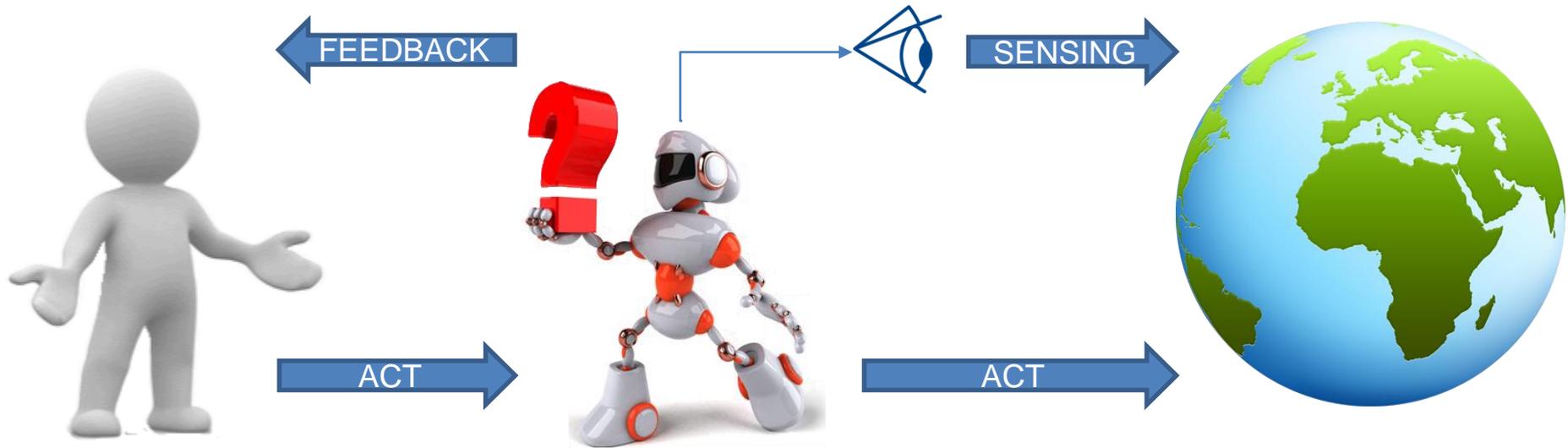
What is communication?

- Communication can be seen as a six factors process: an exchange of messages/information, within a context, through a channel and according to a code, between one system and another of the same nature or of different nature



A model for HRI

- Human acts upon a robot to complete a task. The robot provides feedback to the human (typically information such as task progress, performance, status) while it actively senses the ‘World’ in order to self-evaluate and self-correct (typical sensing information such as distance to target, rate of task completion for machine’s control/action strategy).
- Improve task performance and interaction



An example of HRI language: CADDIAN

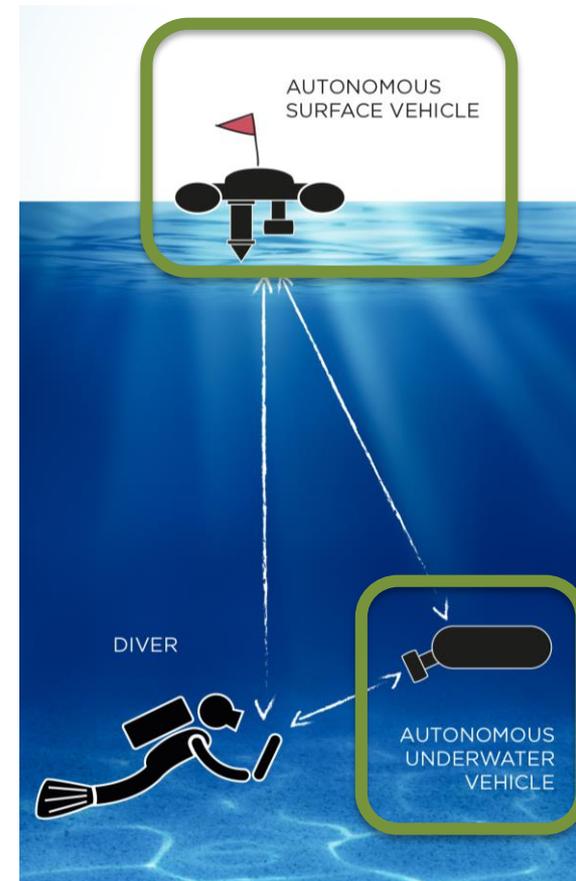
- CADDIAN has been developed inside the CADDY project, funded by the European Community's Seventh Framework Programme

PROBLEMS

- Divers (SCUBA, scientific, and technical) operate in harsh and weakly monitored environments
- Unexpected disturbances, technical malfunctions, or lack of attention can result in catastrophic consequences
- In order to face such situations, standard procedures suggest to pair up divers and to follow well defined rules to avoid the chance of accidents

SOLUTION

- The CADDY project replaces a human buddy diver with an **autonomous underwater vehicle** and adds a new **autonomous surface vehicle** to improve monitoring, assistance, and safety of the diver's mission.



A reliable and helpful robotic support vehicle

HOW

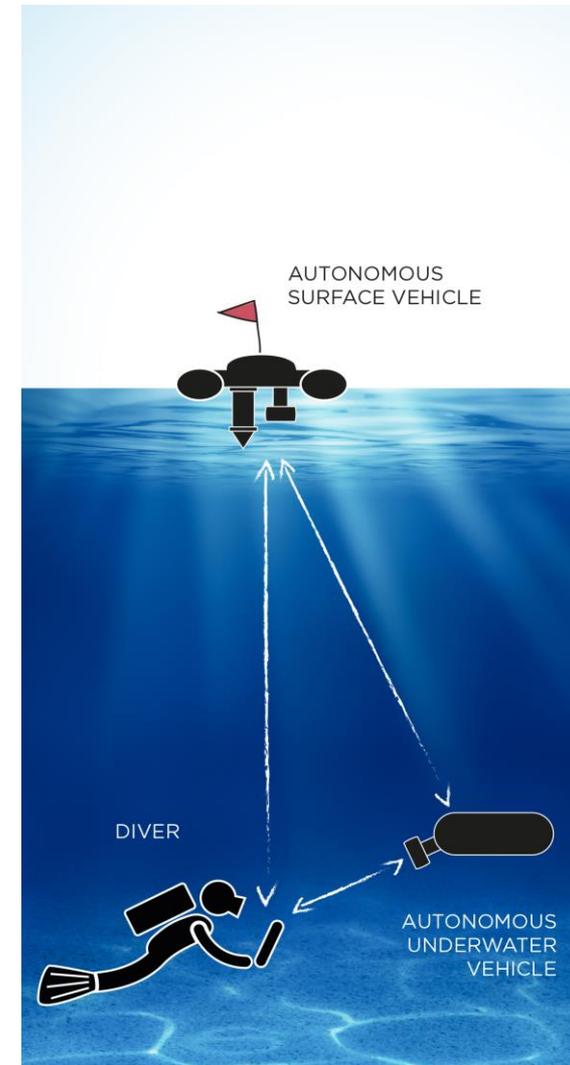
To provide a reliable and helpful robotic support vehicle:

- a communication and interaction methodology allowing the diver and the robot to actively cooperate for the fulfilment of the required tasks during the dives
- correct reception of messages between the diver and the underwater robot is essential for the success of the dive goals.

