INCOSE IS 2016:
Helping Undergraduate Students of any Engineering Discipline Develop a "Systems Perspective"

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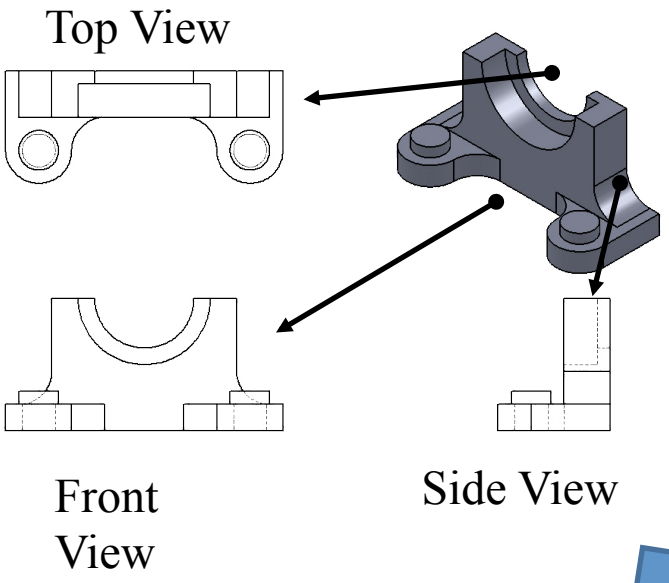
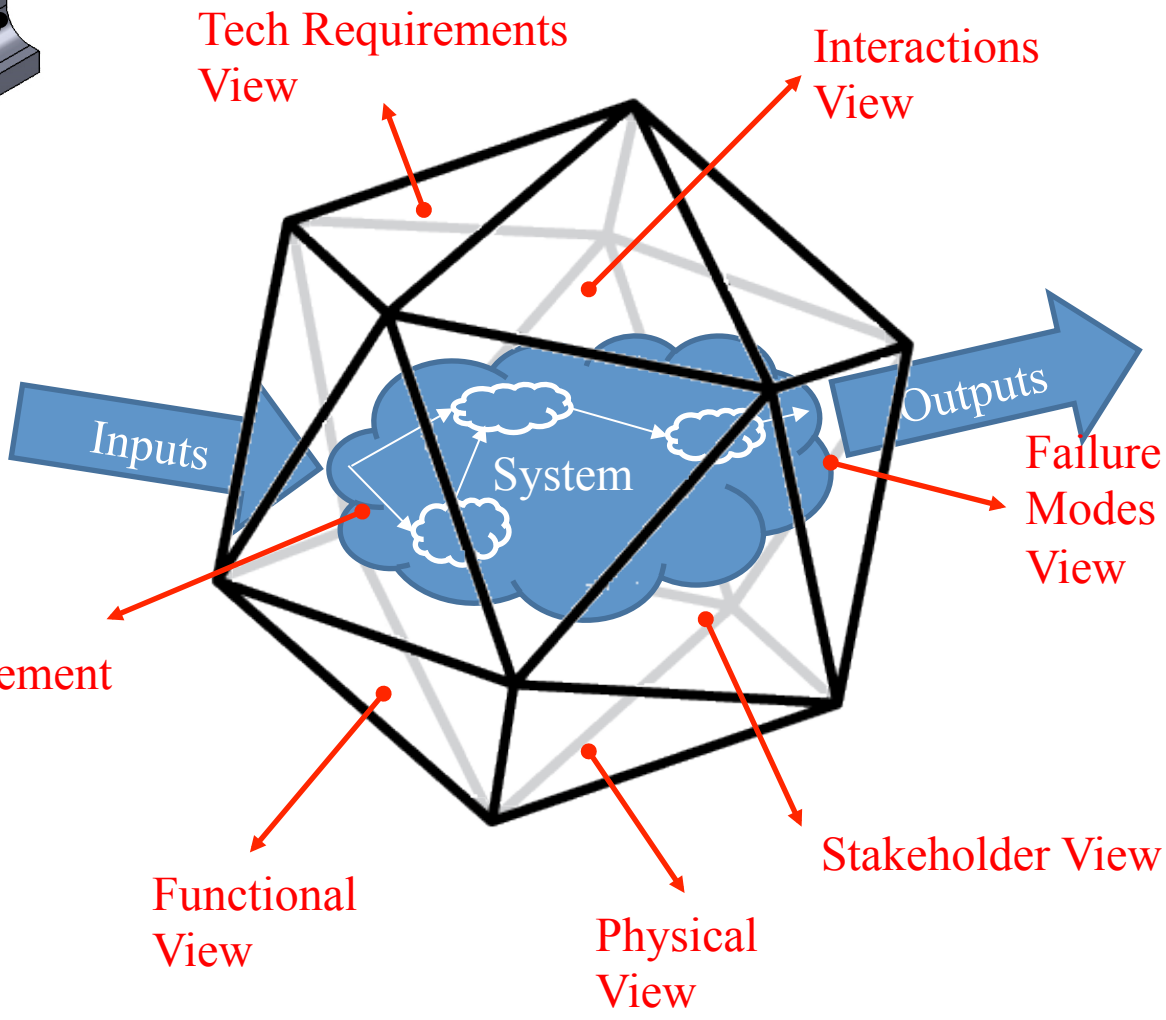
Outline of the talk

- What we mean by a “system’s perspective”
- How we make systems concepts more approachable to undergraduates
- Examples from our students

Systems concepts help our students to view a project from many different angles similar to a CAD drawing.





