UNIVERSITY OF CALIFORNIA, SANTA CRUZ
BOARD OF STUDIES IN ELECTRICAL AND COMPUTER ENGINEERING

ECE-118/L: INTRODUCTION TO MECHATRONICS

SLUG-O-LYMPICS: L'ESCARGO VS. SLUG

Background Briefing:

The 33rd Summer Games of the Modern Olympiad in Paris, France—known as Paris 2024, are set to take place with the athletes preparing and training, the venues being spruced up, and the traffic routing planned. In a bid to showcase the majesty of France, the games are being spread across the entire country, rather than concentrate the games in a single Olympic Arena.

The mascot for the 33rd Summer Games is the quixotic "les Phryges" which is actually a soft (usually red) cap worn by the freed slaves of Phyrgia (in modern day Turkey), symbolizing freedom. Though "les Phryges" have been drawn to look somewhat like a red birds, rather than animated caps.

The spread of the venues, along with the unusual mascot, has created some unforeseen problems; fans are throwing their Phrygian caps on the field as a form of cheering, and the Olympic committee is at a loss on how to get the fans to stop.

In an effort to improve the ratings for the tech nerds around the world, as well as save significantly on costs, the Olympic committee has decided that they will use small robots to clear the field of the dreaded (but sacred) *phryges*. France has been developing their robots, but following a protest from the US Olympic committee, they have decided to engage the UCSC ECE-118 class to develop a US robot and determine who will win the phyges clearing contract by a head to head droid competition.

As this is an engineering competition, the *phryges* have been replaced by 25mm chrome balls (samples in the lab).

Your droid will start out randomly placed (location and orientation) on your side of the field. Two towers (one one each field designated by a standard beacon) will randomly discharge 25mm chrome balls; your task is to collect the balls (cleaning up your field) and either contain them within your droid, or push them into your opponent's field through the slot door. In the dossier below, find further specifications for your droid.

Purpose:

The purpose of this project is to provide an opportunity to apply all that you have learned in ECE-118 to solve an open-ended problem. Your task is to build an autonomous robot that will navigate the game field, locate and trap randomly rolling 25mm chrome balls, and store them within your robot or push them onto your opponent's field, cleaning up as much as possible in the 2-minute round.

Project Requirements:

A. Team and robot meet three Design Reviews (Brainstorm, Mid-Project Review, Final Check-Off)
B. Team maintains an active lab notebook (or website) detailing their progress and designs
C. Each and every week team satisfies Check-offs and meets with their mentor
D. All loaned parts returned to TAs (IO stack, etc.) after tournament
E. Lab cleaned up before end of finals week
F. Final Report due at end of finals week
G. Participation in Public Tournament (0% of your grade; 100% fun)

If your robot can demonstrate robust Final Check-Off one week before the final deadline the Instructor will personally buy your team beer. The beer check-off has rarely been awarded. See beer checkoff rules below.

Project Overview

Your task is to build a small autonomous robot (droid) that can effectively and robustly navigate a standardized field, locate and trap the targets. You must locate the discharge location, and contain the balls or discharge them to the opponent's field. You will receive points based on the number of balls left on your field at the end of the time (see field specs below). The match is won by cleaning up your field. You will be doing this in teams of three, over the next five weeks, during which time you will design, implement, test, and iterate until you can reliably complete the task. There will be practice fields in the labs, and lots of help and guidance available to you. Don't panic. Yet.

The field of play is a large white 4'x8' surface with 2" black tape markings and a low (4") wall separating yours from your opponent's field. The wall contains a slot (marked with a track-wire) with a one-way door to push balls over to your opponent's field. The edge of the field is marked with 2" black tape, and your robot must detect the tape and stay on the field (more than ½ your robot moving out of bounds will disqualify you from the round).

There are two towers on each field (one with a standard 2KHz beacon) from which the 25mm chrome balls will eject randomly. There are also weather stripping bumpers at the edge of the 4'x8' field to prevent balls from rolling away.[†]

If your bot cannot resolve collisions (either with the obstacle or the walls) within 5 seconds, it will be disqualified. There will be an obstacle (dead bot) on the field in a random location/orientation not blocking the trap door; you must work around it.

The 2kHz IR beacons on the ball dispensing towers will be illuminated for the entire match. Only balls contained within your robot or pushed into the opponent's field through the slot count as "cleaned." Scores will be computed by the number of balls on your opponent's field minus the number of balls on your field (1 point for each ball).

