UK LUNABOTICS

KICKOFF EVENT

6 OCTOBER 2025

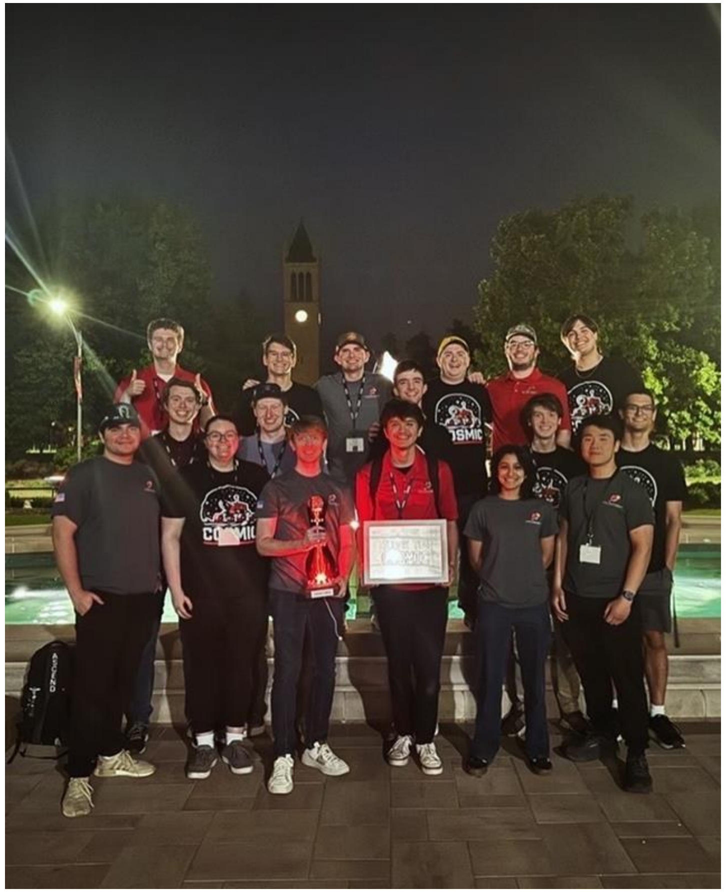
AGENDA

- Student Benefits
- Team Structures
- Leveraging System Engineering
- Robot Designs
- Robot Autonomy
- Operations
- Faculty Guidance
- After the Kickoff

Purdue Lunabotics Representatives

PURDUE™ LUNABOTICS

Iowa State University Introductions



Denise

Jacob

Mason

Sam

CSM

STUDENT BENFITS

- Why you should want to compete in this competition.
- How this competition can benefit you as a busy student.
- What skills can you gain from being in a club

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Student Benefits – Iowa State University

Technical Skills

- Manufacturing
- Computer aided design
- Coding
  - C++

Industry Training

- Interdisciplinary collaboration
- Critical thinking
- Adaptability
- Punctuality

Career Building

- Industry connections
- Resume content
- Space community

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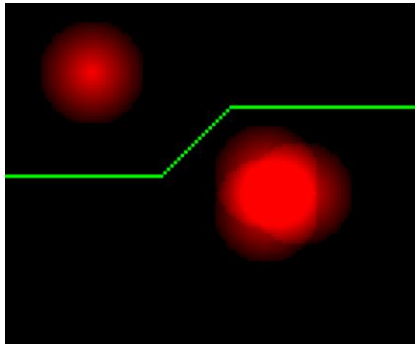
Student Testimonial – Jacob Mosier

Freshman



Sophomore

Junior

Senior

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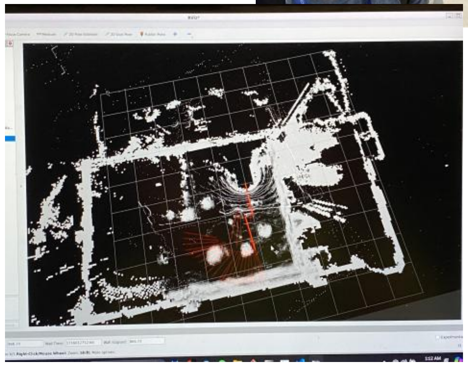
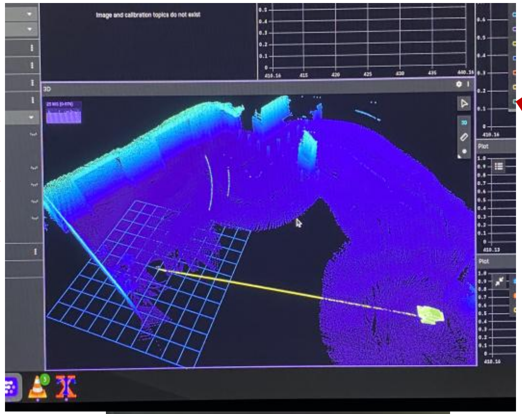
Student Testimonial – Sam Richter

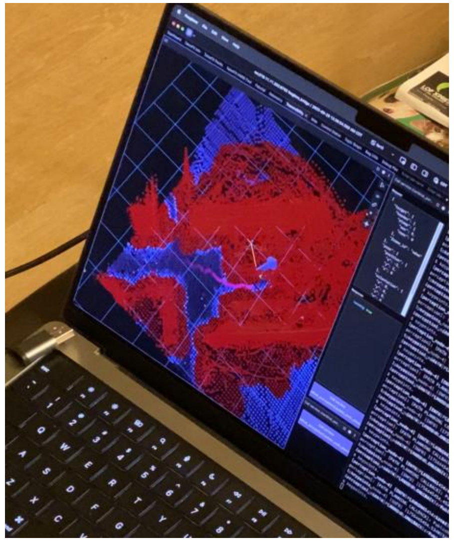
2023

2024

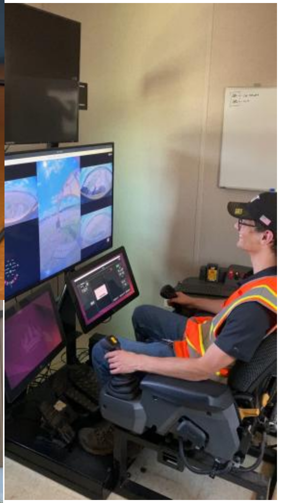


2025



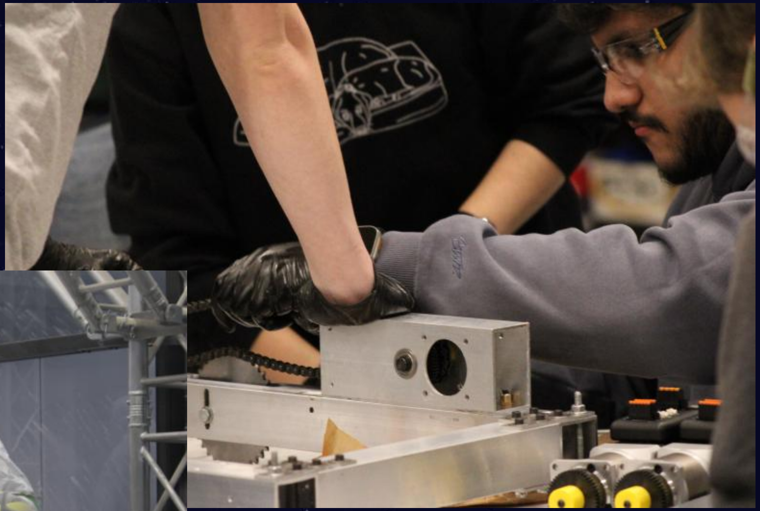


Summer 2025



Student Benefits – Purdue University

- Technical skills
  - Failure analysis, mechanical design, manufacturing, part sourcing
  - PCB design, electrical box layout, power sizing
  - Coding, computer vision, autonomy
- Professional skills
  - Presentations, design reviews
  - Leadership, project management
  - Networking
    - Internships
    - Research
    - Full Time Jobs
- Community



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LUNA TESTIMONIALS – Sofia Velarde

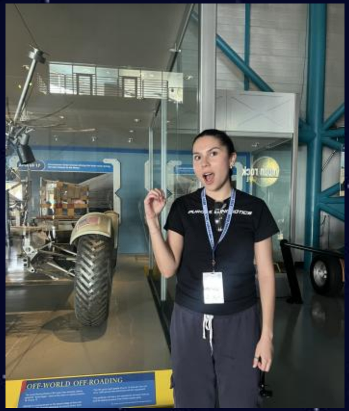
Class ‘26
Mechanical
Engineering

Freshman Year
Ex-Dep Member + VIP
Class

Sophomore Year
Treasurer

Junior Year
President

LUNA TESTIMONIALS – Sofia Velarde



Lunar Tire R&D Intern for Goodyear

Undergrad Research - NASA RETHi Institute

Intern for Solar Turbines Test Engineering → Full Time Test Engineer

<u>2026 Purdue Engineering Fellow</u>
Top 0.05% of the School of Engineering
Receives $25,000 after graduation

→

Tanmaee Ledalla and Sofia Velarde named Purdue Engineering Fellows

Latest cohort of seven seniors selected as Purdue Engineering Fellows

TEAM STRUCTURES

- How do you organize a community of different sizes.
- What structure do other teams use.
- What roles are required in a team.

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Team Structures – Purdue University

<u>Growing your team</u>

- Founded in 2012 over 13 years of continuous development
- Grown from a small 10-member team to thriving organization of 120+ student
- Recruitment Strategies:
    - Club Callouts + Campus Fairs
    - Engaging with certain majors
    - Personal Connections + Peer Recommendations
- Retention
    - Retaining Members can be challenging – structure is key
    - Establish clear onboarding projects to build basic skill
        - Strong subteam leadership

Team Structures – Purdue University

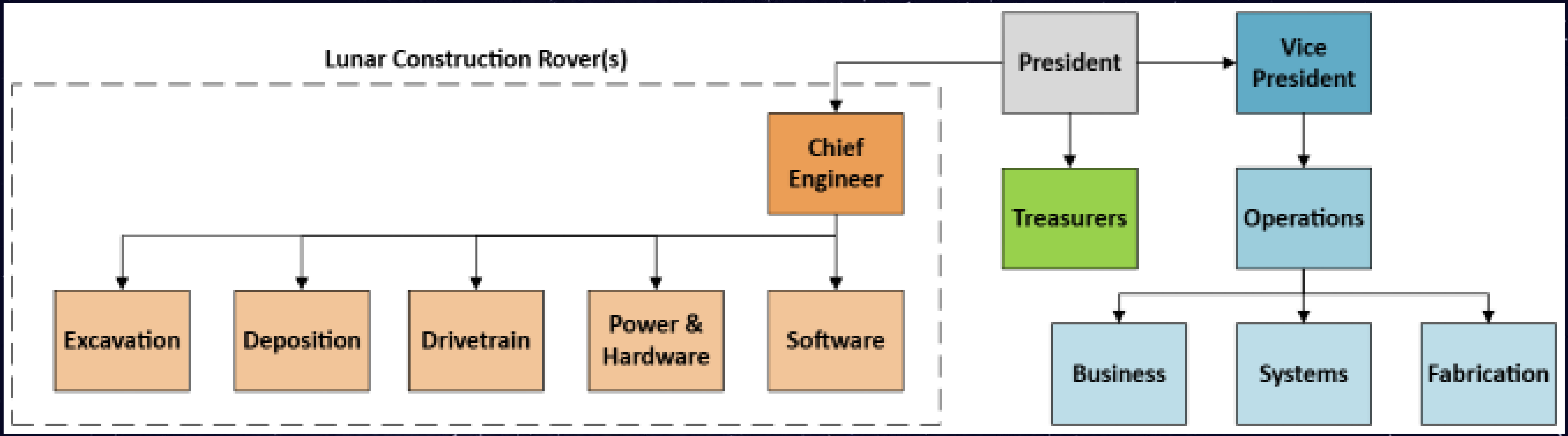


Figure 1. Initial Team System Hierarchy

Team Structures – Purdue University

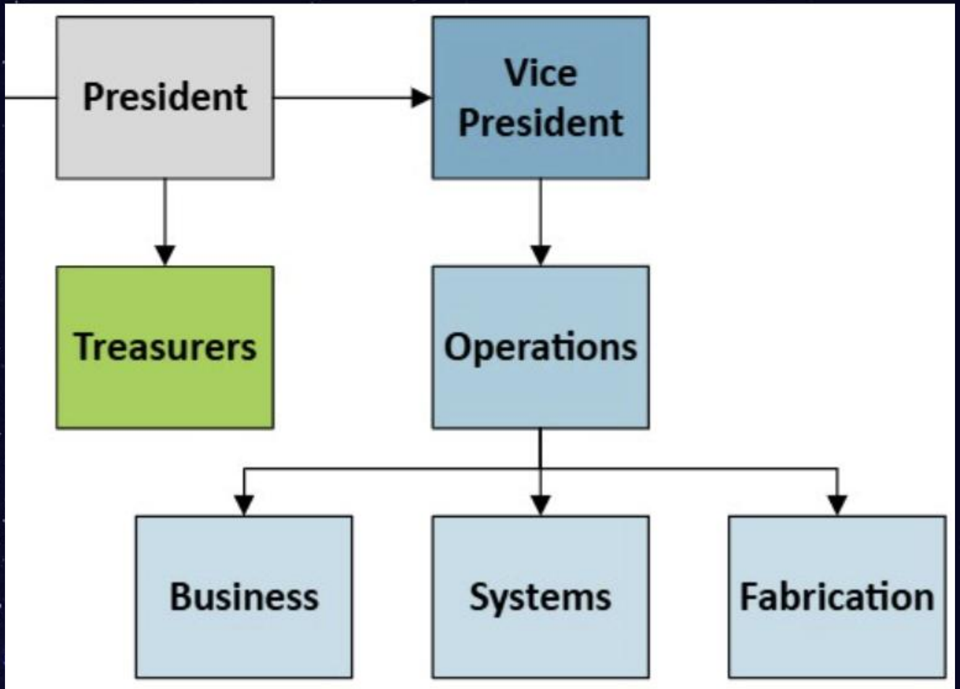
President *[Highly Recommended]*
- Primary Contact for Team
- Oversee Recruitment
- Team Logistics, Schedule, Planning
- Responsible for submitting and meeting competition deliverables/requirements