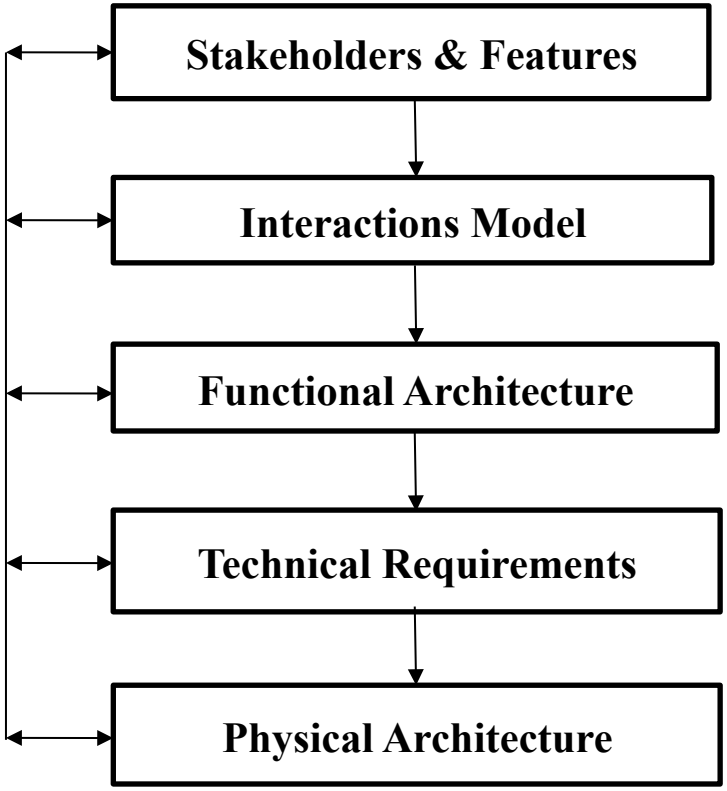
Several faculty at Rose-Hulman have codified this "systems perspective" with a core set of "systems competencies". Students should be able to…

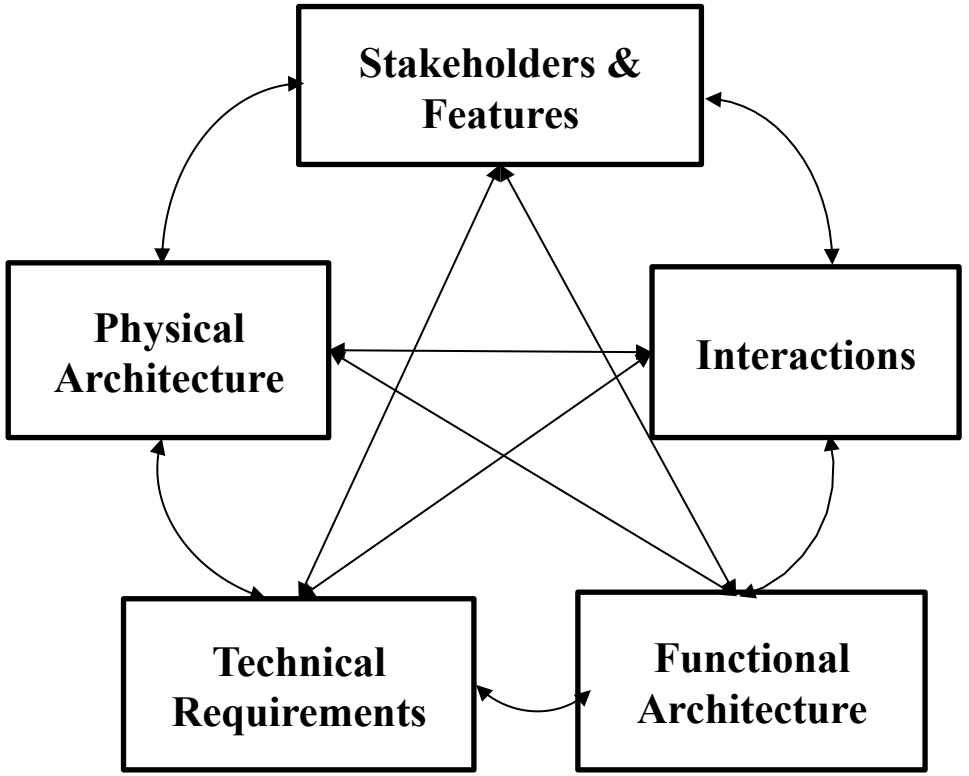
1. **Apply a system stakeholder view of value and features**
2. **Define the project as interconnected subsystems with both internal and external perspectives**
3. **Understand a system's interactions and modes**
4. ***Specify technical requirements***
5. ***Synthesize a physical design from the functional architecture***
6. ***Assess solution feasibility, completeness, and consistency***
7. ***Perform failure modes and risk analysis***

In order to help students develop the systems competencies, we developed a series of model templates with regular structures and processes for creating them.