[†] Note that while the weather stripping should prevent the balls from rolling out, it will certainly not keep a robot on the field. Note also that the field will be up on tables so be prepared to catch your robot if it gets close to the edge.

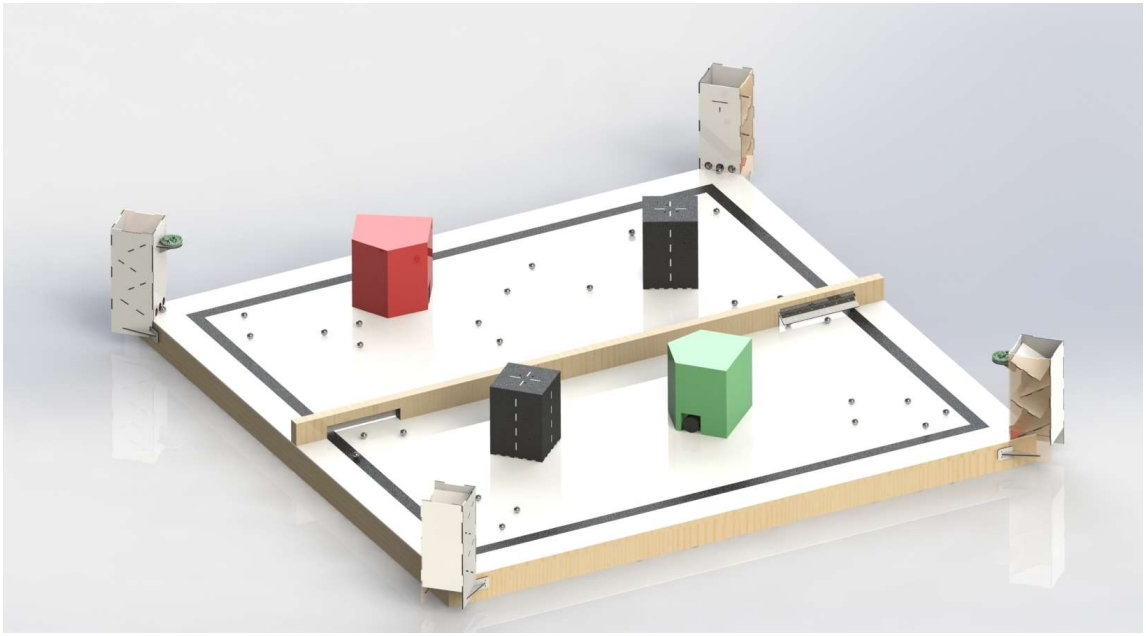

Figure 1: Field of Play for the L'Escargo vs. Slug. Black tape boundaries and alignment marks are 2" thick PVC tape. The trap door slot is marked by track wire (24-26KHz). The ball dispensing towers are at the diagonal corners of the field, with the standard 2Khz beacon is placed in front of one of the towers.

The slot has a one-way door which can be pushed open to deposit balls to your opponent's field (see Fig. 1).

Each droid must start the match within an 11" cube volume (parts may move after the round begins) and remain intact throughout the match. Jamming your opponent in any way is disallowed. Robot sizing will be checked with the *Cube of Compliance*.[‡]

Your robot is required to detect collisions and resolve them (e.g. if an obstacle is blocking your path; you need to be able to maneuver around any immovable obstacle). You are required to break contact within 5 seconds or be disqualified.[§]

Your robot is required to detect and maintain itself within the field of play (field boundary marked by 2" black tape). Failure to keep ½ of your robot within the field of play will result in disqualification.

While every attempt has been made to finalize the project specifications and rules, understand that this is a work in progress. As the project evolves, we will be making

[‡] We have (and will) require you to modify your robot because it does not fit inside the dreaded Cube of Compliance. Remember to take into account things that stick off your robot (e.g.: wires).

[§] Pushing an obstacle out of the way is not allowed.

(minor) tweaks to the specs as we discover what flaws we have not anticipated. These will be announced in class, and posted on Piazza. They are not meant to destroy your winning design, but only to make things work smoothly. Your understanding is appreciated.