Vice President *[Optional]*
- Assist the President in general duties
- Plan outreach and social events
- Assist in coordinating team deliverables and trips

Treasurer *[Optional]*
- Work with President to acquire and manage funds

Operations *[Optional]*
- Business operations (merchandise, social media, corporate relations)
- Ensure systems engineering standards and competition deliverables
- Manage assembly space, training, and equipment

Executive Team



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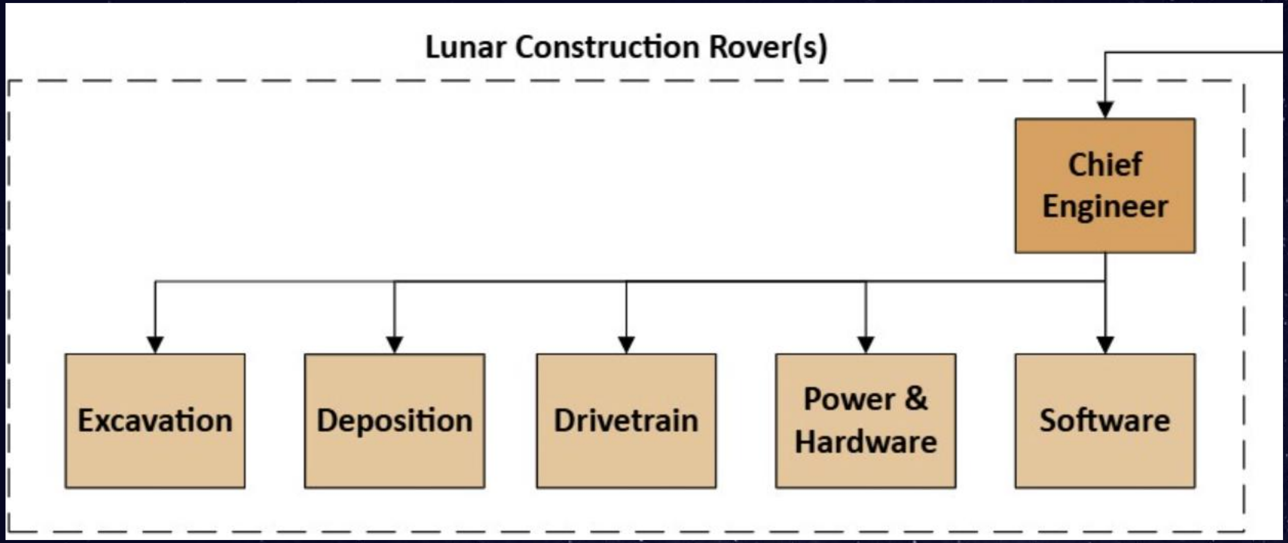
Team Structures – Purdue University

Robot Design Team



- ***Chief Engineer*** – overall technical lead and manages all the technical subteam leads
- ***Excavation Lead*** – in charge of robot's mining system

Previously Ex-Dep

- ***Deposition Lead*** – in charge of depositing/dumping regolith from excavation
- ***Drivetrain Lead*** – in charge of frame and wheels, incorporating every system on one base
- ***P&H Lead*** – in charge of the P&H box that distributes + supply power to systems
- ***Software Lead*** – in charge of Autonomy + programming of robot

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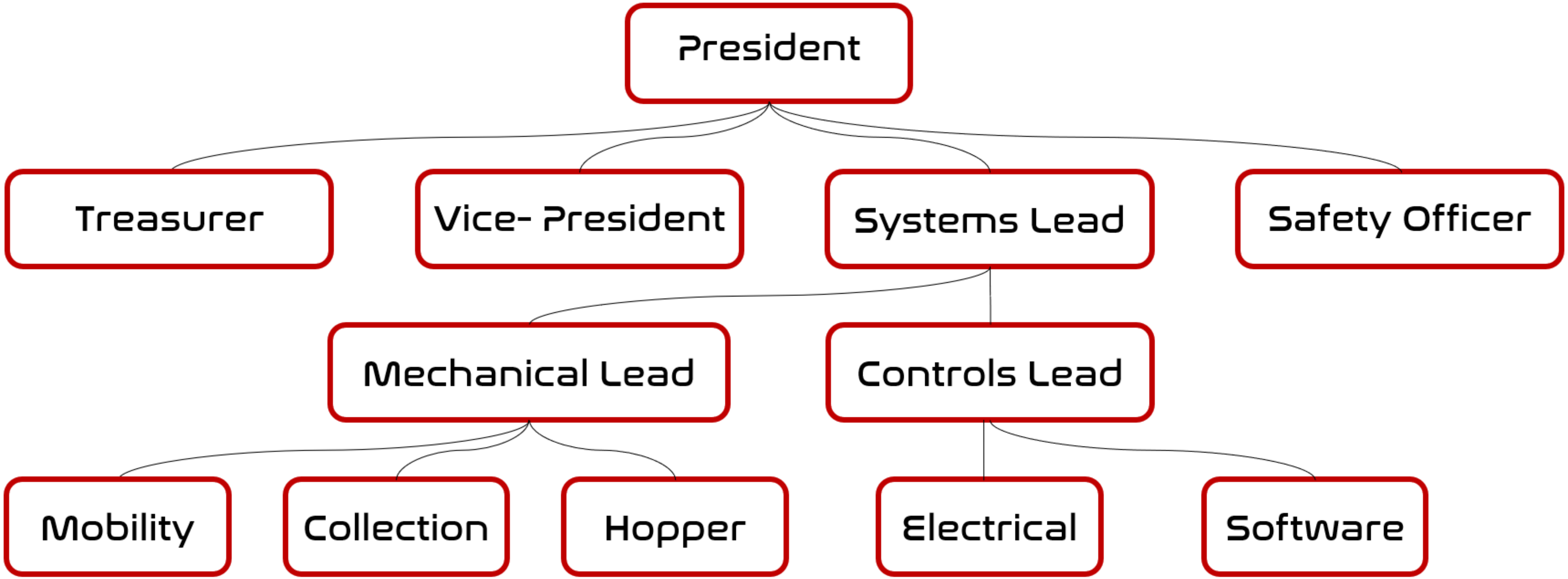
Team Structures – Iowa State University



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LEVERAGING SYSTEM ENGINEERING

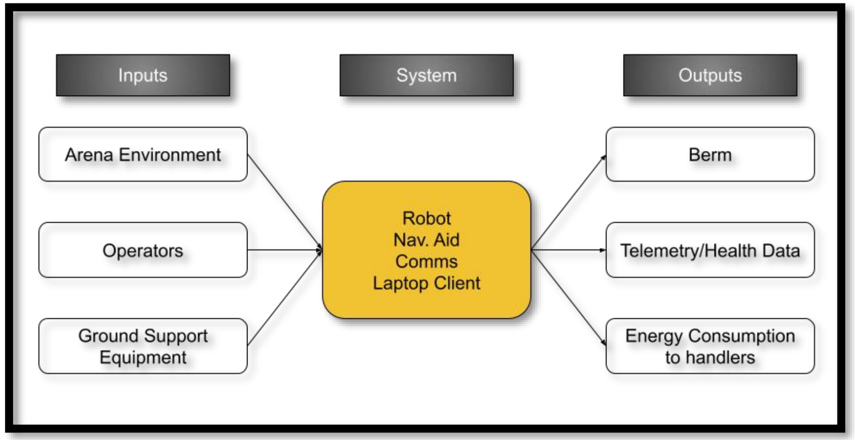
- What tools are used to build a system out.

- How is systems leveraged to improve the robot.

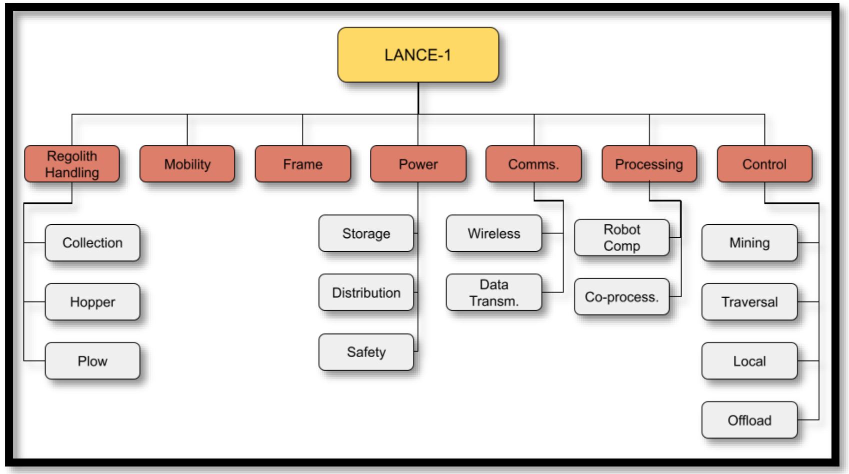
Note: There will be links to supporting tutorials on NASA's System Engineering process in the UK Lunabotics Guidebook.