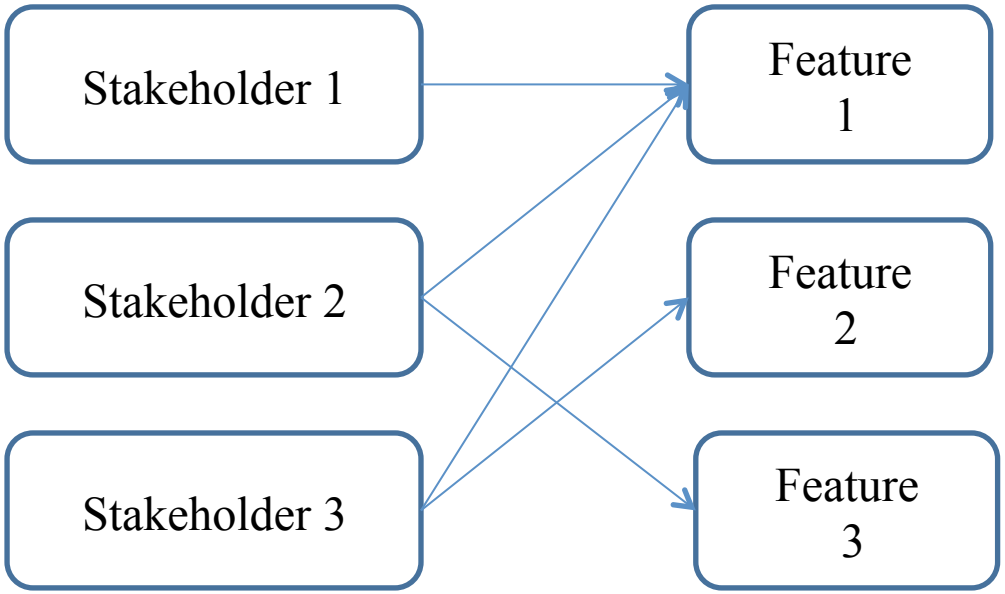
ID	Competency	Model Template
S1	Applying a Stakeholder view	• Stakeholder model
S2	Describing a project as interconnected systems	• Functional Architecture
S3	Understanding interactions and states	• Interactions model (Use Case)
S4	Specifying technical requirements	• I/O requirements at system border
S5	Creating and analyzing high-level design	• Decision matrix • High-level system models • Synthesized physical architecture
S6	Assessing feasibility, consistency, and completeness	• Test plan and evaluation
S7	Failure mode analysis	• Identification of failure modes

When introducing and learning the different views we follow a linear process. Actual application is a never ending cyclical process of achieving higher levels of consistency.





The *Stakeholder Model* template consists of spreadsheet that defines stakeholders and features and a map that associates them.



Stakeholder	Importance	Description
Noun		Any person, group, organization, … with a vested interest in the outcome

Feature	Description
Adjective	Usually an –able word such as “usable”

Master lists provide a starting point and help to ensure the students don't miss something important.

Common Features

- Something to describe the projects primary purpose
- Affordable
- Small-size/form factor/weight (compactness)
- Easy to use
- Adaptable
- Recyclable
- Secure
- Robust
- Efficient
- Environmentally friendly
- Simple
- Repairable

Common Stakeholders

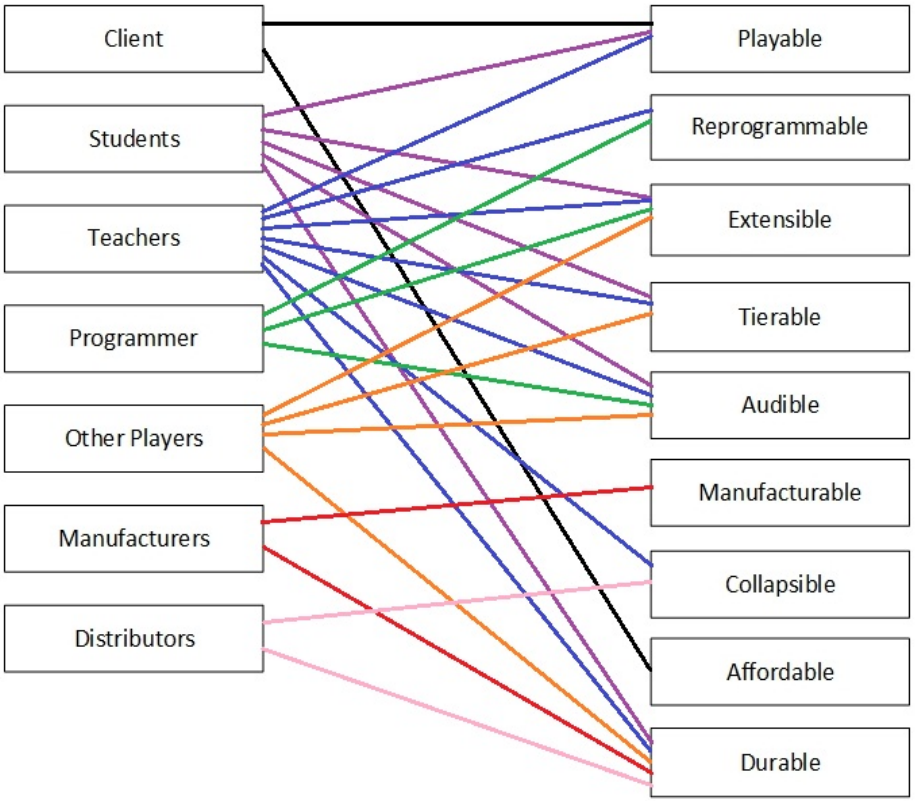
- End user
- Client
- Other engineers or scientists
- Regulatory agencies
- Those who maintain or repair or update
- Societal groups (i.e. government, police/ fire depts, new generation of teenagers)
- Manufacturers
- Shipping department
- Marketing/Sales/Retail department
- Legal department
- Those responsible for disposal/deletion of software

With a regular structure and vocabulary across all varieties of projects, assessment becomes much easier, even binary.