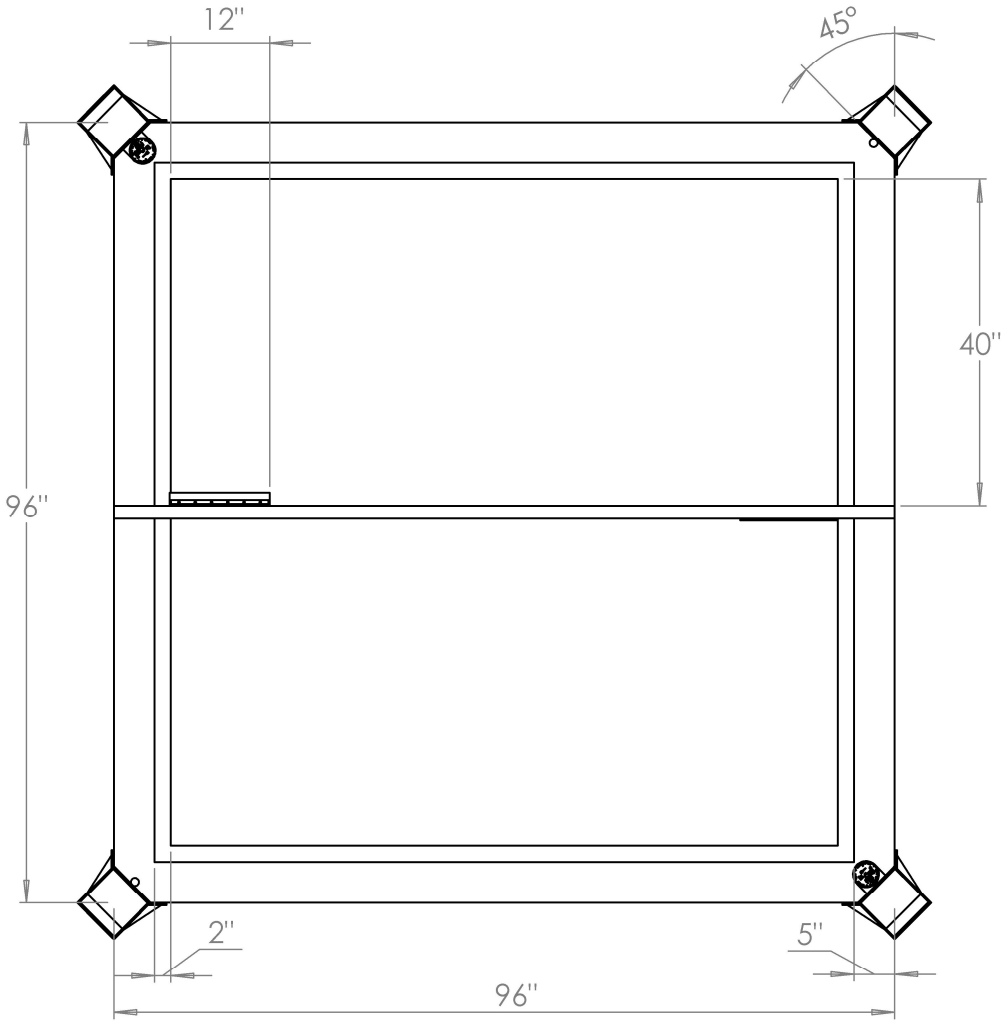

Figure 2: Scale drawing of the field of play including dimensions and designated areas (all dimensions in inches). Note that the beacons are located on the top right and lower left towers. The slot doors are 2" high and located at the edge of your field and can only be opened in the direction of the opponent field.

Minimum Specification Checkoff:

In order to pass this class, your robot must demonstrate that it can complete the task.[**]

[**] Yes, we have had teams go well into the break before they finished. No team passes the class without passing min-spec.

While the rules and specifications are below, teams are free to embellish, go beyond, and otherwise have fun—however, we suggest you aim for "min spec" first, and then go back (and go nuts).

Your robot begins the round randomly placed within your playing field in a random orientation. An (immovable) obstacle is placed somewhere on the field, but not blocking the trap-door to the other field.