Leveraging System Engineering – Iowa State University

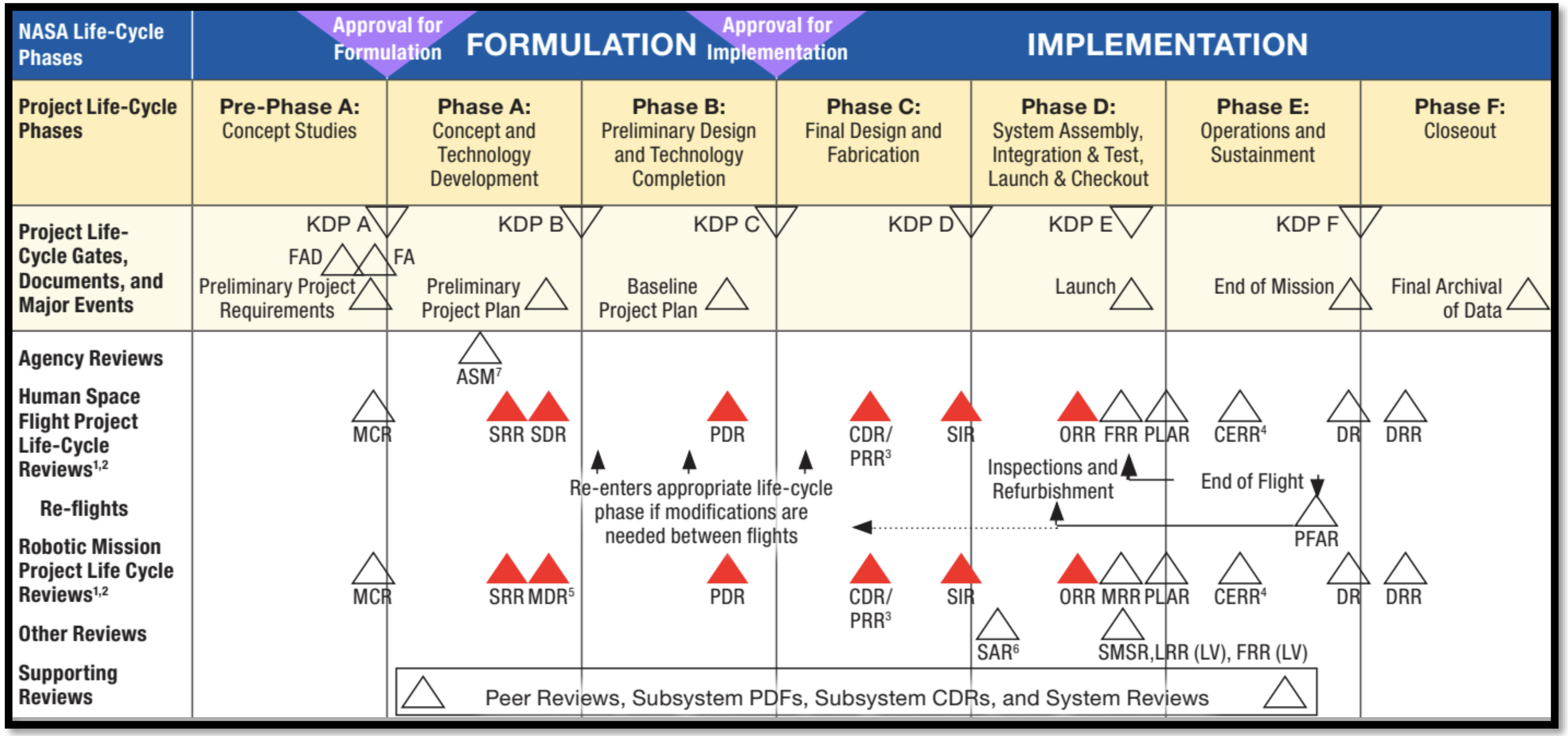
Systems Definitions



Systems Hierarchy



NASA Systems Engineering Handbook



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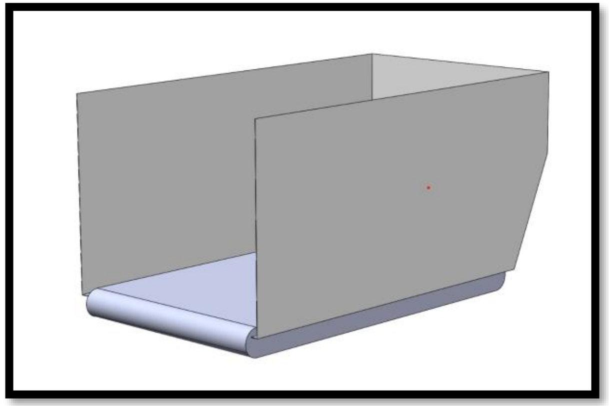
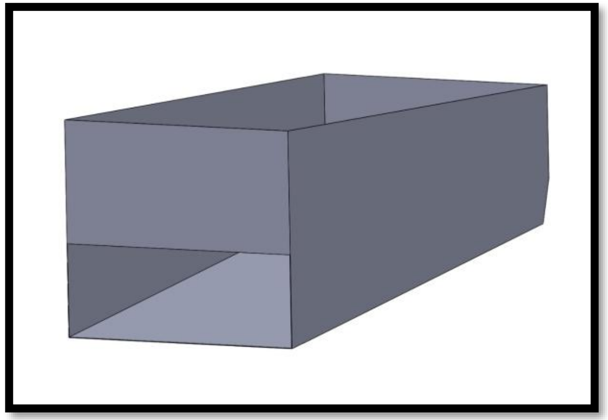
Preliminary Design Review – Iowa State University

CAD Concepts





Trade Study

	Weighting	Gravity Controlled	Conveyor Controlled
Weight	3	S	-1
Offload Speed	6	S	S
Volume	9	1	1
Power Consumption	3	S	-1
Offload Control	9	S	1
Total Weighted Score	33	9	12

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Leveraging System Engineering – Purdue University

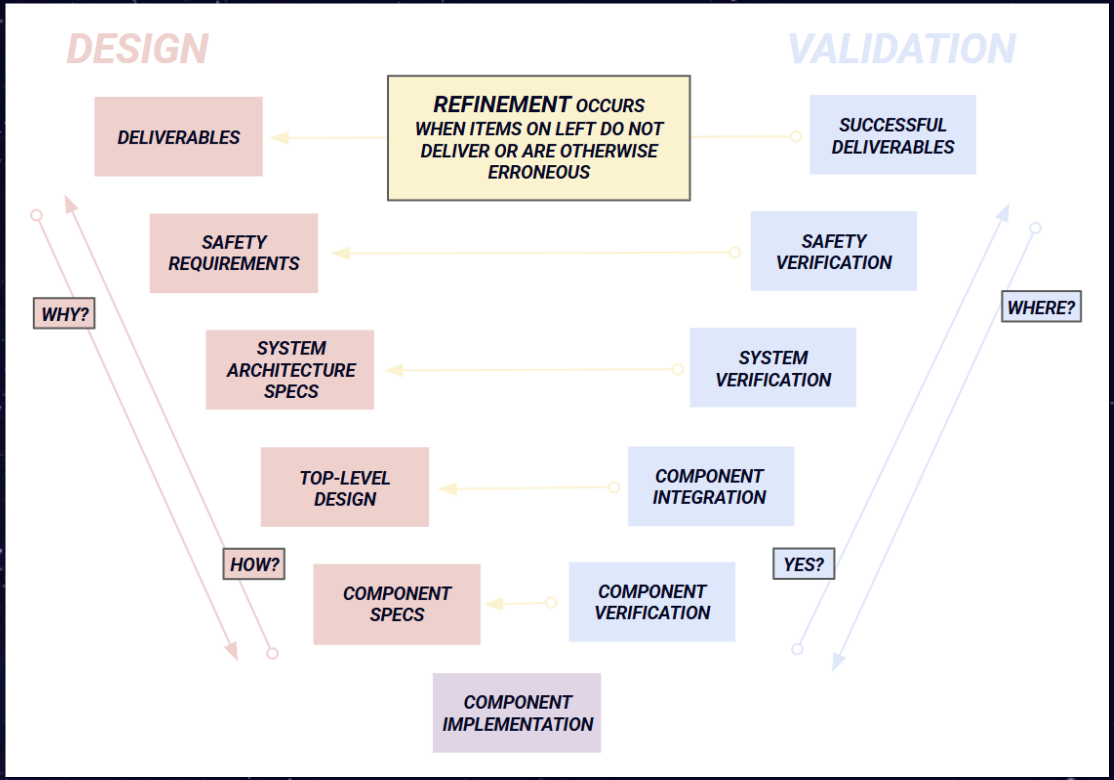
SYSTEMS ENGINEERING…

- Provides structured accountability
- Simplifies communication between subteams
- Creates framework for successful integration

This is **very important** with 120+ members!

METHODOLOGY EVOLUTION

- **2022:** Created Systems subteam (tasks previously fell to executive leadership)
- **2023:** Started standardizing Systems processes, introduced Integration Plan and Risk Assessment
- **2024:** Streamlined Stakeholder Requirements into RSRs
- **2025:** Added two review gates, introduced umbrella subteam of Operations (Fabrication + Business + Systems)



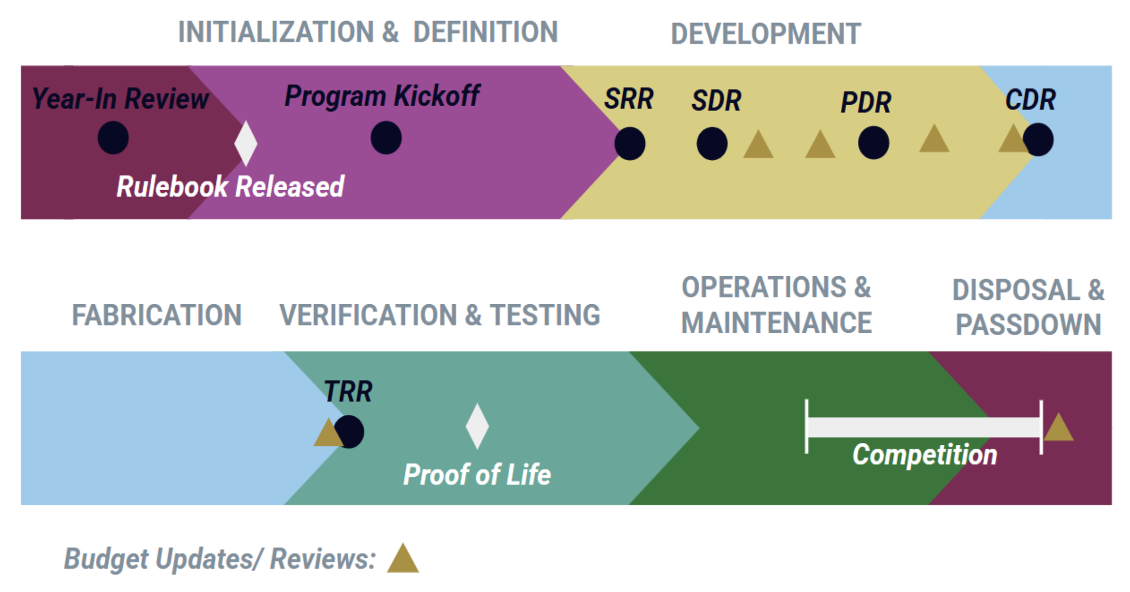
The Systems Engineering V diagram (above) depicts our overall process

Leveraging System Engineering – Purdue University

MAINTAINING ACCOUNTABILITY: REVIEW GATES

- Year-In-Review *[Optional]*
  - Useful for refreshing on prior discoveries
- System Requirement Review (SRR) *[Optional]*
  - Assigning deadlines and broad yearly goals
- System Design Review (SDR) *[Highly Recommended]*
  - Initial system insights and overall robot theories
- Preliminary Design Review (PDR) *[Highly Recommended]*
  - Major design decisions finalized, general CAD completed
- Critical Design Review (CDR) *[Highly Recommended]*
  - All robot designs finalized. Ready to begin manufacturing
- Test Readiness Review (TRR) *[Optional]*
  - End of manufacturing
- Decommissioning Review *[Optional]*
  - Enable us to **better prepare for** and **track** each step of engineering design cycle

The Engineering Lifecycle Diagram shows a timeline of our process



Leveraging System Engineering – Purdue University

CREATING SYSTEMS ENGINEERING METHODOLOGY: GENERAL ADVICE

- Do research on existing approaches (NASA and otherwise)
  - In 2023, we complied documentation from various engineering companies to create an Integration Plan and Risk Assessment (still currently in use)
- It's really easy to overcomplicate—but also to oversimplify
  - Systems Engineering should be flexible and ready to adapt based on situation
  - If something isn't working, you probably don't need to push it → either investigate how to adapt it or get rid of it
  - We added a lot more opportunities for holistic review this year by adding Year-In-Review, Decommissioning Review, and weekly smaller-scale Technical Interchange Reviews to fill our team's need for better/smoother integrations
- 'Documentation!!!!
  - 99% of Systems Engineering is just communication → take comprehensive notes at design reviews, keep an updated calendar, check in weekly about updates and decisions, etc.
  - Much easier if you have solid system documentation
-

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ROBOT DESIGN

- What components make up a robot.
- Best practices to develop a component.

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Robot Design Overview– Purdue University

18mins

- Bucket ladder for excavation
  - Easy for automation, reliable
- Conveyor belt deposition bin
  - Low power, extremely reliable
- 200W brushless stepper motors
- 3D printed covers to protect from dust
- Primary materials: aluminum, PLA
- 55 kg (80 kg max)

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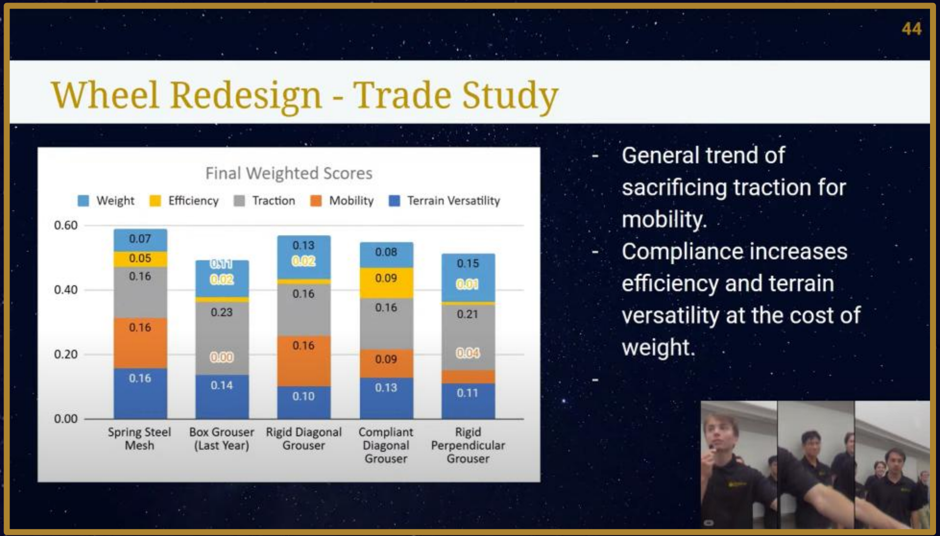
Design Considerations – Purdue University

18mins

- Reliability is key!
  - Doesn't jam with small rocks
  - Repeatable motions
- Mitigate dust
  - Protect key components/systems (belts, chains, electronics, etc)
  - Use shrouds to generate less dust
- Simple is better than complex
- Always be thinking about cost, manufacturing, assembly

