



Goal:

The goal of this project is to provide a framework in which you can apply your knowledge of microcontrollers and multi-processor communications to a task that will provide an enjoyable experience for the users and the observers. Because of the rather unique situation that we find ourselves in this quarter, we are able to leverage the power of the Internet to make this project a reality!

Purpose:

The underlying purpose of this project is to provide you with an opportunity to gain experience in integrating all that you have learned in the ME218 course sequence, with an emphasis on the new material in ME218c.

Background:

The year is 2180. In its race to Mars, humanity has once again laid bare its darker side, with several factions launching competing pioneer spacecraft toward the red planet. The discovery and exploitation of Obtainium in the mid 21st century yielded vast wealth that was promptly funneled in to the Mars Terraforming Project, and Mars is no longer the frigid desert planet it once was. While successful in filling all of Mars' low-lying terrain with water, these aren't the azure seas of Terra, but turbid, rusty seas—at least until the iron oxides have time to settle to the seafloor. Faced with small amounts of remaining dry land, and a much more arable oceanic environment, settlers took to the seas to establish their footholds. Competition for scarce resources is a daily affair and, due to the aquatic nature of the new Mars, conflicts take place mostly at sea. Memories of colonial-era Earth are resurrected as inspiration for the prevailing faction cultures.

The Task:

Design and build a submarine, composed of a Tactical Ordained Range Potatoes with Extremely Disastrous Output station (TORPEDO station), a Console of Naval Navigation (CONN station), and a Sound Navigation And Ranging station (SONAR station), each constructed and operated by one of your crewmembers. All of the submarines will navigate in the ocean¹. During games, each team, by coordinating their stations, will attempt to control their submarine to locate, attack, and attempt to sink the other submarines, and win the battle for Mars naval supremacy.

Specifications

General:

- Each member of each team will construct a station—either the CONN, SONAR, or TORPEDO.
- A team shall coordinate the design and construction of each station such that each team member's station can assume the role of CONN, SONAR, or TORPEDO via run-time configuration.
- The crew of each team will act in a coordinated way to control the navigation, sensing, and weapons capabilities of their submarine using their respective stations.
- The submarines are self-powered unmanned submarines capable of silently patrolling the Martian seas while seeking and destroying other submarines towards conquering all of Mars.
- The stations are I/O devices which control various aspects of the submarine functions, and contain audio modems to communicate between the various stations and submarines.

¹Virtually, on Discord.

Basic Game Play:

- A game round will be a battle royale among all operational submarines.
- The game will proceed in a turn-based fashion, beginning with turn 0.
- During each turn, each station will be permitted to initiate one action which that station is capable of.
- During each turn, each station will also be permitted to respond, if required, to any events requiring a response.
- The goal of the game is for each submarine to locate and destroy all other submarines to emerge victorious.
- The game ends when only one submarine remains undamaged in the ocean, or when people get bored.

The Ocean:

- The ocean comprises a section of Mare Utopia², an ocean in our imagination³, measuring approximately 150 km in diameter (see Figure 1).
- The ocean is divided into a series of hexagonal cells, with the cell at the center having coordinates (7,7,7). Each cell measures 10 km across opposite faces.
- There are three coordinate axes: x , motion to the right; y , corresponding to motion up and to the left; and z , corresponding to motion down and to the left. Coordinates within the grid are defined such that $x+y+z = 21$, $0 \leq x, y, z \leq 14$. Moving from one cell to an adjacent cell will always involve incrementing exactly one coordinate and decrementing exactly one other coordinate⁴.
- At the beginning of each game the participating submarines will be initialized to an assigned starting cell (TBD) in the ocean.
- Each cell can be occupied by more than one submarine or other relevant object.