PROBLEMS

The underwater environment poses a set of technical constraints hardly limiting the communication possibilities:

- The strong attenuation of electro-magnetic waves makes the wifi/radio communications unreliable already at 0.5 m of depth
- optical communication has limited range due to water reverberation and scattering caused by suspended sediments



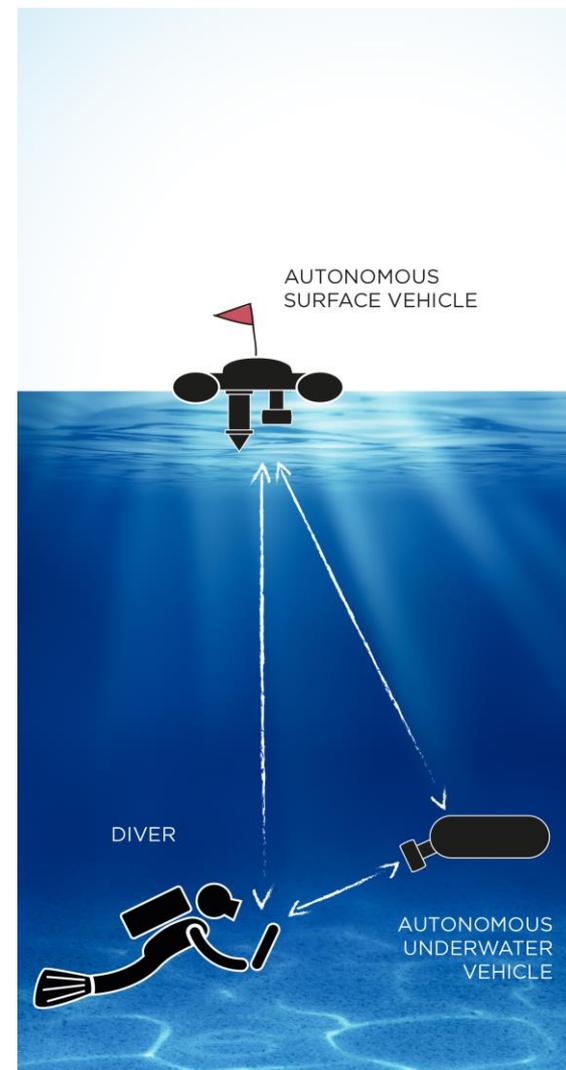
A reliable and helpful robotic support vehicle

ONE SOLUTION

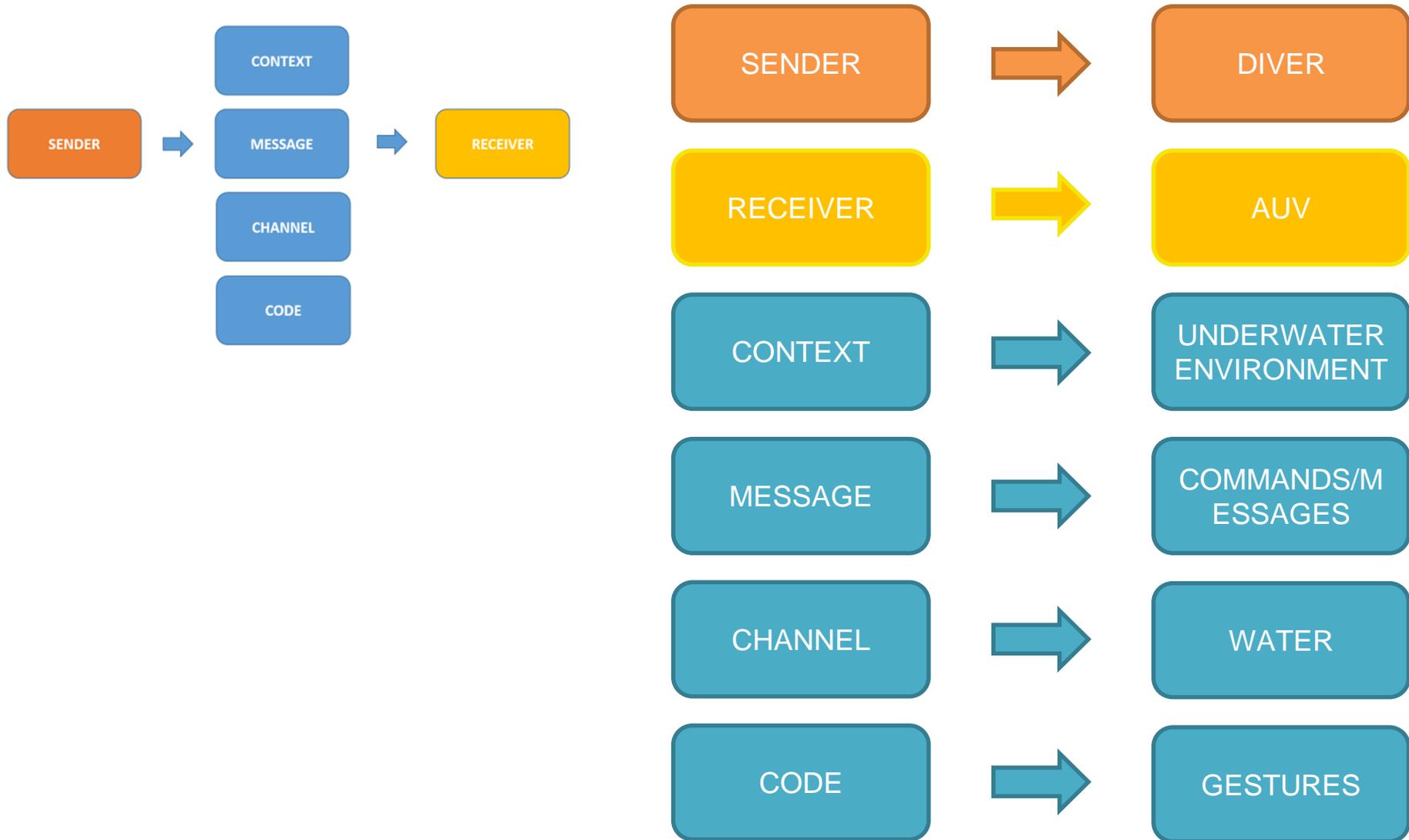
The most reliable solution for underwater communication is given by acoustic technology, with two main drawbacks: high prices of the devices and very low data transmission rate

SOLUTION PROPOSED

For such reasons and aiming to provide the diver with the most “natural” underwater communication method, the solution proposed is to develop a communication language based, in part, on the consolidated and standardized diver gestures that are commonly employed during professional and recreational dives