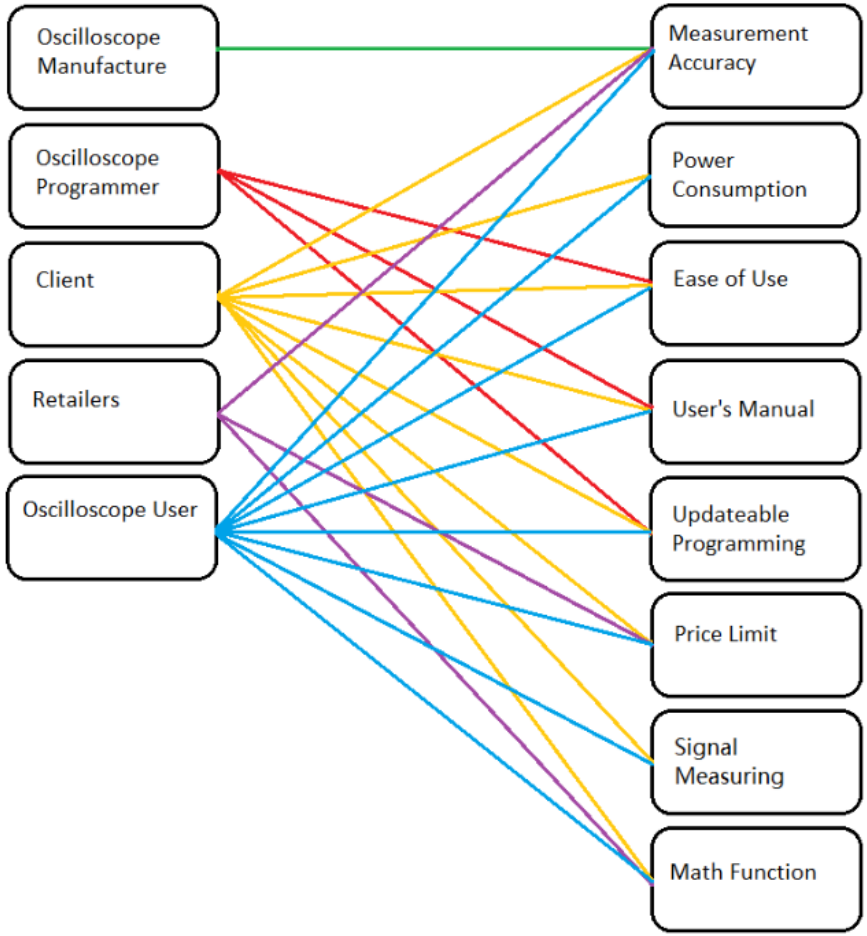
Rubrics for the Stakeholder Model	
Objective Goals	Check
Relevant stakeholders from the master list are included in the model	
Relevant features from the master list are included in the model	
The primary intended purpose of the solution is included as a feature	
Each identified feature has at least one stakeholder	
Each identified stakeholder is mapped to at least one feature	
The team has identified a subset of the most important stakeholders and features	
Each identified stakeholder and feature is given a definition	
Qualitative Goals	
The solution would be satisfactory if it had only these stakeholders and features	
The mapping of features to stakeholders is complete	

Model templates are general enough that they can be applied to ANY project, yet produce similar results.