The Submarines and Stations:

- Each submarine is a collection of stations constructed and operated by a team of three.
- Each submarine occupies a single cell, and has an orientation pointing normal to one of six edges of the cell. That is, the possible headings are Up, RightUp, RightDown, Down, LeftDown, and LeftUp⁵.
- Each submarine is capable, on each turn, of turning in place, moving to the adjacent cell in the direction it is facing, or not moving at all, by operating the controls of the CONN station.
- Each submarine is capable of launching ordnance in the direction it is pointing, initiated by the TORPEDO station.
- Each submarine is capable of sensing its surroundings by sending a variety of sounding actions from the SONAR station.
- Further details and constraints on these actions are provided in the respective station specification section. The [Game Details](#) section provides more information on the relative timing of these actions during a turn.
- All stations must provide the user a method of selecting and initiating an action, as well as selecting the parameters of that action.
- All stations must provide the user a display of information relevant to that crewmember's role.

²The result of filling Utopia Planitia with a whole lot of water.

³<https://www.youtube.com/watch?v=NaSd2d5rwPE>

⁴You'll be moving along a rank with one dimension constant, so this ensures that the invariant is maintained. Since you have three choices for the coordinate to increment and two choices for a different coordinate to decrement, that gives you the six possible directions to move.

⁵Note that because of the way the axes must be defined for this coordinate system to work, the possible headings are between the $\pm x$, $\pm y$, and $\pm z$ axes. If we define unit vectors in the x, y, z axes as $\mathbf{i}, \mathbf{j}, \mathbf{k}$, then the possible headings are (without normalization) $\mathbf{i} - \mathbf{k}$, $\mathbf{k} - \mathbf{i}$, etc. That is, the sum of a basis vector and the negative of another yields a heading. The two examples given are for motion where y is constant, i.e. the LeftDown-RightUp axis.