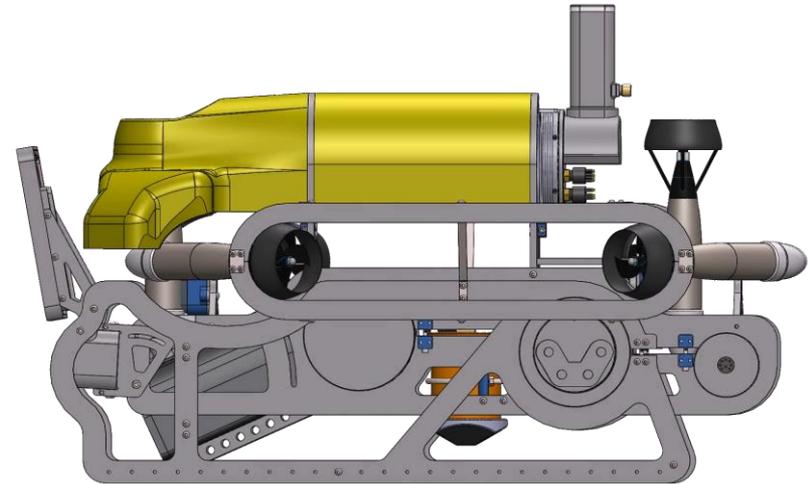
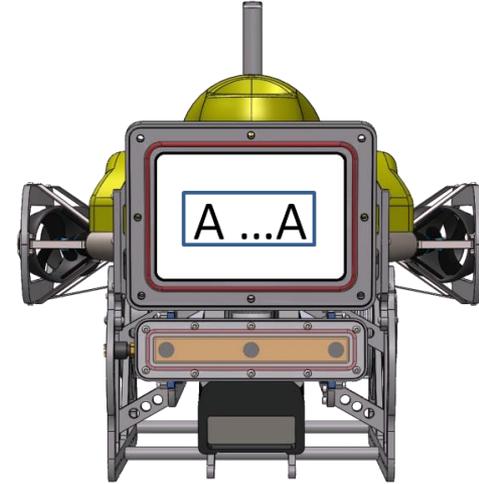
An example of HRI language: CADDIAN



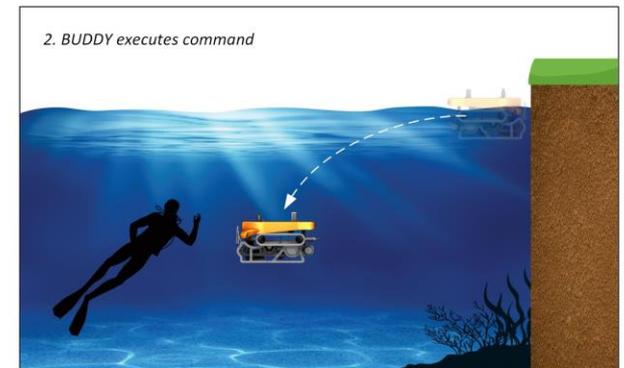
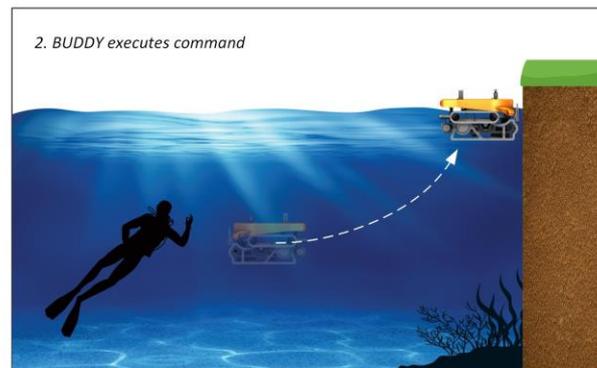
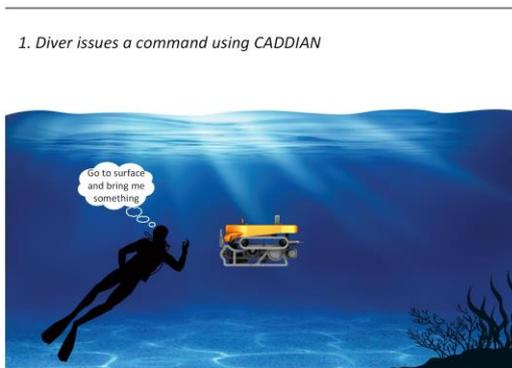
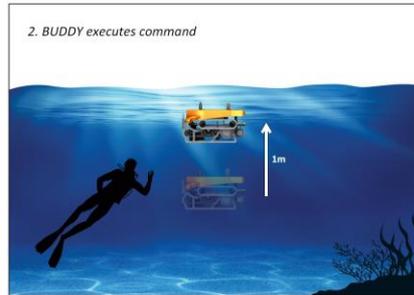
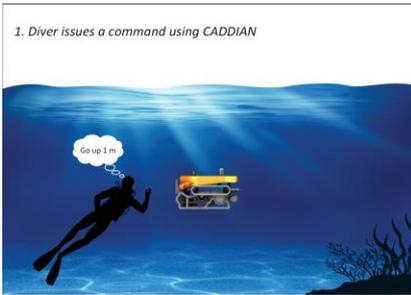
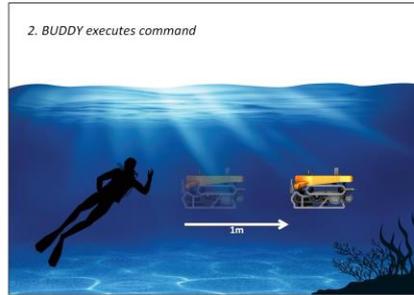
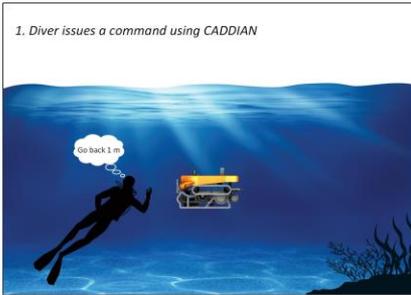
Scenario: actors

Understand capabilities

- Sensing
- Feedback



Scenario: tasks





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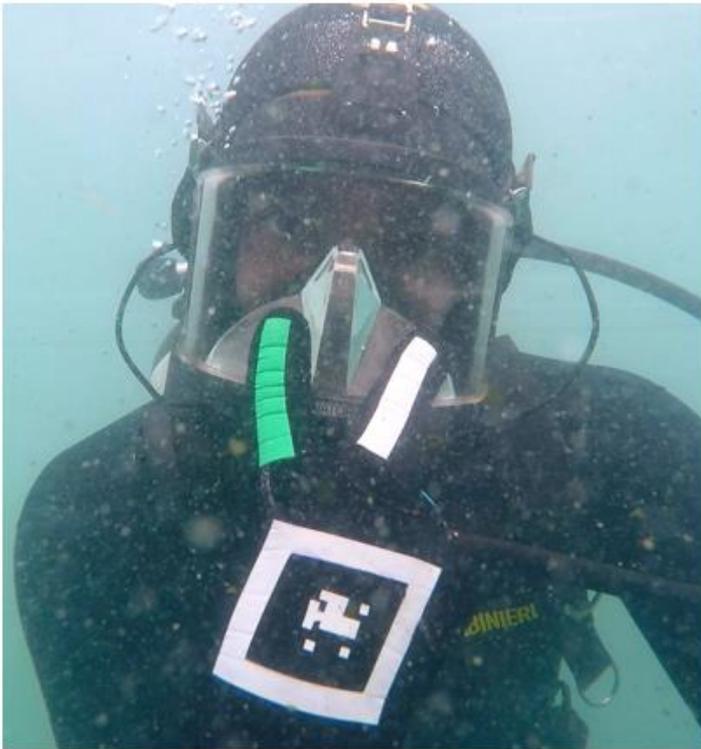
Gestures: first problem