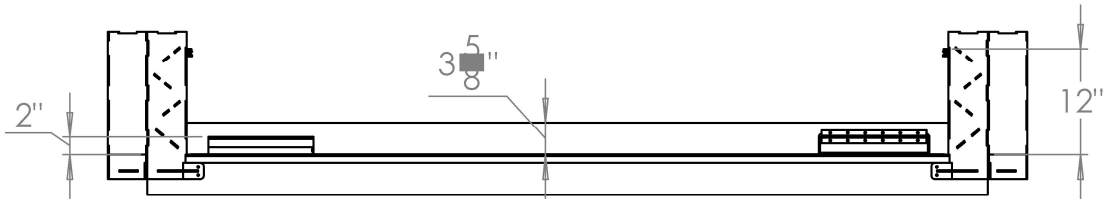

Figure 3: Dimensioned drawing of the side of the field, showing the height of the walls and the height of the beacons above the playing field. (all dimensions in inches).

At the start of every round, your droid will be reset. The towers will have their IR beacons (2KHz) illuminated. Balls will drop into the field at a rate of 20/min (approximately), evenly spaced in time (again, approximately).

Your robot should find the balls. You must contain the balls within your robot, or push them through the trap-door to the opponent's field.[††] Note that balls pushed out of the field other than through the trap door will NOT count as "cleaned." Any ball outside of the field lines will be recovered and resent through the drop tower.

Min-spec is defined as trapping/discarding 75% of the balls deposited on the field (30 during 2 min round), and putting *at least 2 balls* through the slot-door to the other field.

Should it become apparent that a robot will not complete a round (for example, if it fails to resolve a collision for more than 5 seconds, or cannot stay on the field, your robot will be disqualified and the round will end.

Tournament:
In the tournament, you play against another team; each will start on its own field. Note that during Tournament play (and only tournament play), the rate of depositing balls will

[††] A ball is considered "cleaned" if it is no longer able to move about on the field. It can be corralled within your robot, put into a hopper/container, etc. but cannot be free to roll on the field.

likely increase. Each field will have its own obstacle randomly placed.

If you win the match, your robot advances in the tournament, *victory will be awarded by points*. Should a tie occur, we will attempt a rematch.[‡‡]

Points are awarded based on the net balls cleaned as determined by the number of balls on your field vs the number on your opponent's field. No points are awarded for balls outside the 2" tape marks. Balls that leave the field of play will be gathered up by the tutors and reloaded into the dispensing towers.

Robots will be disqualified for failing to resolve collisions (must break contact by 5 seconds) with either the walls or obstacle, or for failure to stay on the field.

We may (will) update these rules and/or points should (when) flaws become apparent.

The Droid

The droid must be a stand-alone entity that fits in an 11"x11"x11" cube at the beginning of the round. It should be capable of meeting all specifications while drawing power only from batteries. It must be able to detect bumps at a height of 3.0" above the ground. The droid must be able to detect and resolve collisions with an obstacle (break contact after 5 seconds). Your droid must be capable of detecting the 2" tape boundary and remaining on the field.

Droids will be programmed in C, using the standard MPLAB-X IDE. Your droid behavior will be constructed using the ES_Framework from Lab 0 (however you may NOT use the Roach projects you wrote).[§§] You may reprogram your droid between rounds if you desire, but you may not alter it once the field configuration is established.

Each droid must be equipped with a remote power switch (using the remote switch header on the Uno stack). At the beginning of the round, you will switch on your droid, and may not interfere with it until the round ends.

Materials

Each team will be provided with one Uno Stack, one L298N H-Bridge, one Stepper Board (if needed), one DS3658 board (if needed), one battery, and one ULN2003 (if needed). There will be also wire, regulators, and solder freely available in the 118 labs.

[‡‡] If you both continuously tie, we will flip a coin and move on.

[§§] If we see a Roach_HSM.c file we will delete all of your code. Seriously, write it from scratch, and use relevant names.

BELS has microswitches, RC servos, wheels, and brushed DC motors for every team (note that these are not very good ones, and if you use them they are expected to come back to BELS in usable form). You are free to buy your own motors or any other part you need for your project.

Each team should not exceed a budget of $150 total for other parts on the robot, and must maintain an up-to-date bill of materials (BOM). If we spot a nice $5K gyro on your bot, we will hand you $150 and take it. We don't want the project to be an arms race over who can purchase better stuff. We will have MDF and Foamcore available for you. BELS, Ace Hardware, Fastenal, and Home Depot are all decent local sources. HSC and Tap Plastic (Acrylic for $1) are most excellent resources in the Bay Area (get together and caravan). McMaster-Carr will deliver nearly any piece of hardware within a couple days but they tend to be expensive. Amazon Prime is free to students for a three-month trial, and will get things to you in two days (or in one day for an extra $5 for shipping).