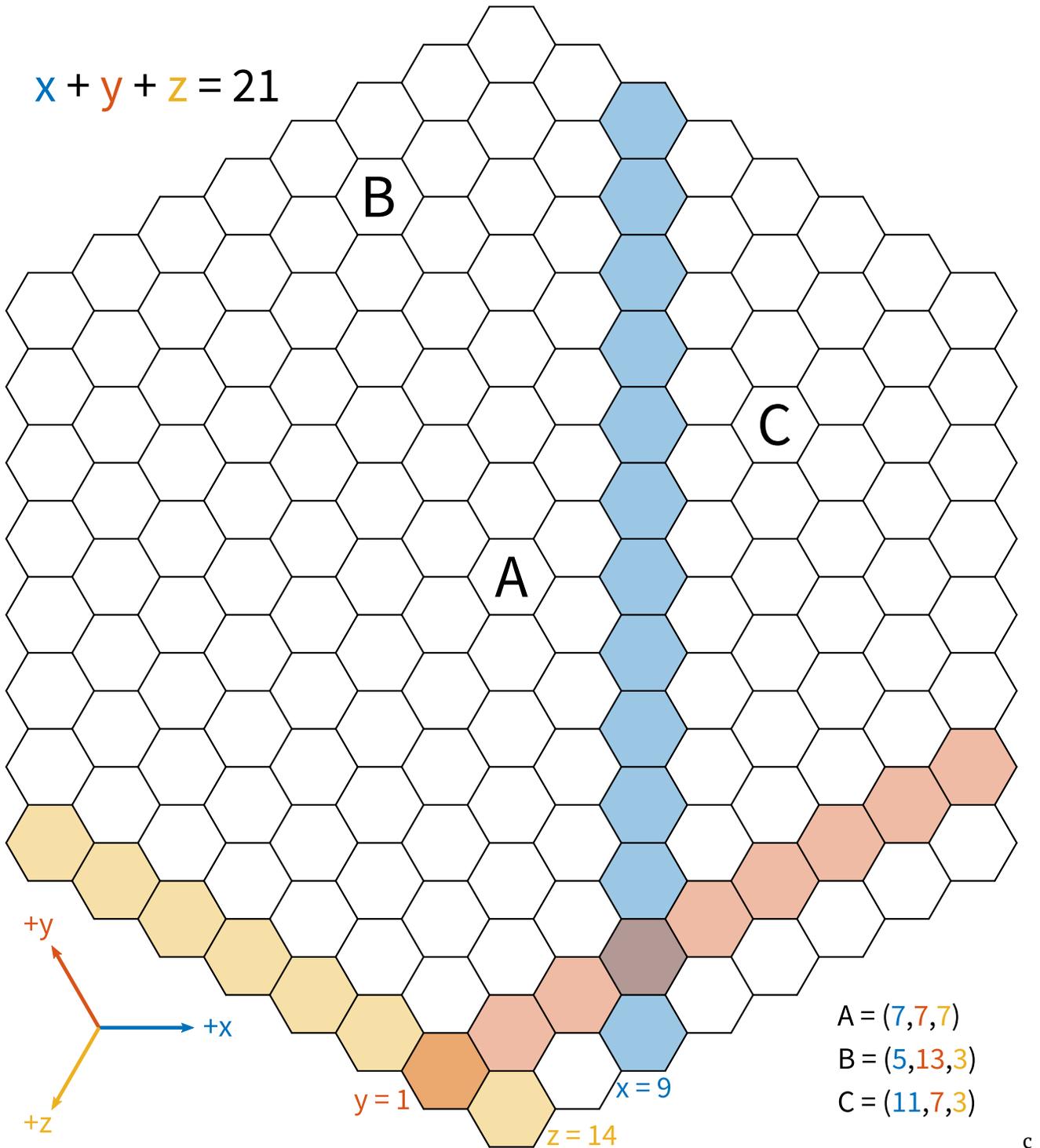


Figure 1: The Ocean. Three axes, x , y , and z , are defines as show at bottom left. Coordinates are defined such that for any hex cell, $x + y + z = 21$. Example coordinates are given for three specific grid cells, as well as an illustration of ranks having constant x , y , or z .

- Stations may use serial terminal I/O, but must incorporate at least 1 physical input, and at least 1 LED output. It is preferred that these physical I/O devices are used for the most dramatic functions.
- Each station must be capable of operating as any of the three roles (CONN, SONAR, TORPEDO) via a run-time configuration. In order to maintain battle readiness, each station must be able to take on additional roles in the event another station on their submarine fails to operate correctly.⁶
- Each station may only serve one role if all of its submarine's stations are functional.
- Each station must implement the class-wide protocol for coordinating game information (See [Communications](#)).
- The stations will use a Discord audio channel as the shared medium; further details are provided in the [Communications](#) section.
- Crewmembers of a single submarine will need to maintain a separate shared audio channel to verbally coordinate their actions.
- Each station may only take one action per turn. See the documentation for each role in the following sections. Superscripts indicate whether the referenced item is an Action, an Event, or a Response. Events and responses are message types, while actions are performed by stations.

The CONN:

- The CONN is responsible for the navigation of the submarine, and is responsible for keeping the authoritative record of the submarine's current location (position coordinates) and heading.
- The CONN must initiate one of three actions for their submarine during a turn:
 - TURN^A** Will turn the ship 60° clockwise (CW) or counter-clockwise (CCW) from its previous heading.
 - MOVE^A** Will move the ship one unit along the axis of its current heading. The CONN must ensure that this motion would not take the submarine out of the ocean. However, the move command does not have to check for co-occupancy of the new hex cell.⁷
 - IDLE^A** The submarine will neither change position nor change orientation at the end of the turn.
- Any time a TURN^A or MOVE^A action is taken, the CONN must send the new submarine coordinates and heading to the SONAR and TORPEDO stations for its submarine.
- The submarine location remains the same for the duration of all actions and events computed during the current turn; TURN^A and MOVE^A actions take effect only at the beginning of the submarine's next turn (See the [Game Details](#) section).
- Only IDLE^A may be selected multiple turns in a row; MOVE^A cannot be followed immediately by MOVE^A, or TURN^A by TURN^A.
- Any time the CONN receives a DETONATION^E, it must check the location of the DETONATION^E against the location of the CONN's own submarine. If there is a match, the CONN must send a HIT^R in response. The HIT^R must be sent to, and received by, at least the source of the DETONATION^E, as well as to the other stations associated with this submarine. The CONN must then display the damaged state to the CONN operator, and may take no further action in the current game.
- Any time the CONN receives a PING^E, it must check if the type and source position of the PING^E would detect its submarine at the current position. If so, it must reply with a ECHO^R containing the submarine's coordinates to the sender of the PING^E.