- A very clever idea, but.... How do I write a document describing grammar and syntax with gestures?

| | | | | | | | |
|---|--------|---|--|----|--|---|----|
| A | | H | | N | | U | |
| B | | I | | O | | V | |
| C | or | J | | P | | W | |
| D | | K | | Q | | X | |
| E | or or | L | | R | | Y | or |
| F | | M | | S | | Z | |
| G | | T | | SH | | | |

Morphism I choose you!

- Gestures have been mapped with easily writable symbols such as the letters of the Latin alphabet/numbers/words etc.



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CADDIAN in short

- Language strictly context dependent
- Scenario (actors and missions) → list of commands
- Currently fifty-two:
 - Problems (9)
 - Movement (at least 13)
 - Interrupt (4)
 - Setting variables (10)
 - Feedback (3)
 - Works/tasks (at least 13)



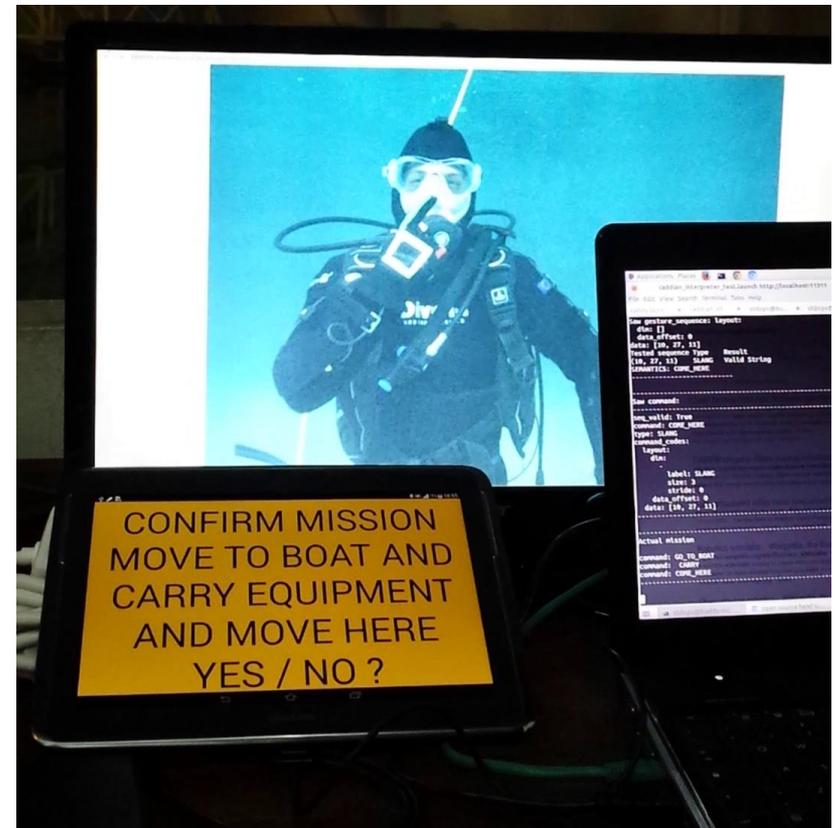
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Communication Protocol

Basic unit of the language defined¹, list of commands/messages identified: we need a set of rules to exchange information → a communication protocol with errors handling

- The diver teaches CADDY the mission to be performed and CADDY, before starting it, repeats what it understood waiting for confirmation from the diver.
- At least three statuses:

- IDLE
- BUSY
- ERROR



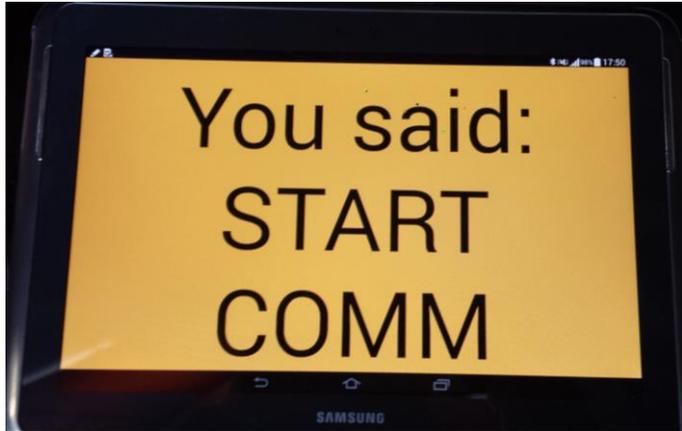
Mission confirmation

¹ see "analogy" among phoneme, grapheme and chereme



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Communication Protocol



Instant feedback per gesture issued



Discerning status



- Every action and every error are logged (disaster recovery, optimization)
- Protocol ensures the interrogability of the robot
 - The diver can understand if the task / mission entrusted to CADDY has been terminated.
 - The diver can query CADDY on the progress of a lengthy mission.

What now?

- ✓ Basic unit of the language: gestures
- ✓ List of commands derived from scenario (actors and tasks)
- ✓ Communication protocol
- ✓ ???????

We need to describe how to put gestures together to say something

How to describe a language: formal way

- The language up to now described is a set of strings of finite length constructed over a finite alphabet Σ and consequently can be defined as a formal language. A formal language can be described by a formal grammar.
- set of strings of finite length = a list of gestures in a given order which means something
- finite alphabet Σ = a finite set of gestures

A formal grammar G is a 4-tuple:

$$G = \langle \Sigma, N, P, S \rangle$$

- $\Sigma = \{A, B, C, \dots Z, \forall, \text{const, limit, check}, \dots, 1, 2 \dots\}$
- N = non-terminal symbols (syntactic categories)
- P = productions or rules (e.g. $A \rightarrow \beta$) where $\beta \in (\Sigma \cup N)^*$
- S = start symbol



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Formal language

- The language L_G generated by grammar G is the set of strings composed of terminal symbols that can be derived from the start symbol S .

$$L_G = \{w / w \text{ is in } \Sigma^* \text{ and } S \rightarrow^* w\}$$

Syntax and Backus-Naur Forms

What is a production? $A \rightarrow \beta$

`<declaration> ::= var <variable list> : <type> ;`

- This notation is called Backus-Naur Form (BNF) and is used to describe the syntax of a language.
- The syntax is a set of rules to build the messages: one way to describe it is a BNF



CADDIAN: context-free grammar

- The grammar of CADDIAN is a **context-free grammar**¹ by definition because on the left side of the productions we find only one non-terminal symbol and no terminal symbol
- The language is an infinite language given that the first production uses recursion: this can also be seen from the dependency graph of the non-terminal symbols (the graph contains a cycle).