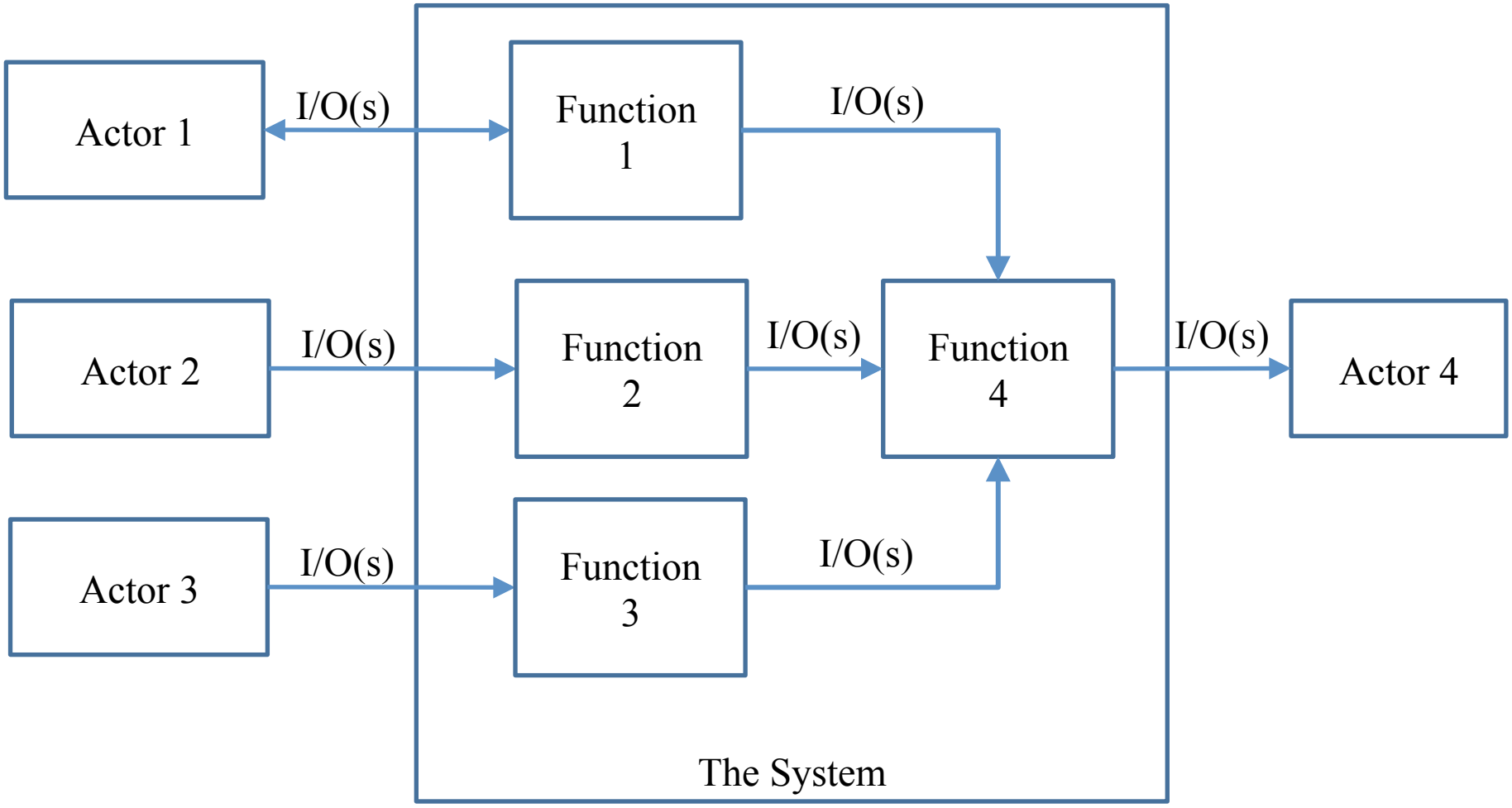
Submission from Project A



Submission from Project B



The *Functional Architecture* template is a high-level behavioral view of the system.



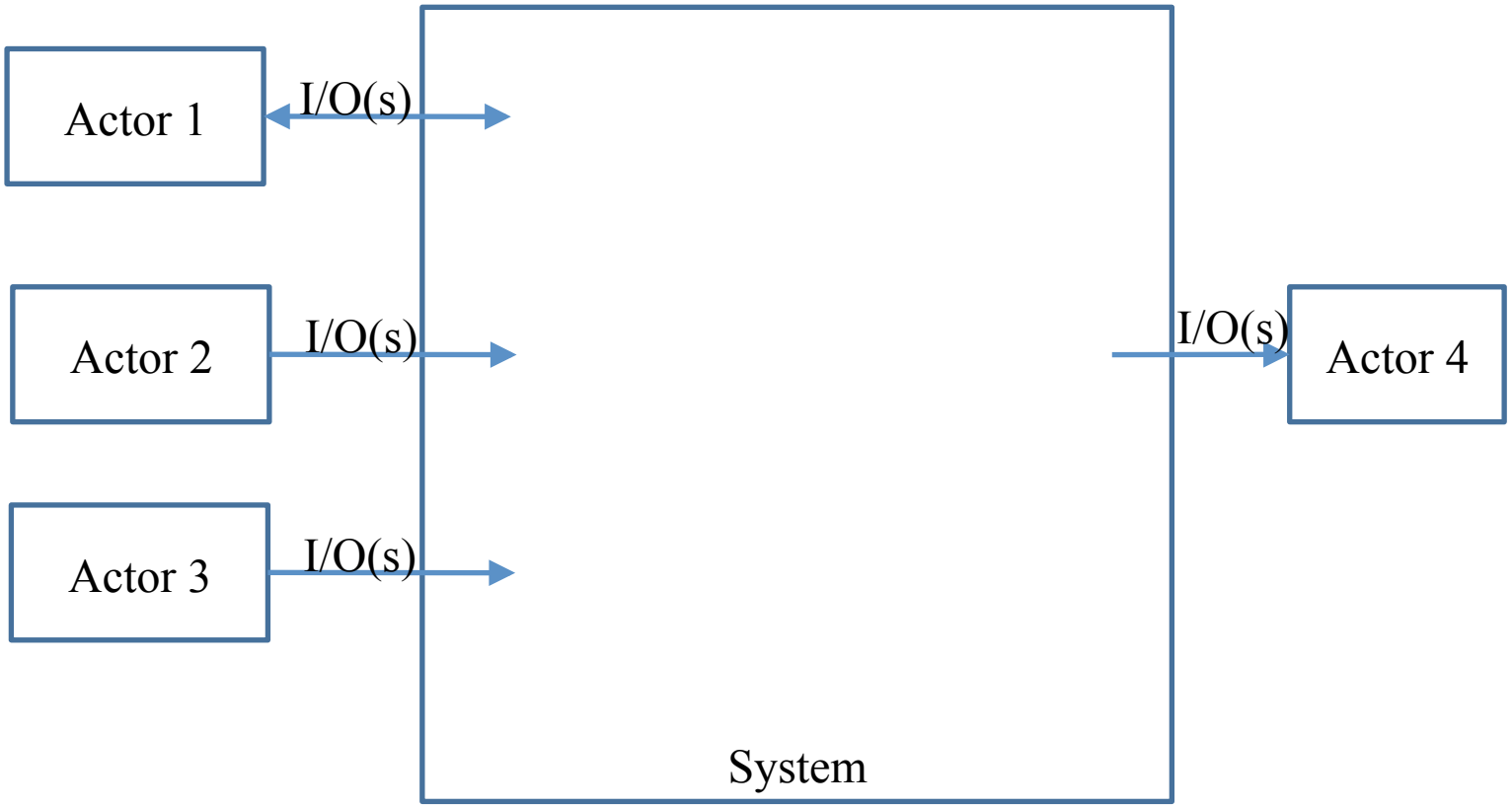
The students are required to name and define each item within the template.