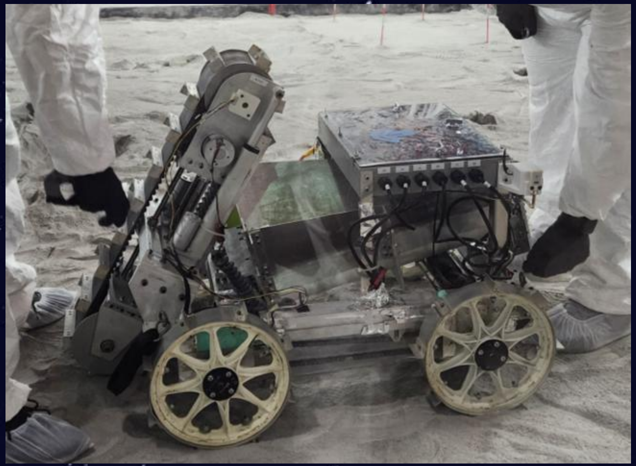


Robot History– Purdue University

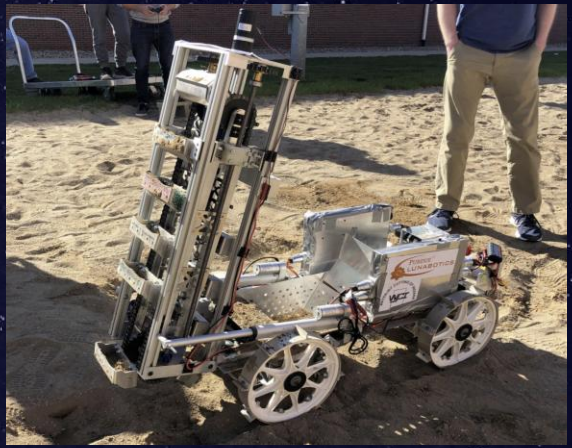
18mins

Design Evolution:
- Improving Bucket Elevator
- Deposition Experimentation

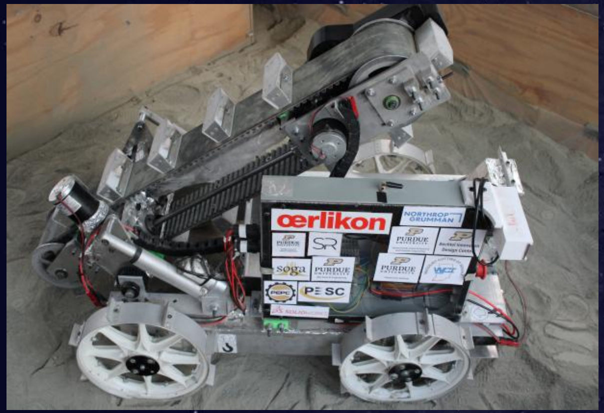
2024-2025



2024-2023



2022-2021

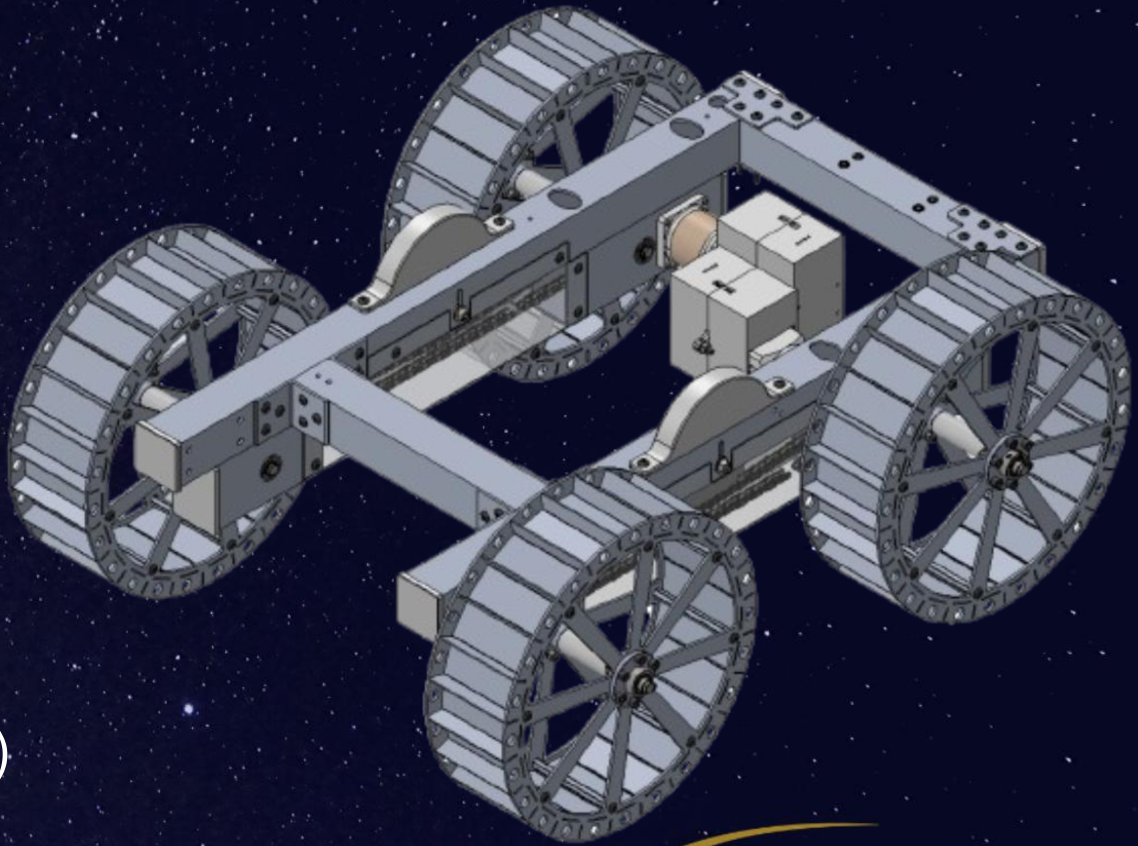


2023-2022

Drivetrain – Purdue University

18mins

- Four-wheel skid steering
  - Two motors, chain drives
- Box tubes bolted together
  - Strong, easy routing,
- Grousers for increased traction
  - Flaps on the outer diameter
- <u>Turning is the big challenge</u>
- Other options:
  - Belt vs chain & sprocket vs 4 motors
  - Steering system, suspension (rocker bogey)
  - Tank treads



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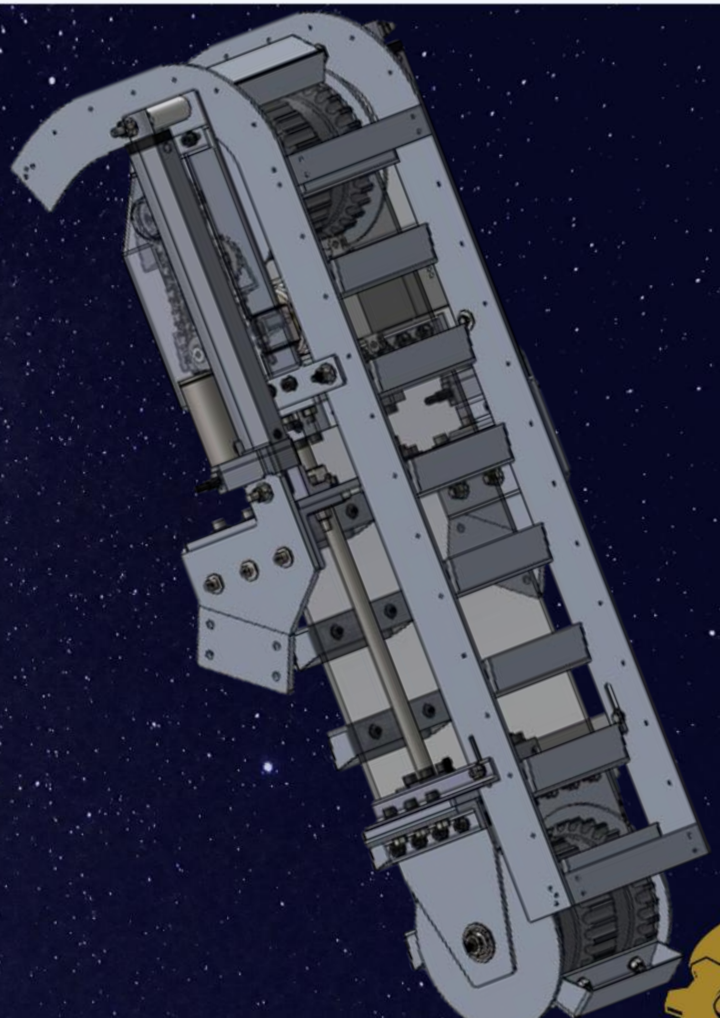
Excavation System – Purdue University

- Bucket ladder system
- Linear actuators to raise/lower
- Tarp cover to mitigate dust
- Bolt-driven tensioner
- Primarily flat plate + L channels
- Fixed mining angle
- Other options:
  - Four-bar actuation
  - Front loader/backhoe
  - Rotating bucket drums



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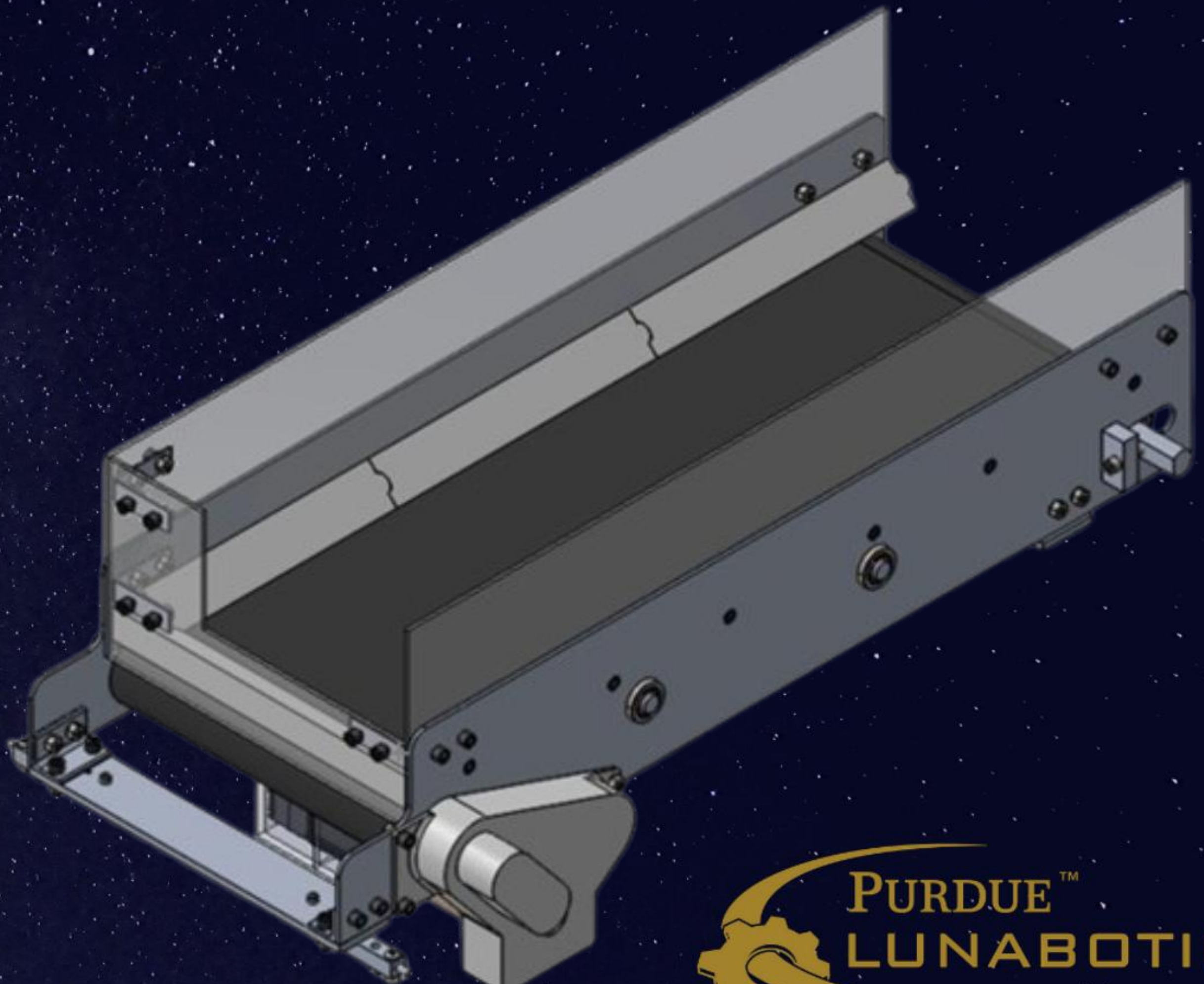
Deposition System – Purdue University