¹Context-free grammars generate context-free languages which have good features (closed for Union operation, concatenation, Kleene star etc. Formally, the set of all context-free languages is identical to the set of languages accepted by pushdown automata which are used in **parser design**

J. E. Hopcroft, R. Motwani and J. D. Ullman (2001): Context-Free Grammars and Languages, in Idem, Introduction to Automata Theory, Languages and Computation. Addison-Wesley, Boston, pp. 169–217

D. Jurafsky and J. H. Martin (2014): Context-Free Grammars, in Idem, Speech and language processing. Pearson Education, Edinburgh Gate, pp. 397-402.



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Beware of the syntax!

However a message built according to the rules of syntax assures us that the message belongs to our language, but not that the message has a meaning.

“David eats the sun”

In other words, only syntax, and not semantics, is addressed by the grammar.

Example: natural numbers

$\Sigma = \{1,2,3,4,5,6,7,8,9,0\}$

BNF

$\langle S \rangle ::= \langle \text{num} \rangle$

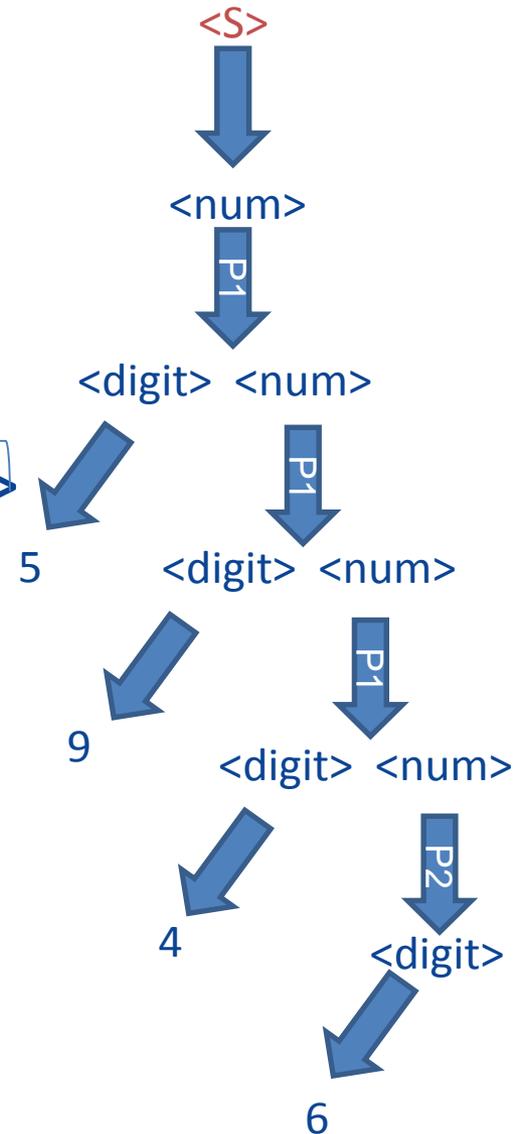
$\langle \text{num} \rangle ::= \overbrace{\langle \text{digit} \rangle \langle \text{num} \rangle}^{P1} \mid \overbrace{\langle \text{digit} \rangle}^{P2}$

$\langle \text{digit} \rangle ::= 1 \mid 2 \mid 3 \mid 4 \mid 5 \mid 6 \mid 7 \mid 8 \mid 9 \mid 0$

Is 5946 a natural number?

Does it belong to our language?

$\langle S \rangle \rightarrow^* 5946$





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CADDIAN syntax I

$\langle S \rangle ::= A \langle \alpha \rangle \langle S \rangle \mid \forall$

$\langle \alpha \rangle ::= \langle \text{slang} \rangle \mid \langle \text{agent} \rangle \langle \text{m_action} \rangle \langle \text{object} \rangle \langle \text{place} \rangle \mid$

$\langle \text{set_variable} \rangle \mid \langle \text{feedback} \rangle \mid \langle \text{interrupt} \rangle \mid \langle \text{work} \rangle \mid \langle \text{questions} \rangle \mid$
 $\emptyset \mid \Delta$

$\langle \text{slang} \rangle ::= \langle \text{quantity} \rangle \mid B_2 \mid B_3 \mid C_1 \mid B \mid \mathfrak{b} \mid P_g \mid \text{const} \mid E \mid K \mid V \mid U$
 $\mid \text{low} \mid \text{reserve}$

$\langle \text{agent} \rangle ::= I \mid Y \mid W$

$\langle \text{m_action} \rangle ::= T \mid C \mid D \mid F \mid G \langle \text{direction} \rangle \langle \text{num} \rangle$

$\langle \text{direction} \rangle ::= \text{forward} \mid \text{back} \mid \text{left} \mid \text{right} \mid \text{up} \mid \text{down}$

$\langle \text{object} \rangle ::= \langle \text{agent} \rangle \mid \Lambda$

$\langle \text{place} \rangle ::= B \mid P \mid H \mid \Lambda$

$\langle \text{feedback} \rangle ::= \text{ok} \mid \text{no} \mid U \mid \Lambda$



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CADDIAN syntax II

$\langle \text{set_variable} \rangle ::= S \langle \text{quantity} \rangle \mid L \langle \text{level} \rangle \mid P \mid L_1 \langle \text{quantity} \rangle \mid A_1 \langle \text{quantity} \rangle$

$\langle \text{quantity} \rangle ::= + \mid -$

$\langle \text{level} \rangle ::= \text{const} \mid \text{limit} \mid \text{free}$

$\langle \text{interrupt} \rangle ::= Y \langle \text{feedback} \rangle D$

$\langle \text{work} \rangle ::= \text{Te} \langle \text{area} \rangle \mid \text{Te} \langle \text{place} \rangle \mid \text{Fo} \langle \text{area} \rangle \mid \text{Fo} \langle \text{place} \rangle \mid \text{wait} \langle \text{num} \rangle \mid \text{check}$

$\mid \langle \text{feedback} \rangle \text{carry} \mid \text{for} \langle \text{num} \rangle \langle \text{works} \rangle \text{end} \mid \text{turn} \mid \Lambda$

$\langle \text{works} \rangle ::= \langle \text{work} \rangle \langle \text{works} \rangle \mid \Lambda$

$\langle \text{area} \rangle ::= \langle \text{num} \rangle \langle \text{num} \rangle \mid \langle \text{num} \rangle$

$\langle \text{num} \rangle ::= \langle \text{digit} \rangle \langle \text{num} \rangle \mid \Psi$

$\langle \text{digit} \rangle ::= 1 \mid 2 \mid 3 \mid 4 \mid 5 \mid 6 \mid 7 \mid 8 \mid 9 \mid 0$