The SONAR:

- The SONAR is responsible for detecting the presence of other submarines within the ocean.

⁶The configuration may be performed via serial commands from a terminal or by the configuration of physical switches. It should be possible to achieve role configuration without requiring a station reset in order for dynamic reallocation during an ongoing battle.

⁷Each cell is about 100 km²—plenty for a couple of submarines!

- The SONAR must initiate one of three actions for their submarine during a turn:
 - OMNI^A** A short-range, omnidirectional sensing method. All other submarines within a range of three cells (along any combination of axes) must return their coordinates via ECHO^R, and have this submarine's location revealed to the pinged submarines' crew.
 - DIRECTED^A** A medium-range sensing method; all other submarines along a single heading, within a range of six cells, must return their coordinates via ECHO^R, and have this submarine's location revealed to the pinged submarines' crew.
 - IDLE^A** The SONAR does not send a PING^E in this turn.
- Any time a OMNI^A or DIRECTED^A action is taken, the SONAR must send a PING^E containing the type and the location of this submarine.
- Any time the SONAR receives a position update from its CONN, it should store the new location of this submarine to take effect next turn.
- Any time the SONAR receives a PING^E, it must check if the type of PING^E would be loud enough to reveal the source submarine's position to this SONAR. if so, it may reveal the position of the source submarine to the SONAR operator.
- Any time the SONAR receives a LAUNCHED^E, it may reveal the origin of the (enemy) ordnance launch to the SONAR operator.
- Any time the SONAR receives a ECHO^R directed to it, it may reveal the position of the submarine that sent the ECHO^R to the SONAR operator.
- Any time the SONAR receives a HIT^R from its CONN, it must mark itself as damaged and display the information to the user. No further action may be taken by the SONAR in the current game.
- On any turn, the action taken by the SONAR may not be the exact same action taken on the previous turn.

The TORPEDO:

- The TORPEDO is responsible for managing weapons systems and attacking other submarines.
- The TORPEDO must initiate one of two actions for their submarine during a turn:
 - FIRE^A** Fire a torpedo along the parent submarine's current heading and only along this heading. Torpedos must be set to detonate at a specific distance (in cells).
 - IDLE^A** Do not fire a weapon this round.
- Any time a FIRE^A action is taken, the TORPEDO must send a LAUNCHED^E containing the location of this submarine. The ordnance is now released, and will detonate at its predetermined target hex cell two turns in the future⁸, at which time the TORPEDO must send a DETONATION^E containing the target location.
- Any and all target submarines occupying the same cell as an ordnance DETONATION^E must return HIT^R events via the CONN.
- The TORPEDO may not FIRE^A additional ordnance while its ordnance is currently en route to target⁹. Martian weapon guidance systems are severely resource-constrained.
- Any time the TORPEDO receives a HIT^R notification from an enemy vessel in response to its own DETONATION^E event, it may display to the TORPEDO station operator that they have successfully hit an enemy submarine.

⁸i.e. if a crewmember chooses to FIRE^A in turn k , then the LAUNCHED^E occurs during turn k , and the ordnance detonates at the beginning of turn $k + 2$.

⁹i.e. released but not yet detonated

- Any time the TORPEDO receives a HIT^R notification from its own CONN, it must mark itself as damaged and display this information to the operator. No further action may be taken by the TORPEDO in the current game.

Game Details:

- Turns will progress as follows:
 1. All submarines update their position according to the action taken by their CONN on the previous turn.
 2. All ordnance scheduled to detonate this turn is detonated, and any submarines which are hit are eliminated from the current game.
 3. Crew members are given the opportunity to discuss and select actions for their stations.
 4. All PING^E are evaluated with respect to the current position of each submarine.
 5. All LAUNCHED^E are evaluated. At the end of this step, all SONARs should have all of the information they are entitled to based on all LAUNCHED^E, PING^E, and ECHO^R generated during this turn.
- The implementation details may vary slightly, but should implement the functional behavior described by this step-by-step process.