Actor	Description
Noun	Anything outside the system boundary that interacts with the system

I/O	Description	Actors
Noun	The physical stuff that is transferred between an Actor and the System (signal, information, heat, force, mass, …)	

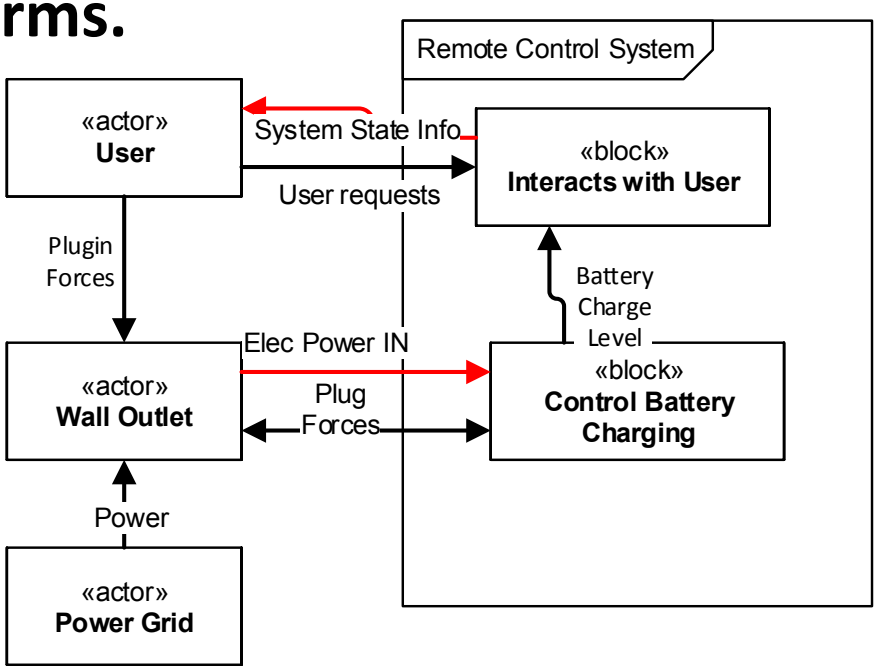
Function	Description	I/Os	Feature(s)
Verb followed by a noun	Describes a sub-behavior of the system. Must be general.		

The *Interactions (use case)* model template names and defines the interactions at the system boundary.



Interactions	Description	Actors	I/Os	Features
Verb followed by noun	Must describe how the actors interact with system through the I/Os			

The *Technical Requirements* describe the input-output relationships of the system in quantitative or measurable terms.