Deposition

- Nylon conveyor belt
- Slopes to keep regolith on belt
- Pulleys made from pipe + inserts
- Low-torque, low-power system
- Crowned pulleys to center belt
- Other options:
  - Dump truck
  - Integrated excavation/deposition



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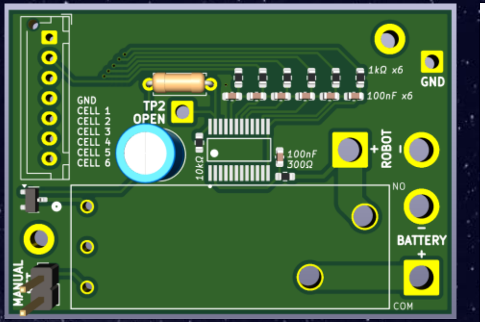
Electrical System – Purdue University

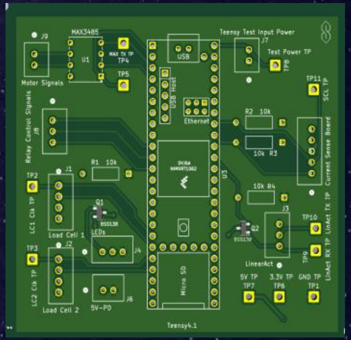
Electrical Box Design

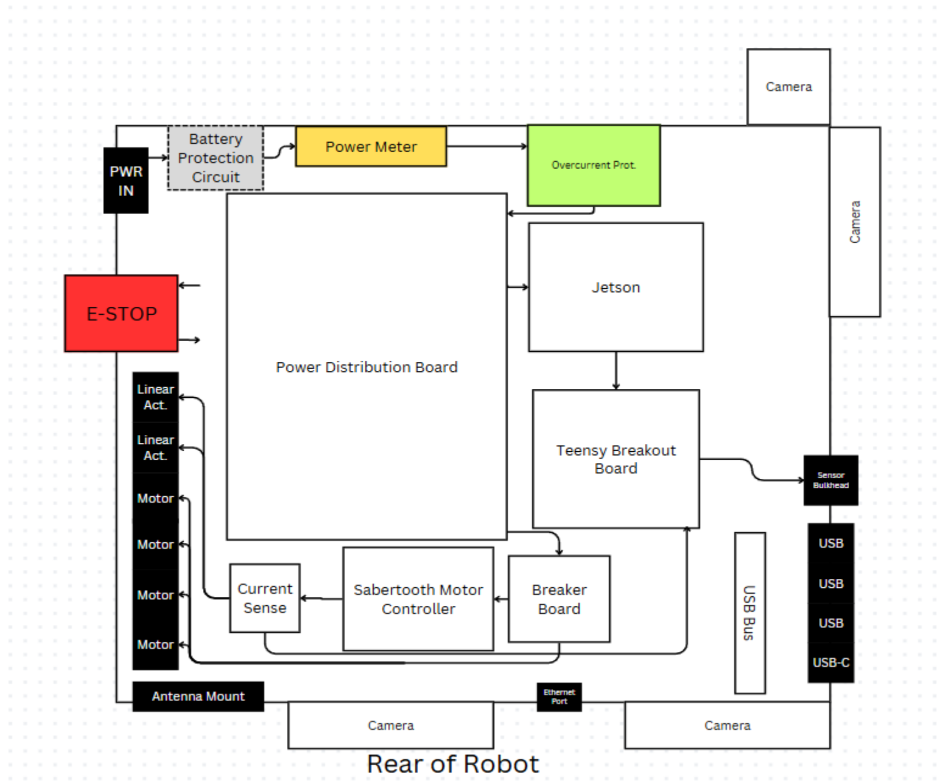
- Fully removable box
- Custom Designed

Battery

- 24V LiPo 350Wh
  - High Energy Density
- Battery Protection Circuit







Controls – Purdue University

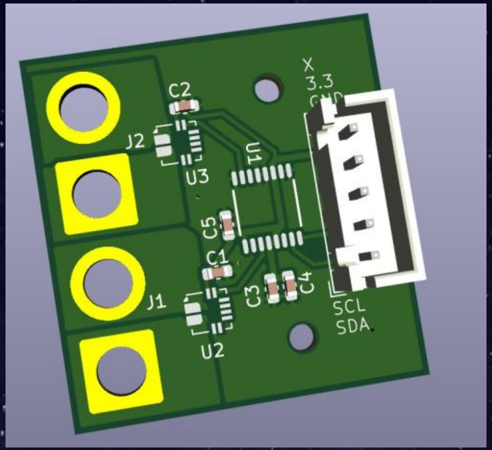
Compute

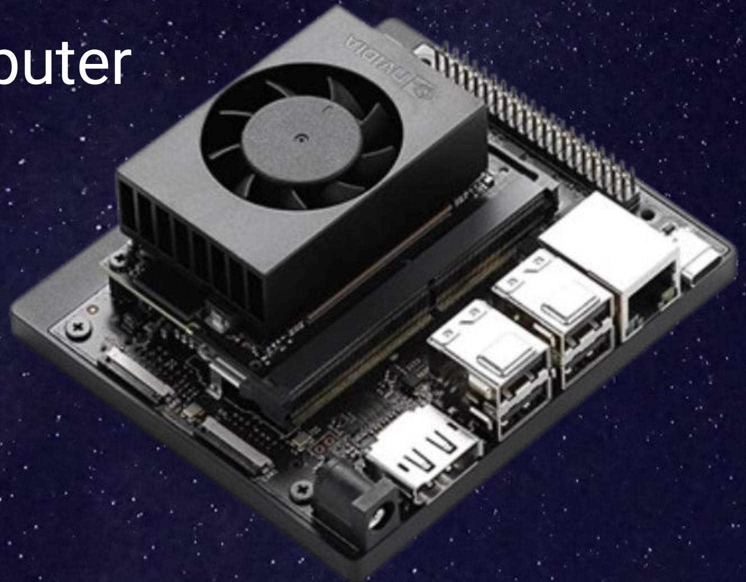
We Use:

- Jetson Orin Nano
- Teensy 4.1

Others Also Use:

- Laptop Computer
- Raspberry Pi
- Mini PC





Sensors

We Use:

- Current Sense
- Encoders
- Load Cells

Others Also Use:

- Distance Sensors
- Beam Break
- Limit Switch

PURDUE™ LUNABOTICS

Robot Design – Iowa State University

2023
MARS VI

Design Philosophy

- Start with System Engineering!
  - Mathematical Analysis
  - Identify gaps in knowledge
  - Test your hypothesis
  - Assign Requirements
- Maximize Second Moment of Area
- Account for regolith infiltration
- Use what you are used to and build off knowledge
- Identify correct motor and gearbox requirements

2011
ART-E 2

2015
HERMES
2.5

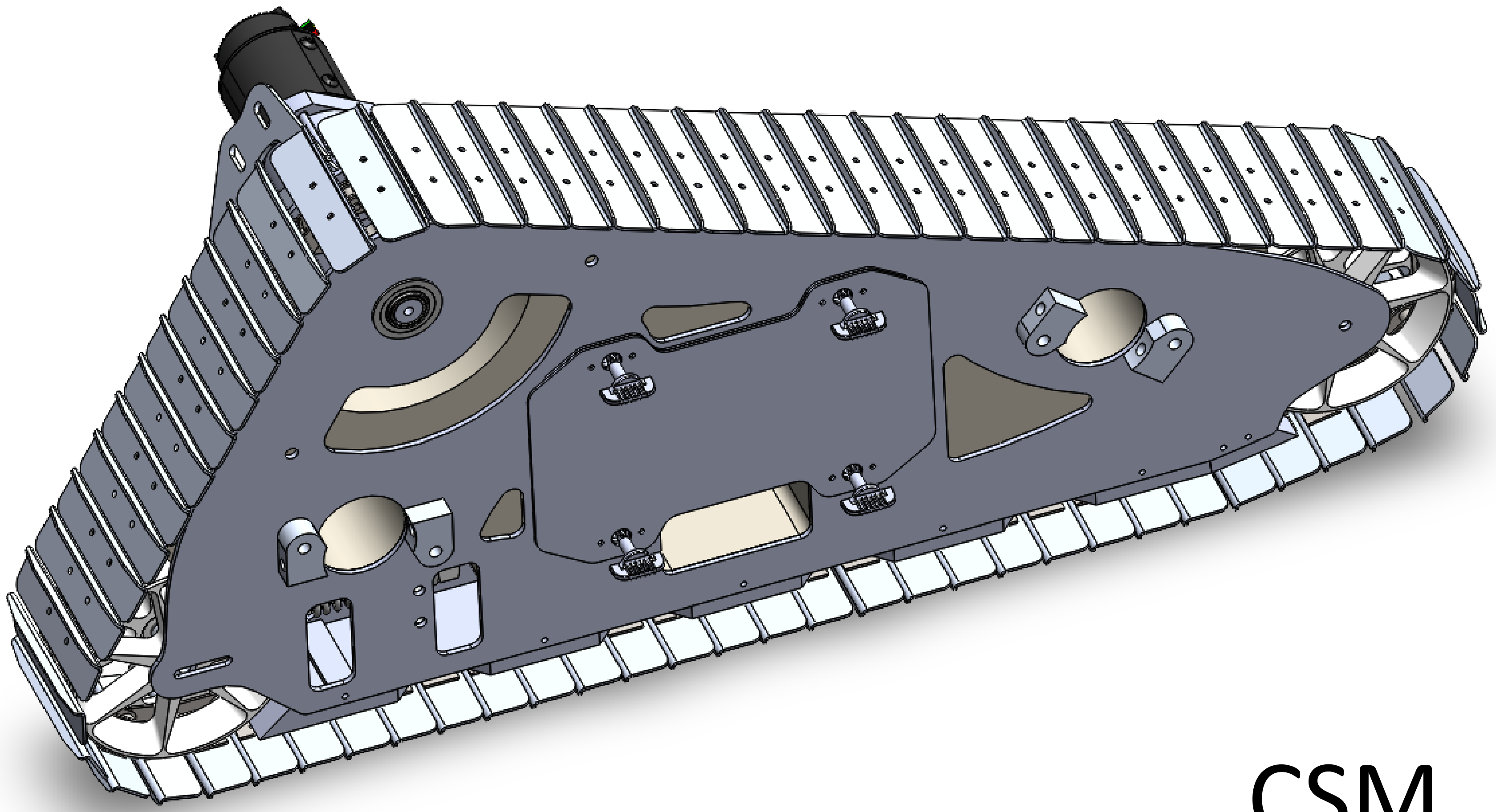
2017
Space
Ketchup
& Space
Mustard

Robot Design – Iowa State University

Robot Design – Iowa State University

Mobility System

- Motor mount position
- Contact surface area
- Ground pressure
- Wrap angle
- Traversal friction
- Sprocket connection



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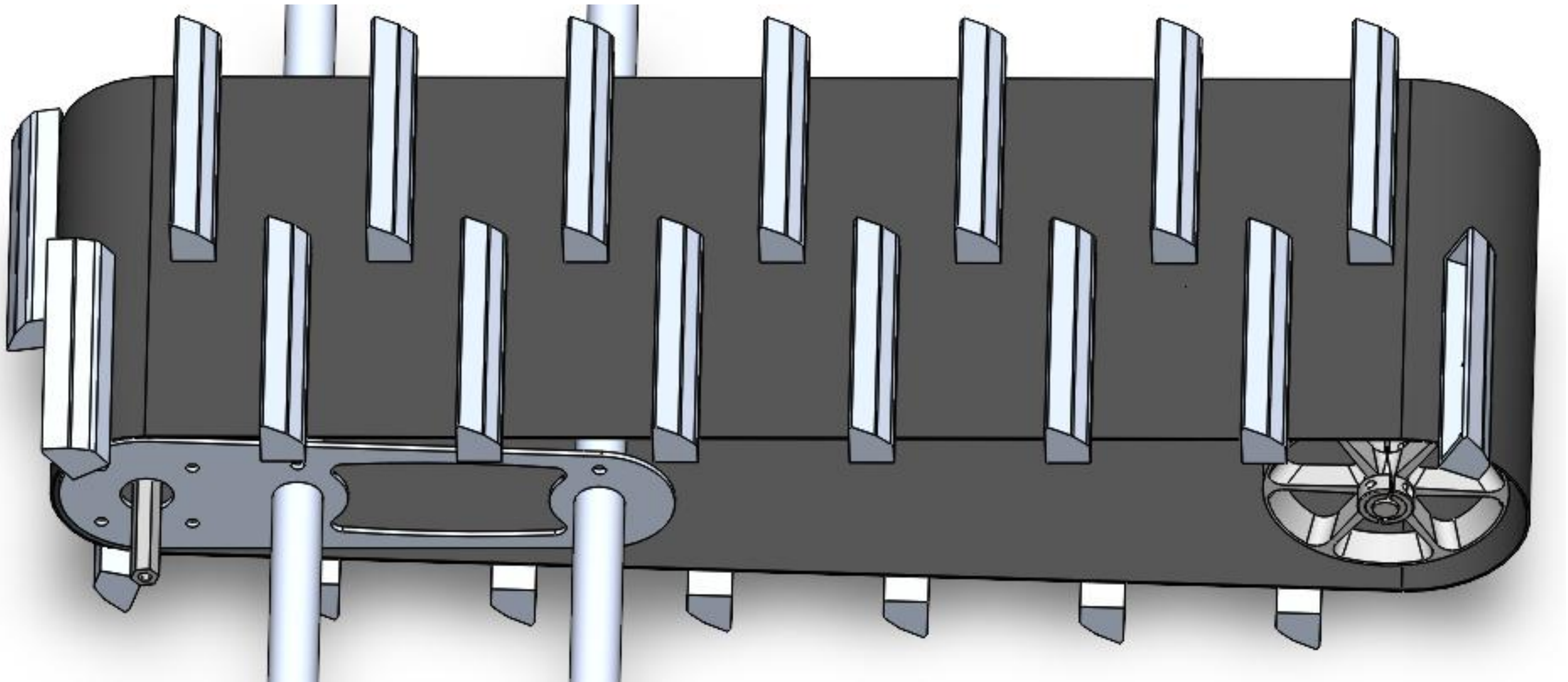
Robot Design – Iowa State University