Communications:

- Communications among the stations will take place over an SPDL-supplied Discord audio channel.
- Each station **shall** use the Discord desktop client¹⁰ and **shall** implement the following settings:
 - Input Volume** Set to maximum.
 - Input Mode** Set to *Push to Talk*. **Recommended** to set keybind to spacebar.
 - Input Sensitivity** Disable automatic sensitivity, and set to -90 dB.
 - Noise Suppression** Disable.
 - Echo Cancellation** To be determined by the Communications Committee. **Recommended** to be left on.
 - Noise Reduction** Disabled.
 - Automatic Gain Control** Disabled.
- Each station **shall** implement the following hardware to support communication using these settings:
 - Modulation** The station **shall** use the PAM8302A and discrete speaker to generate audio signals.
 - Push to Talk** The station **shall** use the provided servo to implement push-to-talk functionality. This is accomplished by physically pressing the selected keybind before transmitting audio to the common channel, and by releasing the selected keybind after completion of transmission.
- Any other hardware or implementation requirements or recommended practices are left to the Communications Committee.
- The details of the communications protocol will be defined and specified by a Communications Committee, which will consist of a designated representative of each project group. The specification must be in a written form and with sufficient detail that someone skilled in ME218 material could implement it.

¹⁰This is because to avoid interference, all devices other than the one intentionally transmitting must not be transmitting any audio. To allow devices to communicate automatically, we need to use the push to talk functionality, which only transmits sound while a specific key on the keyboard is pressed and held. This functionality is only available in the desktop client.

- The class communications protocol must be defined to support the functional requirements listed earlier in this document. The Communications Committee is free to write a protocol of any complexity that fulfills the functional requirements. If a particularly clever messaging definition reduces overhead while maintaining the required functionality, this is perfectly acceptable. Or, if the Communications Committee implements a superset of the functionally required messaging, that would also pass.
- The communications protocol should include procedures for ensuring that no stations attempt to transmit on the common audio channel simultaneously¹¹.
- The communication protocol must define the symbol format and timing to be used when transmitting data¹².
- The communication protocol must define the format for data frames¹³.
- The communication protocol must define any addressing and packet formats if required¹⁴.
- While a clear division of labor is not obvious, we strongly encourage making an effort to have the team members who did not serve on the Communications Committee implement the majority of the communications in software.

General Requirements:

- There is no class-imposed upper limit on the number of processors employed; however, you must use only the PIC16F15356. Tivas, Arduinos, Raspberry Pis, Teensys, and other microcontrollers are not permitted.
- You are limited to an expenditure of **\$220.00/team** for all materials and parts used in the construction of your project. Materials supplied to each team by SPDL, from the lab kit, or the Cabinet Of Freedom do not count against the limit. All other items count at their fair market value. **If it's an issue with something from the kit, we will provide a replacement for free, but we can't guarantee latency. Be careful with your components.**
- A project logbook must be maintained for each group. A blog is appropriate to meet this requirement as long as it is made available to the teaching staff for review. This log should reflect the current state of the project, planning for the future, results of meetings, designs as they evolve, etc. The project logbook will be reviewed at irregular intervals for evaluation.
- A report describing the technical details of the system will be required. The report should be of sufficient detail that a person skilled at the level of ME218c could understand, reproduce, and modify the design. The report must be in website format, and be suitable for posting on the SPDL site.
- stations based substantially on purchased platforms are not allowed.
- All projects must respect the spirit of the rules. If your team is considering anything that may violate the spirit of the rules, you must consult a member of the teaching staff.

Safety:

- The stations should be safe, both to the user and the spectators.
- Caution: being on a submarine may cause seasickness.
- Warning: no virtual lifeguard on duty in the ocean.
- Intentionally disabling or damaging other submarines is encouraged. Prohibited actions include, but are not limited to, the following: ramming at excessive speed (as determined solely at the discretion of the teaching staff).