Available Tools

It should go unsaid that all work needs to be done by the team and not contracted out. *3D printing is disallowed* except for small bracket-type things and holders.[***] You will have the resources in Mechatronics Labs, as well as the drill press, tool chest, and Laser cutter in BE138. Your circuits must be soldered on perfboards, no breadboards. Those of you thinking about PCB houses, you most likely won't get turn-around in time without blowing your $150 budget. Off-the-shelf sensor boards, such as those sold by Sparkfun or Adafruit, are fine (but understand that the software integration for these sensors can take much longer than you anticipate—manage your time carefully).

Field Specifications:

We will have a Solidworks model of the field, ball dispensing tower, balls, and beacon mount available after the midterm. The model in Fig. 1 will be available on the website in higher resolution, and is drawn to scale. Modifications (if any) to the field will be noted on Piazza.

Further questions or clarifications about the field specifications should be posted to the Piazza forum.

Safety:

The machines should be safe to the user, the lab, and the spectators. For this project,

[***] Again, the point of the class is to teach you how to use the resources you have, not to simply have a machine build the entire chassis for you. Building your own robot is part of the experience.

excessively high velocity ball delivery will be discouraged (so go ahead and forget about that CO2 PVC pipe launcher you were thinking about.) Voltages are limited to the rechargeable batteries in the lab (you may purchase your own if you'd like,[†††] but consider 10V an upper limit), and intentional jamming or blocking of the opposing robot or masking of any beacon/trackwire is considered foul play and not allowed. 'Bots deemed unsafe will be disqualified.

NOTE: Young children line the competition field; take this into consideration when designing any launch mechanisms.

Prior to competition your robot should not transcend space or time in any way, nor should your robot alter gravity within our Solar System. However, during competition, gravity and space-time may be altered at will.

Evaluation:

Performance testing procedures: All machines will be operated by at least one of the team members. There will be one round for grading purposes done in the lab to evaluate 'droid performance. The public tournament is purely for entertainment purposes (though if you have not yet checked off, successful completion of the min-spec tasks during the public demo counts as a valid late checkoff).

Grading evaluation: Each machine will be graded based on its performance in the testing before the class competition at the end of the quarter. Each machine will have up to 2 minutes to solve the challenge. Grading is not based on point values, but how robustly your robot performs.

Grading Criteria:

1. Concept (20%): 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 and software and use of physical principles in the solution.

2. Implementation (20%): This will be based on the prototype displayed at the evaluation session. Included in this grade will be an evaluation of the physical appearance of the prototype and the quality of construction. We will not presume to judge true aesthetics (though we might comment on it), but will concentrate on craftsmanship and finished appearance.

[†††] If you plan on using LiPo batteries, have your *own* charger and *bomb-bag* to charge them in. You are NOT welcome to use ours.

3. Report (10%): This will be based on an evaluation of the written report. It will be judged on clarity of explanations, completeness and appropriateness of the documentation.

4. Performance (20%): Based on the results of the performance during the evaluation session.

5. Design Evaluations (30%): Based on check-off completion.

Project Milestones:

Each week, your team will need to achieve a list of check-offs to stay on schedule and each partner will need to work as part of the team. **IF YOU DO NOT STAY ON SCHEDULE WITH THE CHECK-OFFS** you will NOT finish in time and be forced to stay through summer break until your robot is complete: **STAY ON SCHEDULE**.

Your weeks will essentially break into the following (see Canvas for specific dates):
Week 1: Design, Schedule, and Group Order (Design Review I)
Week 2: Electronics and Mechanical Prototyping
Week 3: Working Prototype for moving robot and ball catcher; State Machine (Design Review II)
Week 4: Finalizing robot and getting everything to work together.
Week 5: Competition and Final Check Off (Design Review III)

There will be **weekly checkoffs**, **three design reviews** throughout the project, **one project report**, and **one and only one competition.**

Half of this project is communicating well and documenting progress to stay on schedule. With that in mind, we expect each team to maintain and update a lab notebook with everything you are doing and copious notes.[‡‡‡] We very (very) strongly recommend that your lab notebook stays with the robot in lab. We will use this to verify your check-offs for each week. We recommend sharing some form of file/team drive/GIT repo to help you keep your selves on task, but do not require it. That said, each team will need to submit their lab notebook and schedules for the Design Review #1. See "check-offs" section for further details. Note that if you want to use GIT for your storage for the project, you will be able to create a repo on the UCSC GITLAB server.