$\langle \text{questions} \rangle ::= U \langle \text{question} \rangle$

$\langle \text{question} \rangle ::= B \mid A_1 \mid \mathfrak{b} \mid P_g$



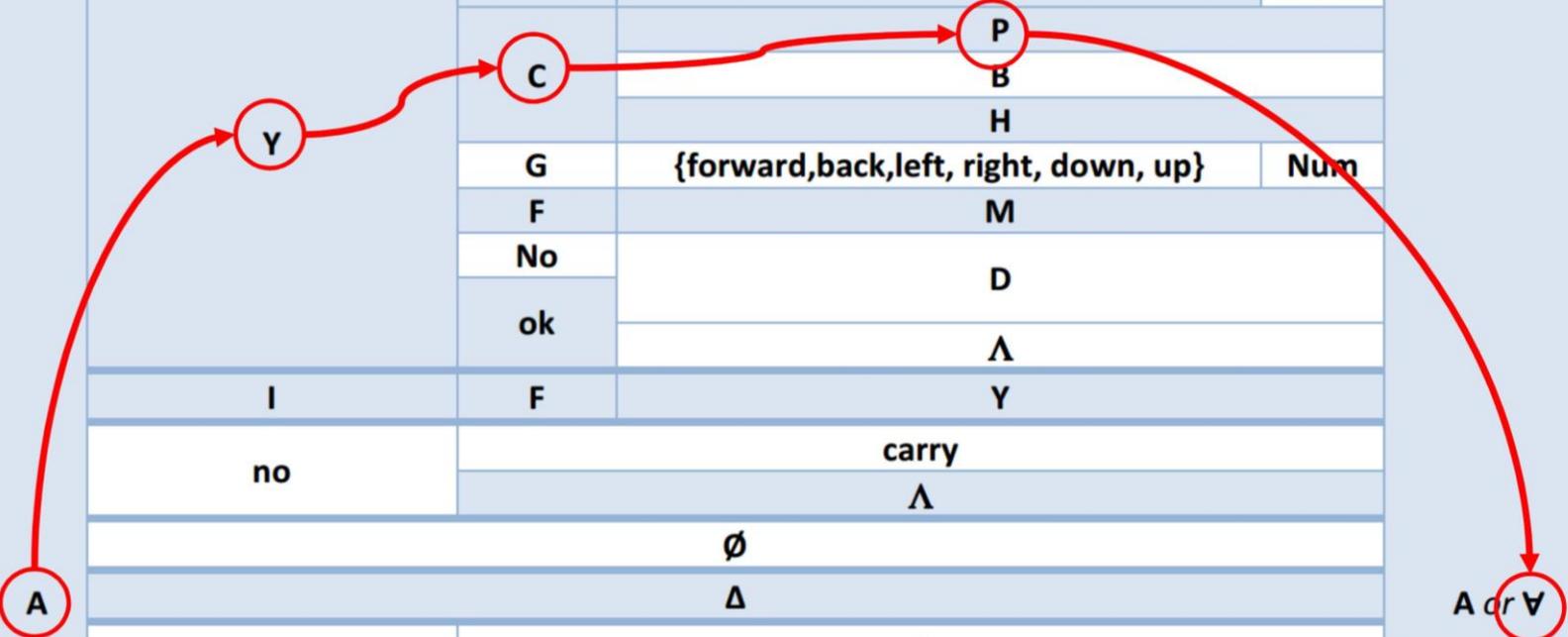
Translation table: excerpt

| | Message/Command | Translation into CADDY language |
|-----------------|---|---|
| Problems | I have an ear problem | $A E \forall$ |
| | I am out of air [air almost over] | $A B_2 \forall$ |
| | I'm cold | $A C_1 \forall$ |
| | I'm out of breath | $A B_3 \forall$ |
| | Something is wrong [on me] | $A \bar{b} \forall$ |
| | Something is wrong, danger [environment] | $A P_g \forall$ |
| | I have a cramp | $A K \forall$ |
| I have vertigo | $A V \forall$ | |
| Movement | Take me to the boat | $A Y T M B \forall$ $A I F Y$ $A Y C B \forall$ |
| | Take me to the Point of interest | $A Y T M P \forall$ $A I F Y$ $A Y C P \forall$ |
| | Return/come to X $X \in \{\text{point of interest, boat, here}\}$ i.e. go to point of interest, boat, come here | $A Y C P \forall$ $A Y C B \forall = A B \forall$ $A Y C H \forall$ |
| | Go X Y $X \in \{\text{forward, back, left, right, up down}\}$ $Y \in \mathbb{N}$ | $A Y G$ forward $n \forall$, $A Y G$ back $n \forall$, $A Y G$ left $n \forall$, $A Y G$ right $n \forall$, $A Y G$ up $n \forall$, $A Y G$ down $n \forall$ |
| | I follow you | $A I F Y \forall$ |
| You follow me | $A Y F M \forall$ | |

Table of possible sequences

'Come to the point of interest' \leftrightarrow A Y C P V

| | | V | | |
|--|---------------------------------------|--------------------------------------|---|-----|
| | | T | M | B |
| | | P | | |
| | | C | P | |
| | | | B | |
| | | | H | |
| | G | {forward,back,left, right, down, up} | | Num |
| | F | M | | |
| | No | D | | |
| | ok | Δ | | |
| | I | F | Y | |
| | no | carry | | |
| | | Δ | | |
| | | \emptyset | | |
| | | Δ | | |
| | S or L ₁ or A ₁ | + | | |
| | | - | | |