¹¹That is, no two submarines are permitted to be generating sound on the common channel at the same time

¹²That is, Layer 1 of the OSI model

¹³That is, Layer 2 of the OSI model

¹⁴That is, Layer 3 of the OSI model.

- No part of the submarine may become ballistic. (All ordnance is launched, propelled, and detonated below the ocean surface.)
- Approved small portable electronic devices may now be used while at periscope depth, while diving, and while surfacing.
- There have been no proven health effects due to 5G networks, so feel free to use those to connect your station to the Discord channel.
- The teaching staff reserves the right to disqualify any device considered unsafe.

Checkpoints

Design Review:

On 5/11/20 we will conduct a design review, one team at a time. Each team should prepare a few images showing your proposed designs for the stations. You will have 5 minutes to walk us through your ideas. **The focus should be on system level concepts¹⁵, not detailed hardware or software.** We will spend the balance of the time giving feedback and asking questions. In addition to your concepts, you must present, as a PDF, your plan for the development, integration and testing steps that you will follow to complete the project. The plan must identify what functionality you will demonstrate at the two checkpoints and the project preview along with the test procedures that you will use to prove that your team has met the checkpoint. Checkpoint tests must follow an incremental integration strategy with each successive checkpoint demonstrating all of the functionality of the prior checkpoint(s) as well as the new functionality. This plan must be approved by the teaching staff. If we feel that it is seriously flawed, we will ask you to revise and resubmit the following day.

Ocean is a mighty harmonist.

William Wordsworth

First Draft of Communications Standard:

Due by 5:00 pm on 5/11/20. This draft will be made available to the entire class, so that everyone is ready to deliver feedback at the in-class review.

Give me a ping Vasili, one ping only.

Capt. Marko Ramius

In-Class Communications Standard Review:

In class on 5/12/20 we will conduct a top-to-bottom review of the Communications Committee's draft protocol. Bring your prepared questions, concerns, and suggestions for improvement! Everyone should attend, if possible—the more eyes we can put on the protocol early, the earlier we can catch the weird edge cases.

And we lived beneath the waves / In our yellow submarine.

Lennon/McCartney

Communications Standard:

Due by 5:00 pm on 5/13/20. This is the working draft of the communications standard.

The [submarines] do not sing because they have an answer, they sing because they have a song.

Gregory Colbert

First Checkpoint:

On 5/15/20, you must demonstrate your approved 1st checkpoint functionality according to your defined testing procedure. Note: this is a functional evaluation only. The focus should be on demonstrating functional hardware and software. You may submit for approval a final revision of your checkpoint plan at this time.

¹⁵I/O, signal conditioning architecture, etc.

The final working version of the communications standard is due. No further changes are allowed to the standard. This protocol will be evaluated with respect to its completeness and suitability for the proposed system.

Look at me, I'm the captain now.

Abduwali Muse

Second Checkpoint:

On 5/22/20, you must demonstrate your approved 1st and 2nd checkpoint functionality according to your defined testing procedure. The functionality demonstrated at this time must include full implementation of the communications protocol.

Swimming is a confusing sport, because sometimes you do it for fun, and other times you do it not to die. And when I'm swimming, sometimes I'm not sure which one it is.

Demetri Martin

Project Preview:

At the Project Preview on 5/28/20, each team must demonstrate (in addition to the 1st & 2nd checkpoints' functionality) your approved project preview functionality. The functionality demonstrated at this time must include a demonstration of interaction between at least 2 teams' submarines and stations.

Going outside is highly overrated.

Anorak's Almanac, Chapter 17, Verse 32

Grading Session:

During the Grading Session on 6/2/20, each team will be required to demonstrate the ability to successfully participate in a game. This will include

1. Commencing a game with at least one other submarine;
2. Demonstrating all required functionality of all stations, including user interface and implementation of the Communications Committee-designed communications protocol;
3. Successful execution of at least three turns of play.

A detailed grading check-off procedure will be published at a later date.