A report describing the technical details of the machine will be required. The report should be of sufficient detail that any skilled ECE118 alum could understand, reproduce,

[‡‡‡] If you want to use WordPress, Wiki, or Google website for the project posting block diagrams, sketches, pictures, schematics, videos, etc., we don't mind but a paper and pencil version is still required.

and modify the design.[§§§]

Design Review 1: Thursday, post midterm (PDR)

Team Concepts, present your best design to the class for five minutes

Come up with 3 team concepts for your design from your individual ideas (from your midterm) and a bit of brainstorming (you will present your best 2). Mix and match between the best of your designs. How are you and your team going to accomplish your project goals? Schedule out your time as well as your team's.

You will need to upload your designs to CANVAS, and present your lab notebook to the tutors/TAs for checkoff. Submit your best team design and backup design before class on Thursday (see CANVAS assignment). You will have 5 minutes to present your design (and get some feedback on it). Have a primary and a backup in case it is too similar to someone else's.

Design Review 2: Mid-Project Review:

Full Prototype, presented to the staff for 15 minutes.

Present your currently working parts and your full design to the instructors for review and insight into potential roadblocks. Every system (both mechanical and electrical) should be prototyped at this point.

Mechatronics Beer Challenge:

Each team gets exactly three consecutive tries on the field to successfully complete your final check-off. If you can complete the task 3 out of 3 attempts, AND your robot still functions (i.e.: meeting min spec) in the public demo, you get beer. In the history of mechatronics only three teams have succeeded (and it was easier then). Note that in the beer challenge, the field is NOT random, but (possibly) set in a way to be difficult for your particular robot. *We reserve the right to be evil here*.

Design Review 3: Final Check-Off:

Present your final check-off robot to the staff. You get three tries to succeed on the field in each session.

Deliverables are:

- Robot that meets all requirements and completes the challenge.

Competition/Public Demo: the public demo of your finished, operational machines. This fun performance will likely have a large and enthusiastic audience. Demo will be on June 7, 2024 at 6:00 pm in the new Kresge Auditorium.[****]

[§§§] Almost everyone uses this report as one of their portfolio pieces, so you might as well spend the time to make it comprehensive.

[****] We expect you to show up with your robot by 5:20PM. We will do everything we can to give you access to the room beforehand so you can test your robot in the tournament

There will be a post-tournament beer, dancing, decompress at one of the Santa Cruz watering holes (traditionally Woodstock Pizza). Friends and hangers-on are welcome. We will post plans on Piazza.

Clean-up and Class Review: Monday after Public Demo (time will go out on Piazza)

Lab Report:

Electronic copy of your lab report, turned in as a group assignment in CANVAS.
Create a section for each design and write an evaluation of each aspect of your design: what went well and what didn't. Make sure to include pictures and links to video as necessary. Also include your final BOM.

Check Off Schedule:

Check-Off's are used to ensure that you are on track and keeping up. It allows the teaching staff to allocate their resources to help teams out in an appropriate way. Treat them seriously and your project will be completed well and on time.

Check-off 1:

Using the three concepts that each of you created for the midterm, now that you are assigned to teams, come up with 3 team concepts for your design. Mix and match between the best of your individual designs (and/or specific parts). How are you and your team going to accomplish your project goals? Get some details written down in your engineering notebook.

Deliverables are:

- 3 detailed TEAM concepts for solving the project.
- Make copies of them for your teammates and yourself.

Check-off 2:

Basic project management and system component design. This is where you define who is primary/secondary on which tasks. How you will coordinate time and schedules, etc.

Deliverables are:

- Time schedules
- Personnel assignments
- System Block Diagram
- Mechanical Design Sketches
- Working beacon detectors on perf-board with LEDs (at least one) with

environment. Also, this room can seat 600, so invite everyone you know.

accompanying schematics[††††]

Check-off 3:

Mechanical and Software Designs. You should at this point have your final robot design completed in appropriate CAD software, and your state machines should be entirely drawn out (neatly). Your mechanical design should easily fit within an 11" cube. While both of these may need to be updated as you progress, they should be in close to final form.