I/O involved

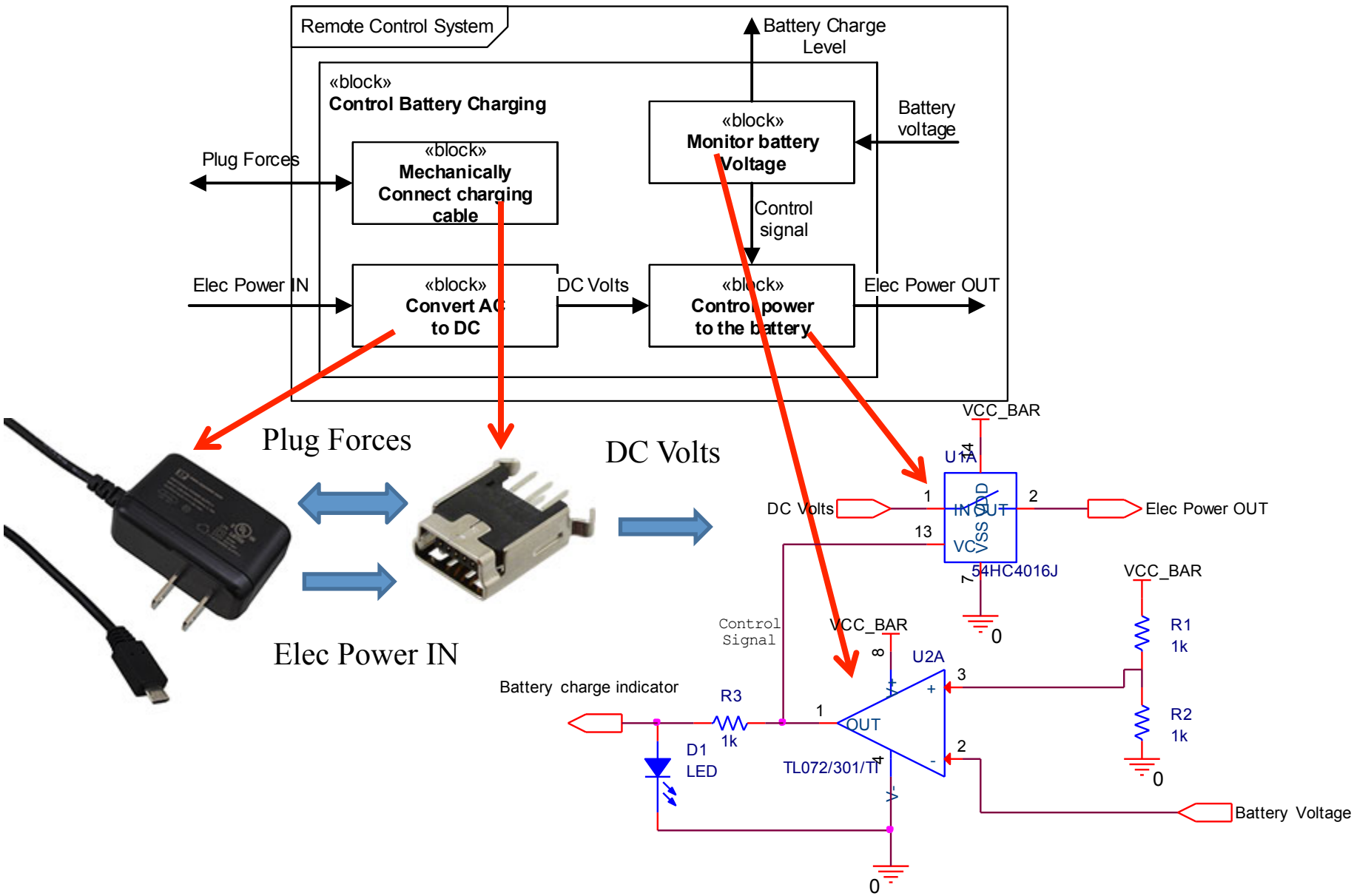
I/O not involved

- Inputs and outputs are underlined.
- [Attributes] are in brackets.
- Relationships are *italicized*.

Interaction	Block	ID	Requirement	Feature(s)
Recharge the battery	Wall Outlet Recharging	RB-1	The system must *accept* an Electrical Power IN at a [Wall Voltage] range of 110-240VRMS.	Rechargeable
Recharge the battery	User	RB-2	While charging, the system should *produce* System State Info as a [Charging Symbol] of a filling battery and a [Minimum brightness] of 10 lumens.	Rechargeable

- The requirement RB-1 shall be verified by instrument test

Decomposition and Synthesis is difficult to fit into a template but can be easily described using the previous models.