Comrades, this is your captain. It is an honor to speak to you today, and I am honored to be sailing with you on the maiden voyage of our motherland's most recent achievement. Once more, we play our dangerous game, a game of chess against our old adversary — The American Navy.

Capt. Marko Ramius

Public Presentation:

This will take place on 6/3/20 starting at 5:00 pm on the Internet (aka the ocean). At this event, members of the public will be encouraged to watch you fight it out to rule the Martian Seas.

You will hear it for yourself, and it will surely fill you with wonder.

Marco Polo

Report:

Draft due on 6/8/20 by 4:00 pm. The final version (with revisions incorporated) is due by 5:00 pm on 6/12/20.

It was [REDACTED] and [REDACTED].

After-action report from the Battle of [REDACTED]

Celebration:

A celebration of the past 3 quarters of ME218 **may** take place at the Alpine Inn on 6/12/2020 starting at 3:00 pm. Mark your calendars now and save the date.

Then, and when we are finished, the only sound they will hear is our laughter, while we sail to Havana, where the sun is warm, and so is the comradeship. A great day, comrades. We sail into history.

Capt. Marko Ramius

Performance Testing Procedures:

Each team member will demonstrate their station during the first & second checkpoints and project preview. Members of the teaching team will randomly assign roles to each station during the grading session.

Grading Criteria:

- Concept (15 %)** This will be based on the technical merit of the design and coding for the machine. Included in this grade will be evaluation of the appropriateness of the solution, as well as innovative hardware, software and use of physical principles in the solution.
- Implementation (15 %)** This will be based on the prototype displayed at the evaluation session. Included in this grade will be evaluation of the physical appearance of the prototype and quality of construction. We will not presume to judge true aesthetics, but will concentrate on craftsmanship and finished appearance.
- First Checkpoint (10 %)** Based on the results of the performance demonstrated on 5/15/20.
- Second Checkpoint (10 %)** Based on the results of the performance demonstrated on 5/22/20.
- Preliminary Performance (10 %)** Based on the results of the performance demonstrated during the Project Preview.
- Performance (20 %)** Based on the results of the performance testing during the Grading Session.
- Report (10 %)** This will be based on an evaluation of the report. It will be judged on clarity of explanations, completeness and appropriateness of the documentation.
- Report Review (5 %)** These points will be awarded based on the thoroughness of your review of your partner team's report. Read the explanations, do they make sense? Review the circuits, do they look like they should work?
- Log Book (5 %)** This will be evaluated by the evidence of consistent maintenance as well as the quality and relevance of the material in the log book.

Resources**Websites:**

[SparkFun Newark](#)
[DigiKey](#)

[Seeed Studio](#)
[Ponoko](#)
[McMaster-Carr](#)

[Jameco](#)
[Adafruit](#)
[HobbyKing](#)

[Mouser](#)
[Hackaday](#)
[ServoCity](#)

You may also find [PlantUML](#) and [PlantText](#) helpful for creating message sequence diagrams.

Local Stores (Not applicable while quarantine is in effect):

[J&M Hobby House](#) in San Carlos
[Jameco](#) in Belmont
[TAP Plastics](#) in San Mateo

Gems of Wisdom:

Be sure to check out [The ME218 Archive](#) for guidance from past generations.

There's also some helpful material on audio and the PIC on [The SPDL Docs Repository](#).

You may find this article on [Hexagonal Grids](#) to be helpful when developing your navigation and ranging code. We've defined a slightly modified version of the cubic coordinate system; you only need to worry about storing a few locations at a time, so don't worry about storing the full map.

Communication is relatively more fundamental this year than most years; however, keep in mind that there's still plenty to be doing while one of your teammates is getting the Comm Protocol sorted. Make effective use of this time to develop and test other systems.

This year, the communication protocol encompasses more OSI layers than usual for a 218C specification, so keep in mind that you will need to provide more information on some aspects than the example protocols, and less information in other aspects.

Revision History

Revision 0: Initial draft out for review. (5/7/20)

Revision 1: Minor clarifications, initial published specification. (5/8/20)