Excavation

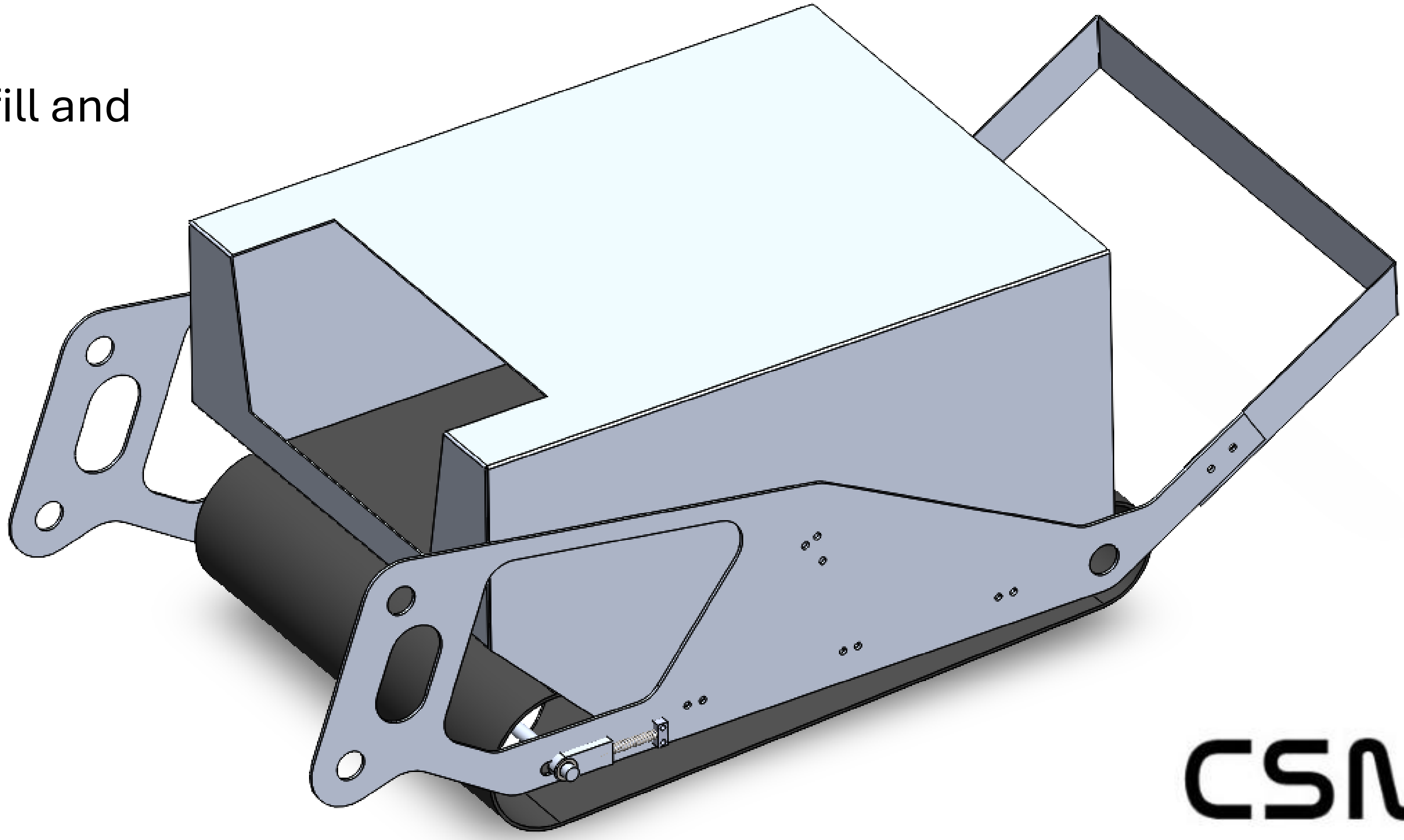
- Staggered buckets
- Belt driven
- Spring suspension
- Throw angle



Robot Design – Iowa State University

Deposition

- High angle of repose needed
- Shorten actuators
- Double usage of axles
- Offload skirt to reduce spread
- Understand system at different fill and tilt states



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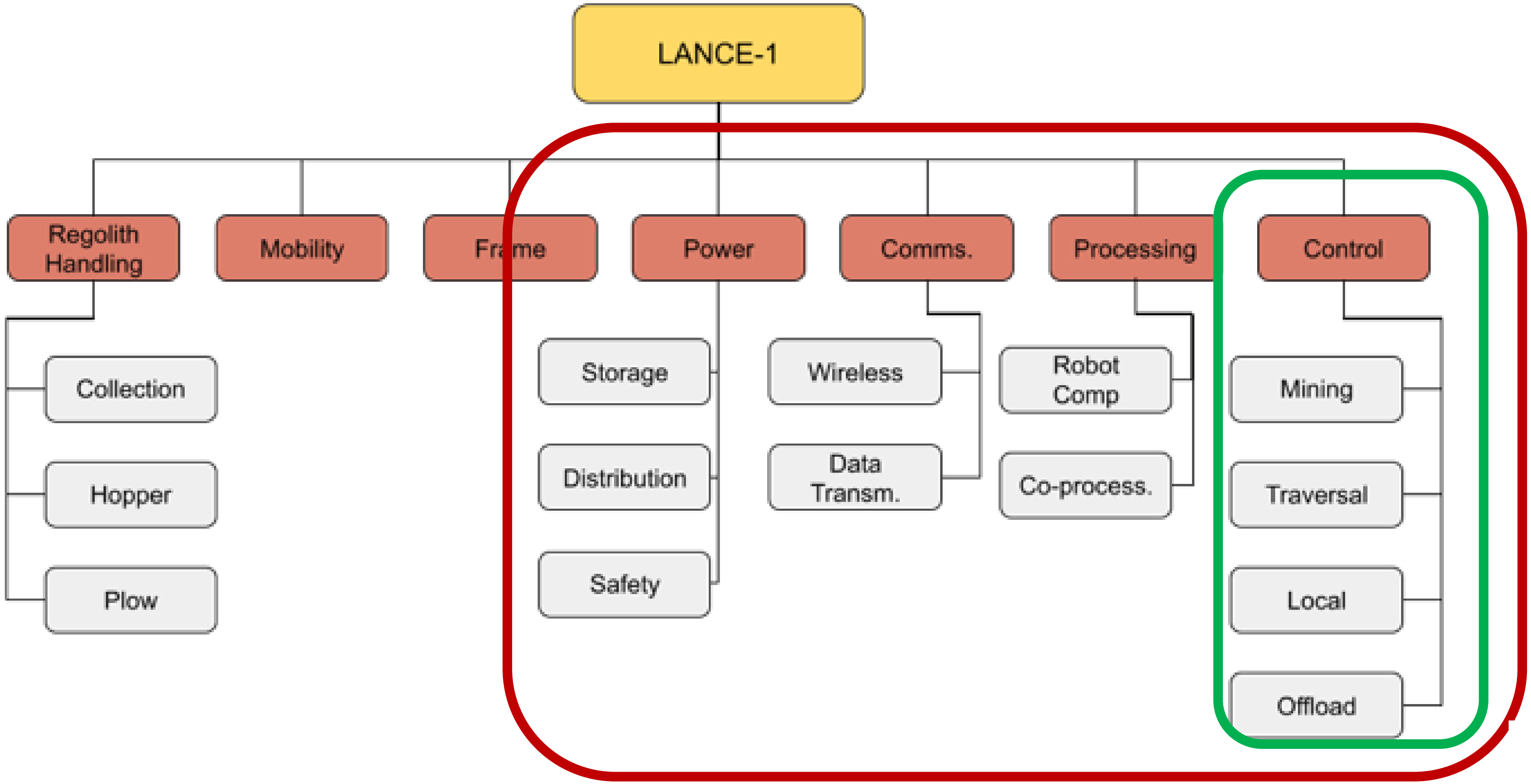
Controls Breakdown – Iowa State University



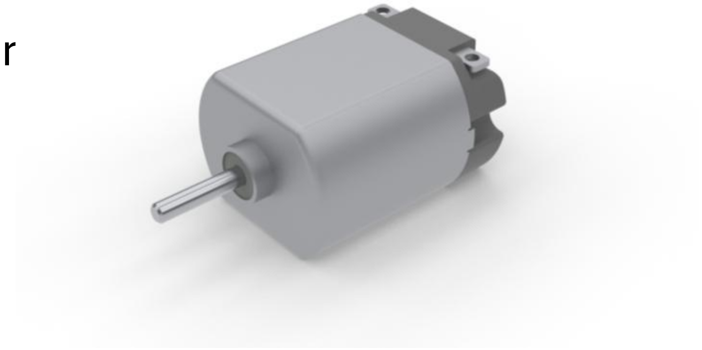
Robot Power – Iowa State University

Constraints:

- Mass
- High Transient Current Draw
- Power Distribution
- Mechanical interface constraints
- Controls interface constraints

Results:

- Higher Voltage is better
- Li-Pos are great!
- Watch your VDI (~5% drop max)
- Coordinate on motor choices
- Watch the differences between BLDC and BDC motor



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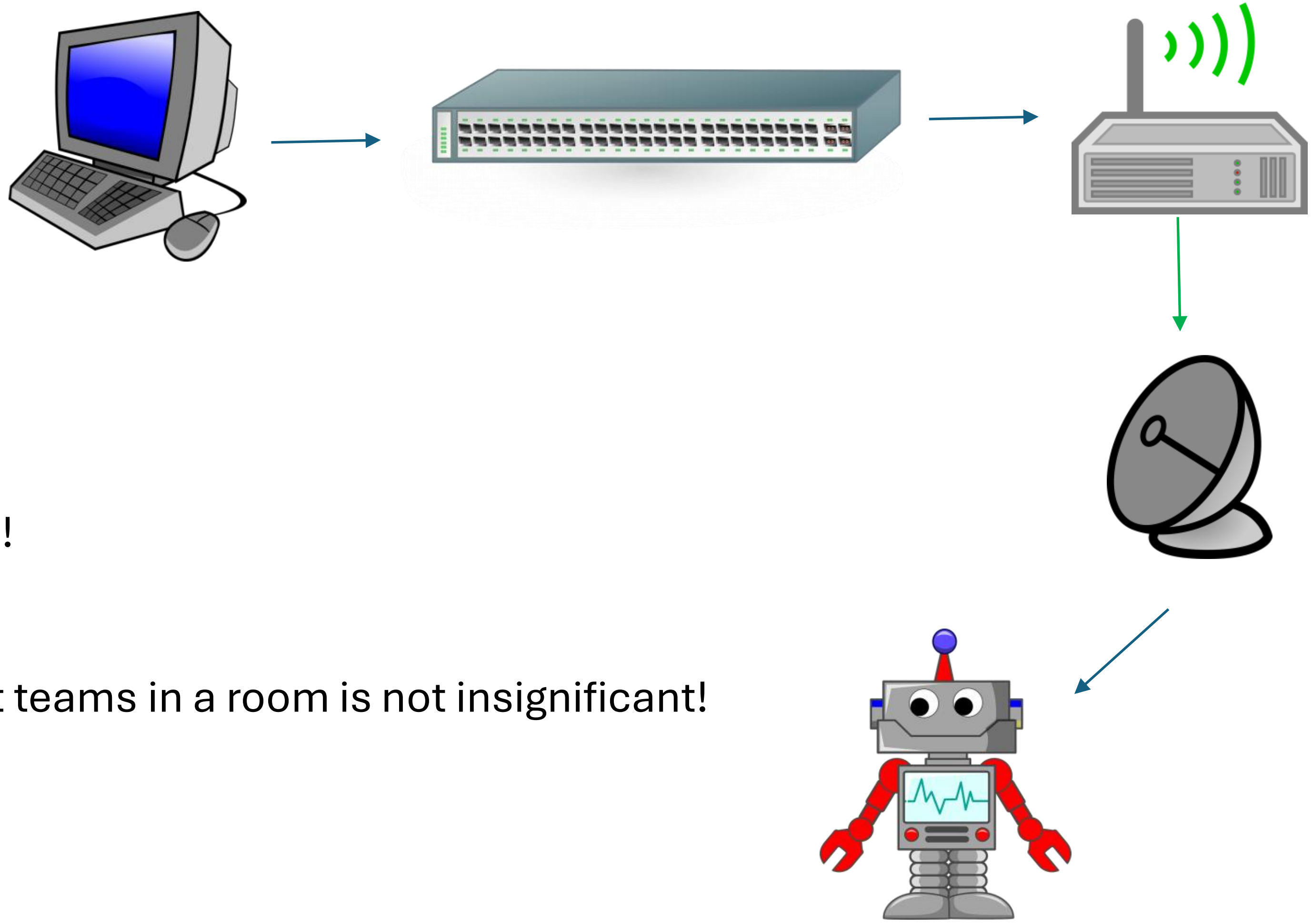
Robot Communications – Iowa State University

Constraints:

- Mass
- Power Consumption
- Latency
- Bandwidth
- Interference
- Packet loss

Results:

- All 802.11 hardware is not the same!
- Compression is your friend
- Wireless Bridge / Travel Router
- The interference caused by 50 robot teams in a room is not insignificant!