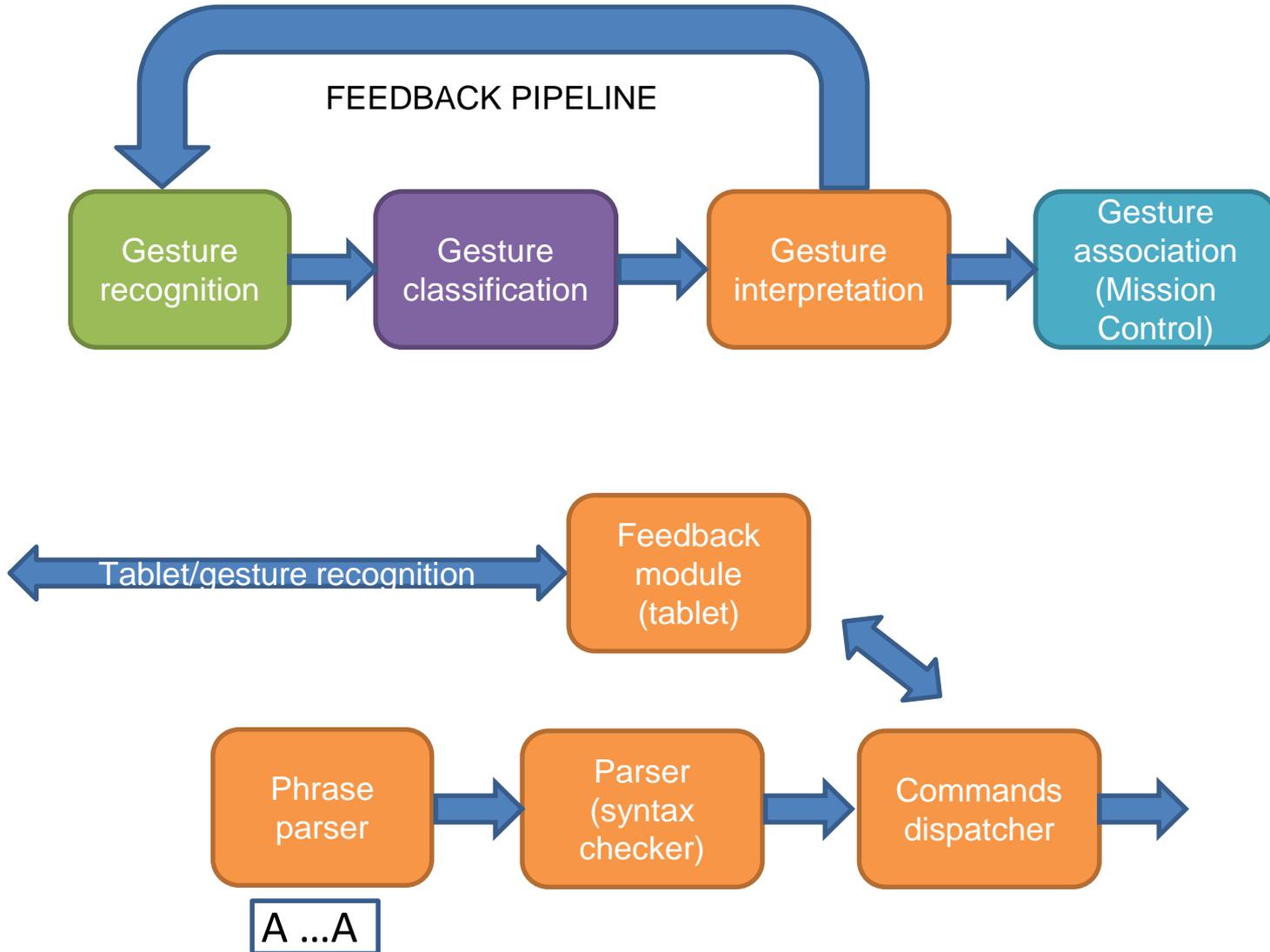


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Graph



The big picture





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Parsing a language I

Defined a language, a parser/syntax checker has to be developed and integrated within the robot to accept correct commands/messages.

For CADDIAN:



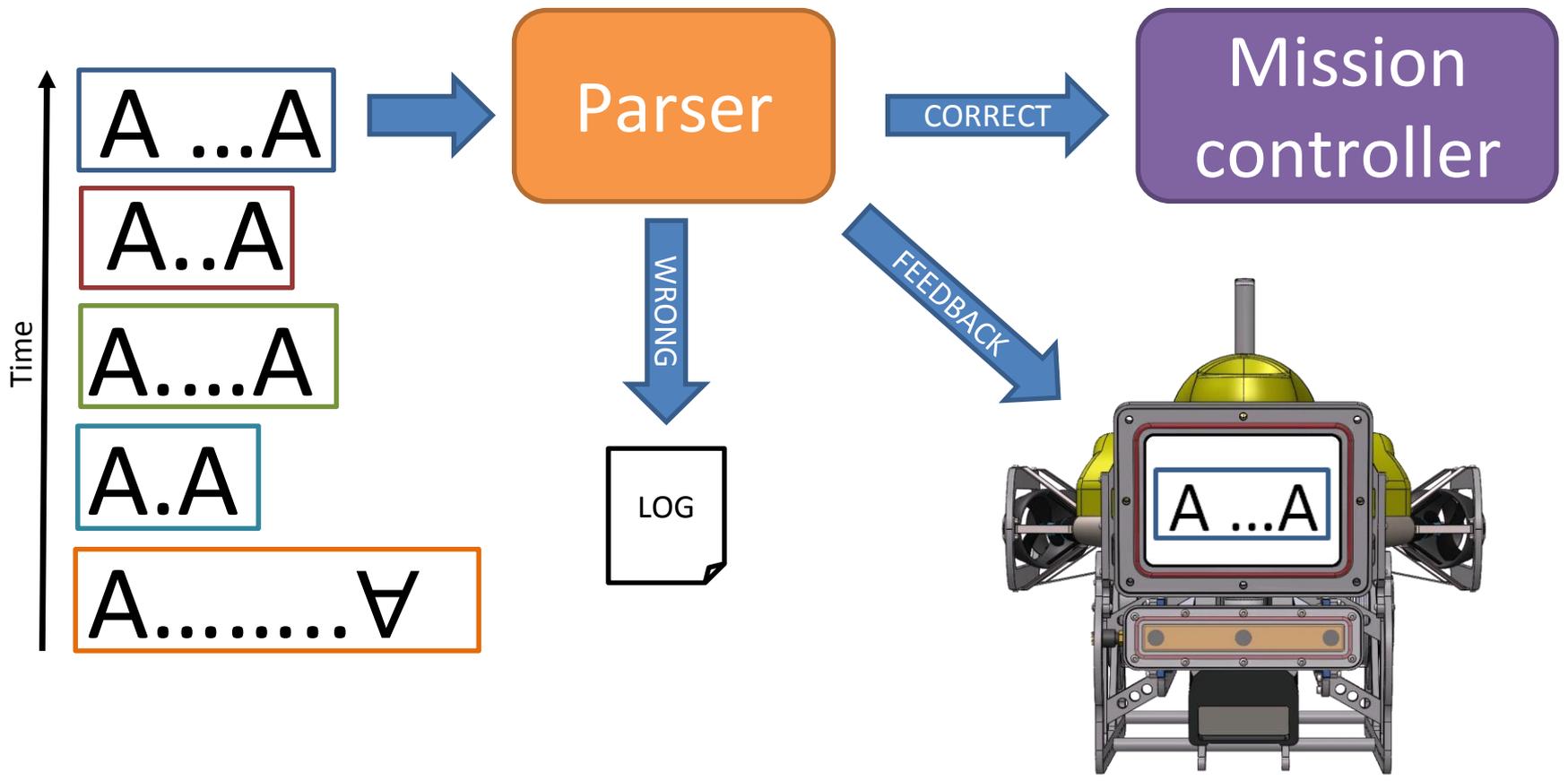
MISSION DIVIDED INTO
MESSAGES



A Mission (a sequence of commands/messages) is segmented into messages.