Deliverables are:

- State Machine(s)
- Final Mechanical Design (Solidworks)

Check-off 4:

Sensors and Actuators. Your full sensor suite should be functional and documented at this point. All ball capture mechanisms should be prototyped and tested (this gives time to redesign if necessary). Any door shuttling mechanisms as well.

Deliverables are:

- Working sensors (breadboard is ok) and schematics
- Actuators (breadboard is ok) and schematics

Check-off 5:

Final Sensor and Actuator designs. Final working (perfboard) prototypes of all sensors and actuators that your robot will use. Fully tested, fully documented.

Deliverables are:

- Final sensors and final schematics
- Final actuators and final schematics

Check-off 6:

Mobile platform with basic reactive navigation. Your platform should be integrated into a moving droid, which can navigate the field (tape sensing) and resolve collisions (bump sensors).

Deliverables are:

- Autonomous platform that can move and sense

[††††] This should be the best one from Lab 2 among your team. If you really, truly, have to build a new one, make sure you use the best of the designs from lab 2. This is not the time to redesign a better filter.

- Reverse off of a collision sensor
- Keep itself on the field

Check-off 7:

Basic Navigation. Robot that can move from initial point, orient and stay on field, find and trap balls or get them through the trap-door.

Deliverables are:

- Robot that can autonomously navigate the field, and score points
- Robot fits entirely within the *Cube of Compliance*.

Specifications Check-Off:

Min Spec. Your robot should be able to meet the minimum specifications. After that you may go home and celebrate (or sleep).

Deliverables are:

- Robot that meets minimum specifications

Notes on successful projects management: There are a few rules of thumb to follow that will make your project much more successful, and keep you working well as a team.

The first rule is a bit paradoxical, but nonetheless important: *Do what you are bad at*. That is, if you are good at software but bad at mechanics, then you take the lead on mechanical stuff, and take a secondary role in software design.

The second rule: Double-team every single task you need done. That means one person is primary/lead the other person is secondary. Note that if you follow the first tip, then likely the secondary is better at the task than the primary. Do **NOT** attempt to split tasks up so that each one of you go off and do it and then come back—this never works and is *always* slower in the long run.

When crunch time comes, you can run a rotation with your three team members such that one sleeps, two work (the just woken up one works under the one who has been up). Then the lead goes to sleep, the secondary goes into lead position (on another task), and the sleeping one gets woken up to be secondary. While this is not sustainable beyond a couple of weeks, you can get an enormous amount done this way.[‡‡‡‡]

Be careful about sleeplessness and cars/bikes/etc. There are plenty of couches around to

[‡‡‡‡] I personally have kept this up for approximately 21 days—not recommended but boy did we get a lot done (DoD deadline)

crash on, and a number of students live in GSH (200 ft. from the lab). Don't think you can keep yourself awake long enough to drive/bike home. Be smart about this. We really don't want to see anyone get hurt through a senseless crash.[§§§§]

PS: With this many people in the lab, it is going to be very important that you keep the lab clean and not leave your things lying around. We will be assigning I/O boards and batteries to each team, and they will be yours until the project is over. You will also get a milk crate to keep your robot in.

People occasionally donate random parts, and if you happen to find surplus printers, or other random electronics that people no longer want, feel free to dismantle and salvage what you want. However, please discard all parts that are not salvageable in an appropriate e-waste container so as to reduce clutter in the lab.

Drive motors have, in general, been a make-or-break part of the project. BELS has two per team in stock, though you will have to give them back after the project.[*****] I would strongly suggest you consider purchasing some gearhead motors from Jameco, MPJA.com, or Amazon.com. Ordering them early (i.e.: now) would ensure that you have a set that will work by the time you need them.

PPS: *The Mechatronics Beer Challenge*—any team that is able to complete the beer challenge spec (see above) with a fully functioning and finished 'droid a full week ahead of the deadline gets a case of beer or other equivalent adult beverage (within reason) supplied by Instructor. Only three teams have ever collected this. See rules above.

[§§§§] If you need a ride home and are too sleepy, call one of the staff—we will come get you or find a couch for you.

[*****] The motors we spec'd from Amazon are decent, but not fantastic. If you want better, buy better. Note that this is a change from previous years as required by UC admin. Figuring out what you need and buying it is a good experience for later projects.