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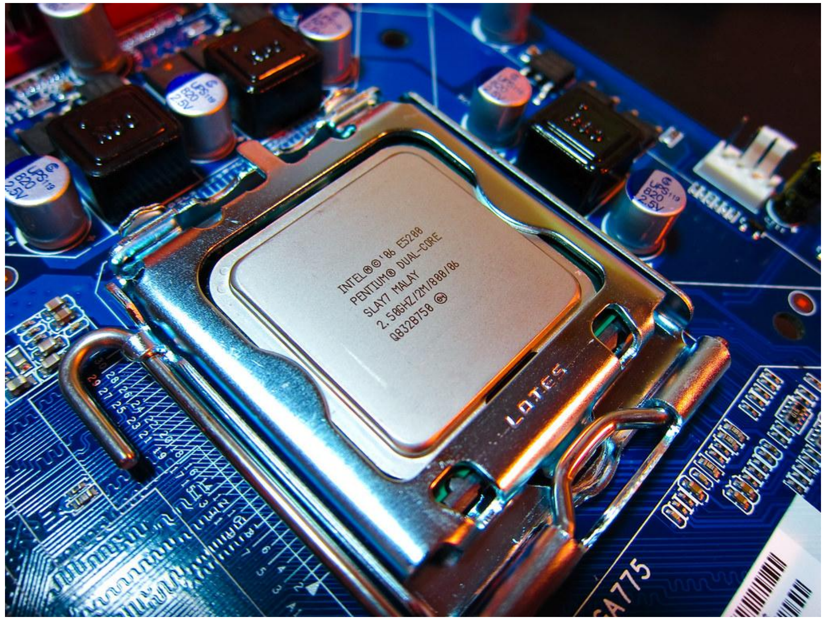
Robot Processing – Iowa State University



Constraints:

- Mass
- Power Consumption
- Real time compute requirements
- IO requirements
- Restrictive software distribution

Results:

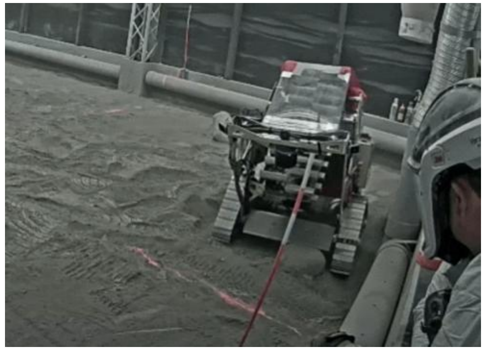
- ARM is efficent, but most SBCs are not quite enough
- X86-64 is less power efficient, but you hit thermal dissipation problems
- GPU sounds great, but GPU code is fairly specialized
- Building from source comes with challenges
- Industrial applications tend towards Linux, High School level robotics parts tend towards Windows, MAC is hard
- Off robot compute is constrained by latency and bandwidth considerations

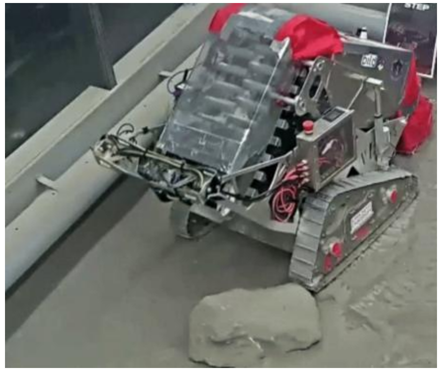
Robot Autonomy

- How to approach autonomy.
- Example systems.

Autonomy - Iowa State University

- Simple tasks are trivial, advanced/full autonomy is exponentially difficult to achieve
- Considerations:
  - Consistency is key
  - Resilience in edge cases
  - Functionality over speed/algorithmic efficiency ("if it works it works")
- Advice:
  - **Development takes 10X longer than you think it will, R&D takes 100X longer...**
  - Planned Abstraction
  - Simpler systems --> less bugs





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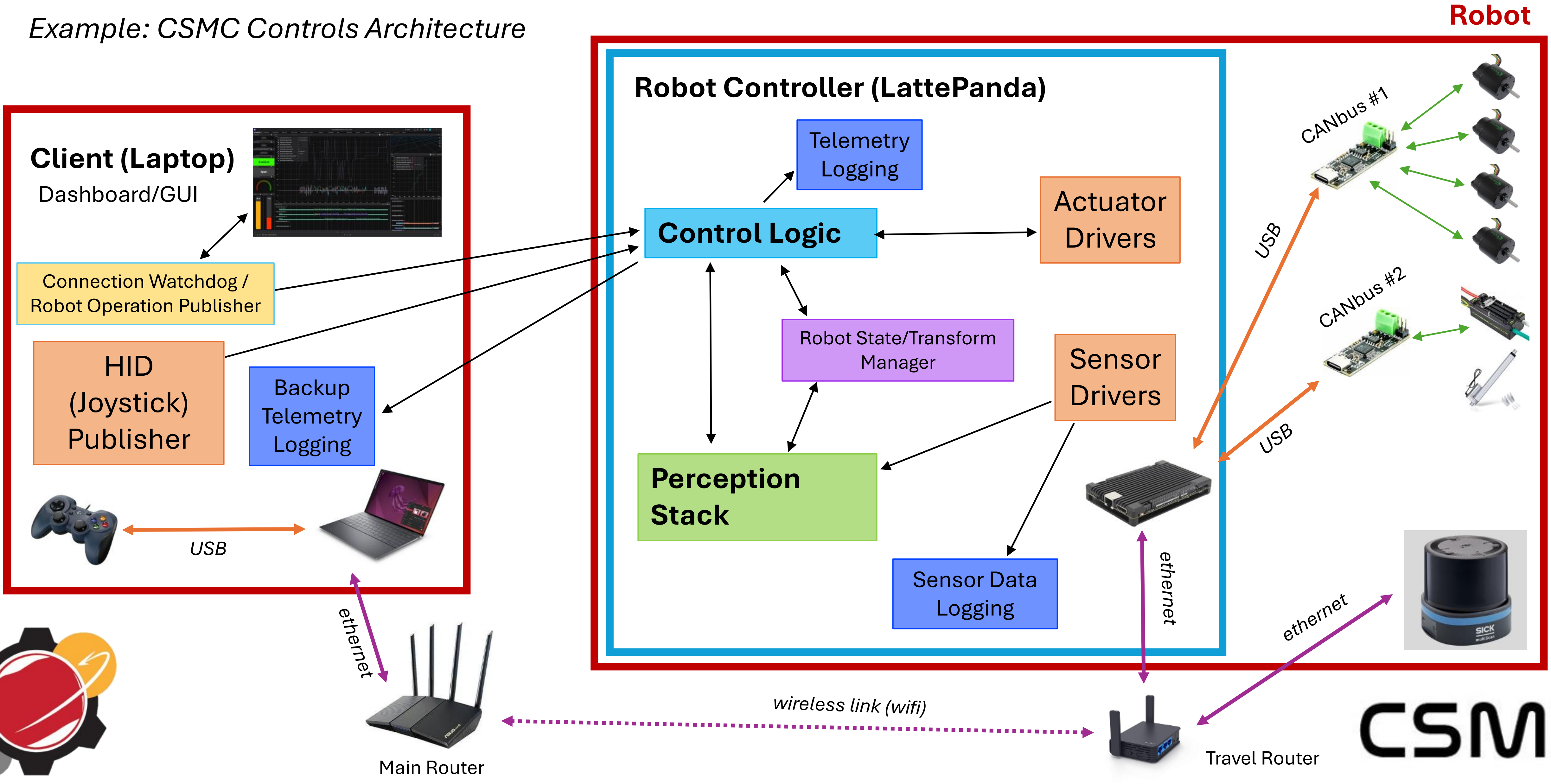
Autonomy – Iowa State University

- *Example: CSMC Controls Architecture*



Autonomy – Purdue University

ROS (Robot Operating System)

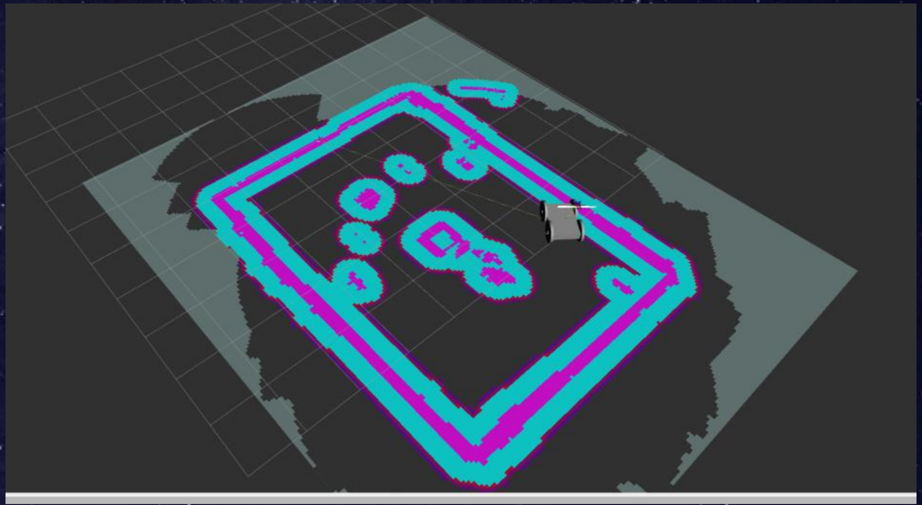
- Provides a method for different programs to access shared data and communicate
- Allows us to access a vast array of libraries to quickly add functionality