Parsing a language II

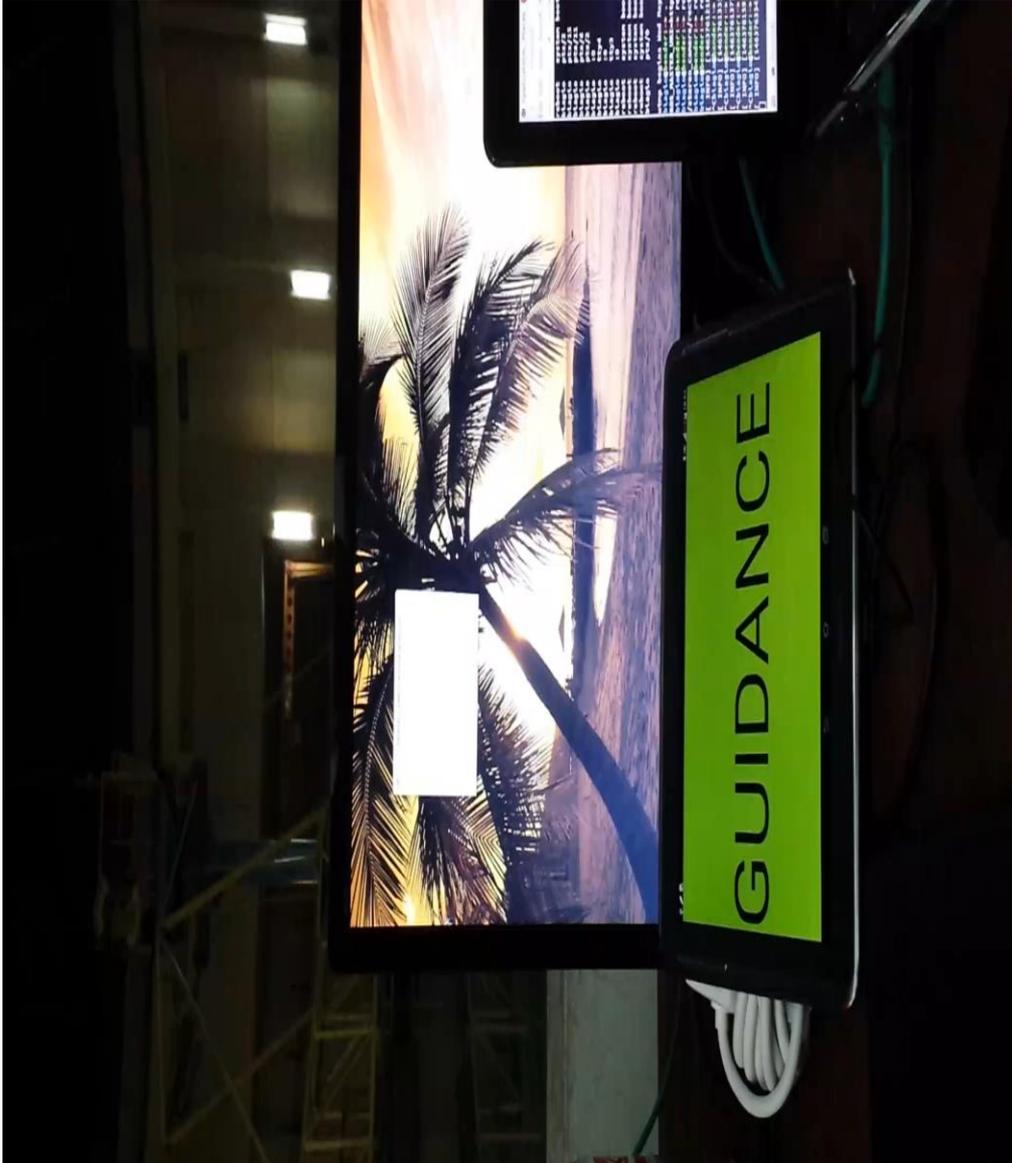
The syntax checker (parser) parses each message passing to mission controller the sequence of commands to be executed.





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Putting all together



Zagreb May 2016 –
Software Integration
workshop



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ROBOT DONE, AND THE HUMAN?

Teach and learn HRI languages

Create exhaustive document about the language

End of communication

CADDIAN written form (symbol): 

Semantics: end of communication

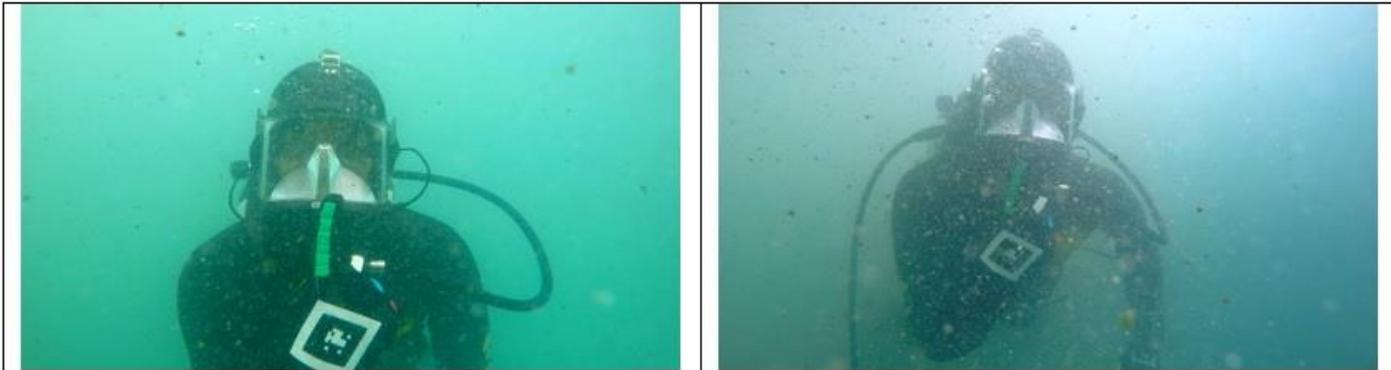
Type: static gesture

Hands: R

Palm/back: back to camera

Fingers: 2R

Notes: none



Teach and learn HRI languages

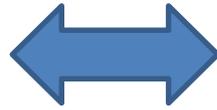


- Teaching and acceptance: surveys and feedback
- HRI involves social sciences
- Tips: mental association
- ‘Take a photo’ ↔ tripod.

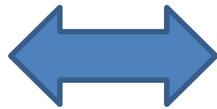


Teach and learn HRI languages

‘Do a mosaic’ ↔ ‘think of holding a map’



‘End of communication’ ↔ ‘Shut up, you AUV!’





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EVALUATION



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Dictionary I





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Dictionary II

1

2

3

4

5

6

7

8

9

0

Close_number

ψ

Boat B

Start_message

A

End_comm V

Come_Here H



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Missions

1. “Go up 1 meter”: A up 1 Ψ \forall
2. “Go down 1 meter”: A down 1 Ψ \forall
3. “Go back 1 meter”: A back 1 Ψ \forall
4. “Take a photo” mission: A Fo \forall
5. “Do a mosaic” mission: A Te 2 Ψ 4 Ψ \forall
6. Complex mission:
“Go to boat, bring me something (carry equipment), come back here”
A B A carry A H \forall



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Evaluation

DIVER EXPERIENCE YES NO AGE: GENDER M F

MISSION 1:

CORRECT

INCORRECT

-WRONG GESTURES:

MISSION 2:

CORRECT

INCORRECT

-WRONG GESTURES:

MISSION 3:

CORRECT

INCORRECT

-WRONG GESTURES:



Evaluation

MISSION 4:

CORRECT

INCORRECT

-WRONG GESTURES:

MISSION 5:

CORRECT

INCORRECT

-WRONG GESTURES:

MISSION 6:

CORRECT

INCORRECT

-WRONG GESTURES:

Thanks!



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