Gazebo Simulation

- Physics-based simulation of our arena to allow for quicker development

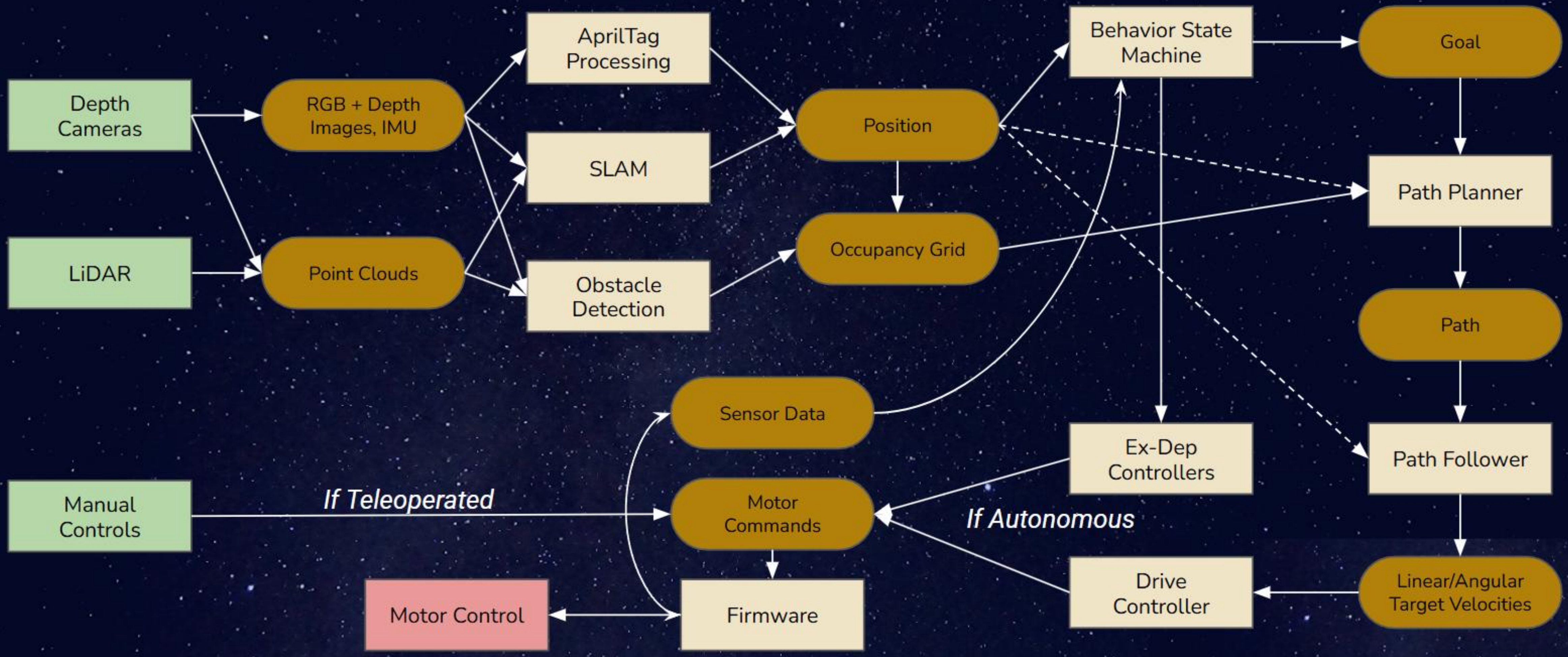
Languages

- Python
- C, C++



PURDUE™ LUNABOTICS

Autonomy – Purdue University



Autonomy – Purdue University

- **Perception**
  - Depth Camera – Intel RealSense D455
  - LiDAR – UniTree L2
- **Localization + Mapping**
  - RTAB-Map
- **Path Planner**
  - D*
- **Path Follower**
  - Point to Point
  - Pure Pursuit
- **Drive Controller**
  - Differential Drive Math
- **Behavior**
  - State Machine
  - Individual Controllers
- **Firmware**
  - Teensy Driver Node
  -

Autonomy – Purdue University

Misc Advice

- NEED a Mechanically Consistent Robot
- Plan for Autonomy
- Test Test Test
- Use existing libraries to start
- Start with minimum viable product
- Do processing on the robot
- Be ready to fix code at competition
- Ask for help

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Operations

- How to prepare for competition.
- Best practices for success.

Funding and Budgeting

- Funding
  - University & Departmental Support
  - Corporate Sponsorships – Industry Partners
  - Licensing & Technical Sponsorships
  - Space Partnerships – Workshops + Offices
  - Corporate Mentorships – Professional Guidance & Networking
- Budgeting
  - Have a total operating budget for the year
    - Each subteam can creates an estimated budget
  - Update the budget monthly
    - Important to understand how this money will carry over next year
- Total Robot Costs can range from $5k-10k
- Total Operating Costs can range from $2k-10k

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Mission Control– Purdue University

Setup

- 1 person designated to talk to judges
- 2 people from software to run autonomy/drive
- Laptop and Portable Monitor for visualization and monitoring

Competing

- Know the rules and what counts for points
- Know when to abort autonomy
- Be ready to plan around issues and failures.

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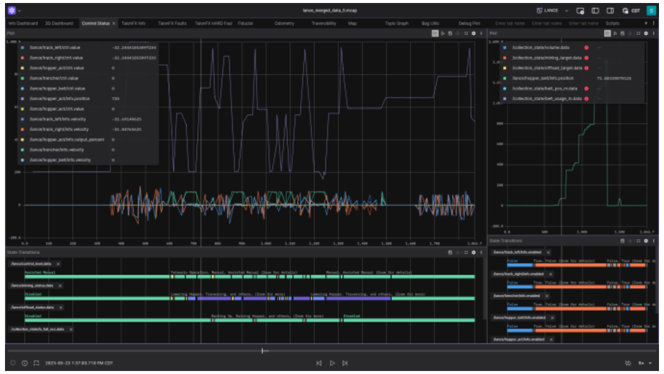
Preparing for Competition – Iowa State University

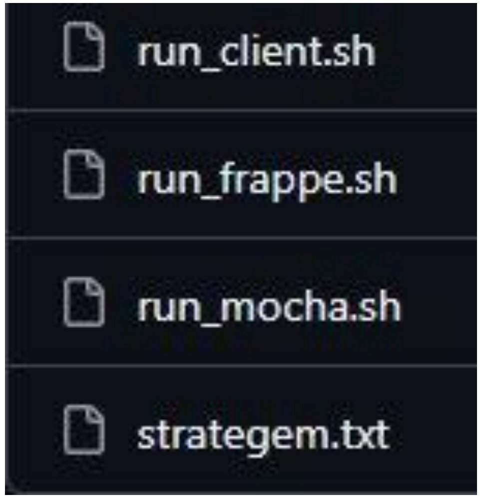
Systems:

- Create a mission plan:
  - Pre-run checklist
  - General strategy
  - Operation order and time allocations
  - Contingency plan(s)



Controls:

- Automate EVERYTHING – in the heat of the moment you may not remember everything
- Consider what telemetry you need to see and how you will display it
  - Advice: "Third person" >> "first person" (data visualization / camera placement)
- Prepare to log telemetry and sensor data – this is useful for future development!



Mechanical:

- Bring spare parts (anything and everything can break)

Driving:

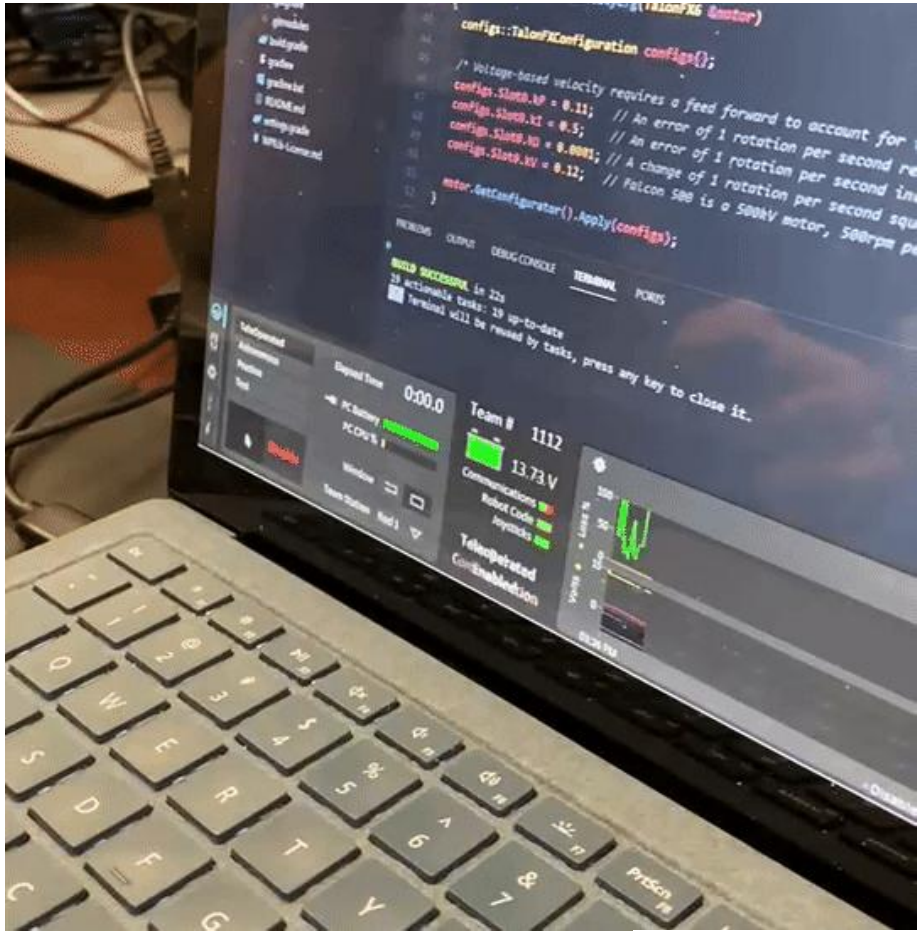
- Choose drivers who are cool under pressure, and/or know your robot really well
- Know the rules!
- Practice (hopefully)

CSM

Competition – Iowa State University

Advice:

- Don't panic
- Stick to your checklist no matter how obvious it may be
- Start by trying autonomy and revert to teleoperated operation if needed
- Prepare to improvise
- Be aware of system constraints - and which can be bent
- Take a breather as needed
- **Debrief immediately**



CSM

FACULTY GUIDANCE

- What is expected of a faculty advisor.
- How can you best support students.
- Benefits of being an advisor for a team.

Faculty Guidance – Iowa State University

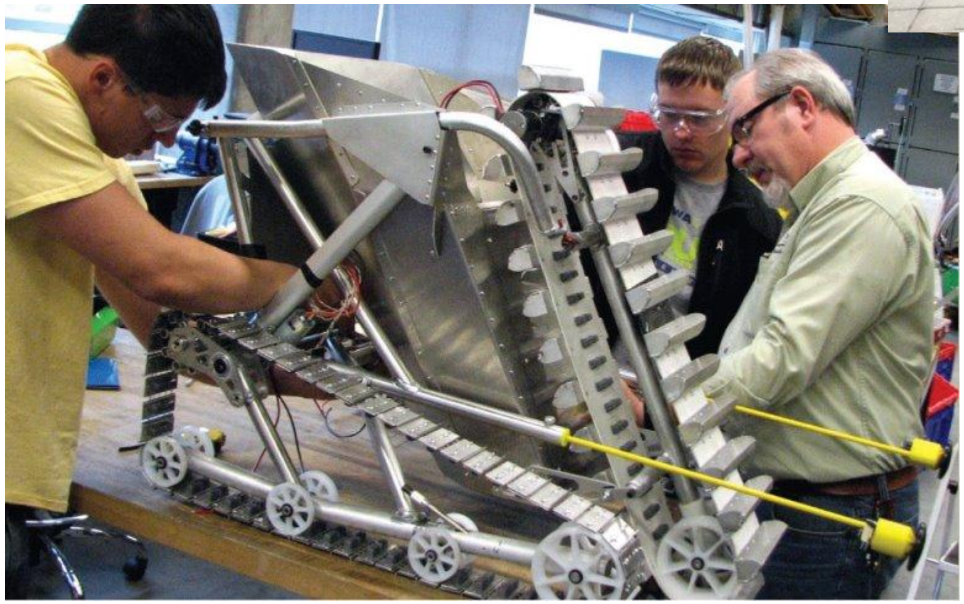
Key Elements of Leading a Student Team -

1) Get the team set up with elected leadership – President (or Chair), Vice President (Asst. Chair), Treasurer, System Lead, Mechanical Lead, and Controls Lead.
2) Stay alert to competition key dates and deliverables, make sure team leadership is aware of what is due and how it is to be submitted.

Faculty Guidance – Iowa State University

Supporting the Student Team

- Have regular meetings with team leadership to cover status of:
  - Funding from sponsors and grants
  - Systems engineering progress
  - Manufacturing progress (including training for shop safety).



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Faculty Guidance – Purdue University

5mins

Advising a strongly student driven/large team

- Likely some correlation
  - independence⟺size
  - club vs. class
- However, many student clubs at Purdue are fiercely independent
- Purdue also has in place facilities and procedures that may make it less necessary to be a "middleman" or relied upon or integral

"easier" on an advisor

→ **lost touch** with a team's week-to-week activities

→ **Extra mile** more important to attend unrequired activities and read club documentation

Faculty Guidance – Purdue University

- Benefits of attending unrequired activities, etc.
  - **Earn** trust or next-level respect the more you
    - show up and/or
    - show your interest through communication/questions
  - Flexibility or range in where you provide input to the team
- Input Strategy
  - Safety issues, first and foremost (Regolith, Fabrication, Assembly, Construction)
  - Weaknesses
- Input Mechanics
  - General Meetings
  - Emails
  - Specially called meeting (important vehicle)

Higher frequency ↕

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Faculty Guidance – Purdue University

- Benefits of earning trust/respect
  - Students reaching out
    - Certain areas of interest or concern (**Me:** regolith safety, **Students:** university computing resources)
    - Club members: in-person approaches >> emails
  - Easier to help the team succeed ➡ Retain club experiences ➡ Avoid reinventing the wheel
  - Strong(er) connections with students

- Overall benefits of being a Lunabotics advisor
  - Small part of the future of space exploration
  - Work with highly talented and dedicated students
  - Develop strong(er) connections with…
    - Students
    - Across universities and organizations
  - Opportunity to learn outside your discipline (ROS, NASA systems, etc.)

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After the Launch

- How Is Discord used by US teams
- You Are Invited!
  - Ability to continue to engage with US teams and ask questions going forward.

Lunabotics Worldwide Discord

LUNABOTICS