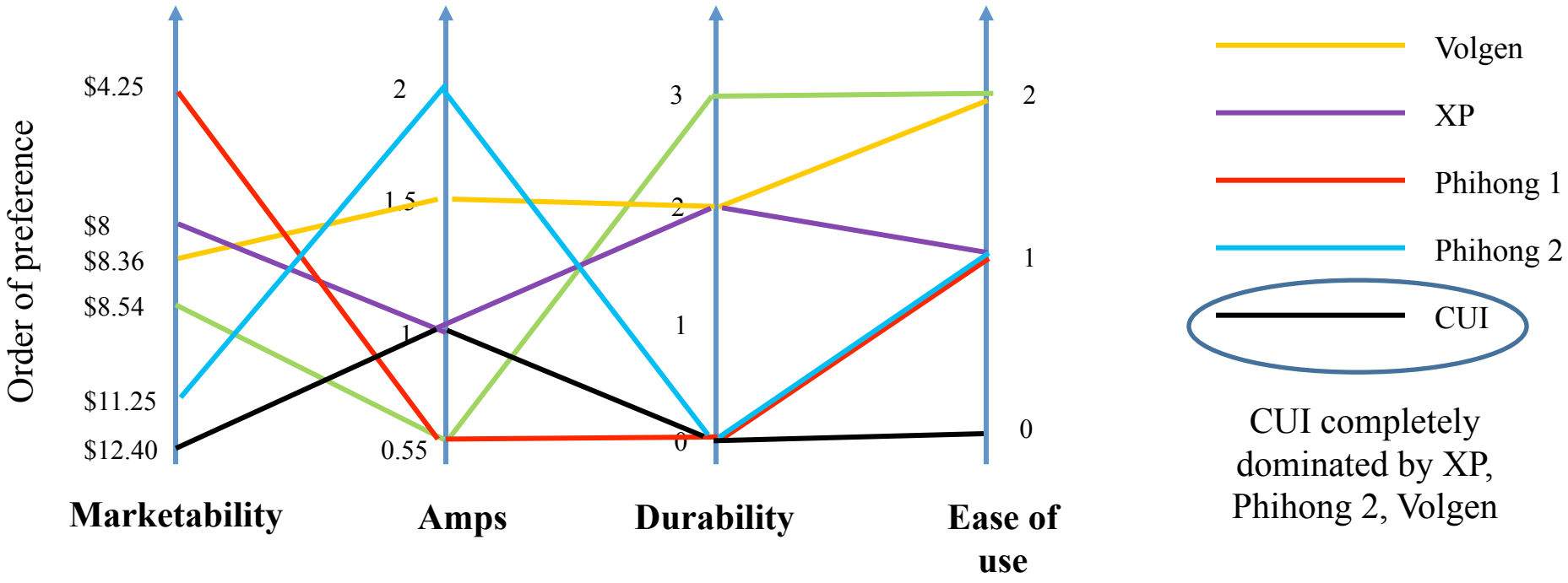


Some of the questions that arise during decomposition and synthesis are …

1. **What happens if you don't know enough about a function to decompose it?**
2. **To what level of detail should you decompose?**
3. **What happens when there are multiple different ways to decompose a functional block?**
4. **What is the difference between a modular versus integrated synthesis approach?**

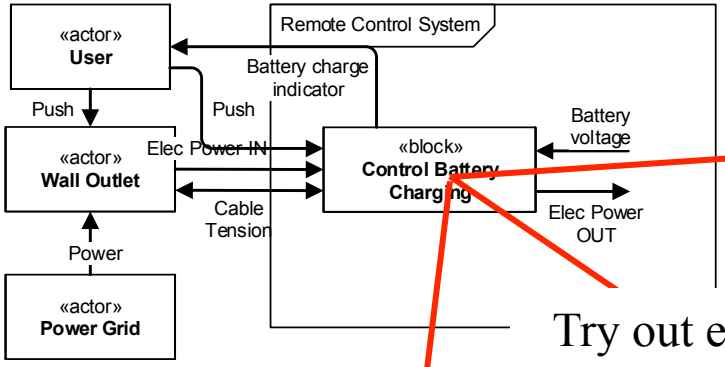
Client interaction is focused on decisions relative to the stakeholder features

Profile plot: Comparing alternatives

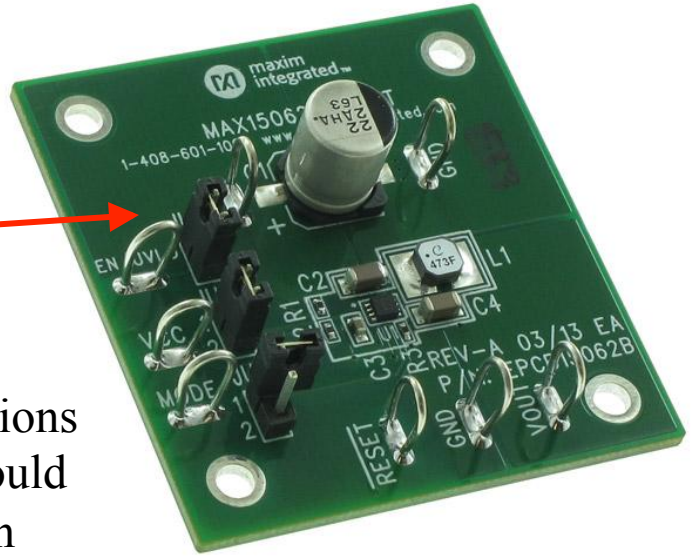


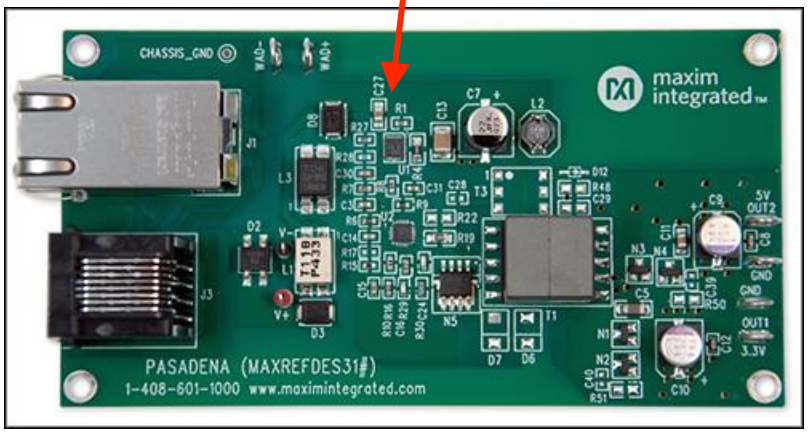
No alternative is better than all others when considering all attributes (features)! Some of the features are conflicting and non-commensurate, so we need to make tradeoffs!

Students are encouraged to assess various alternatives in terms of the stakeholder features.



Try out each of these options and determine which would make the ***best*** solution





Using the systems competencies can help faculty with challenges related to open-ended projects.

Still Have

Many open-ended and unique projects

Now faculty have formal methods for

- Guidance and Reflection
- Assessment and Evaluation

While providing

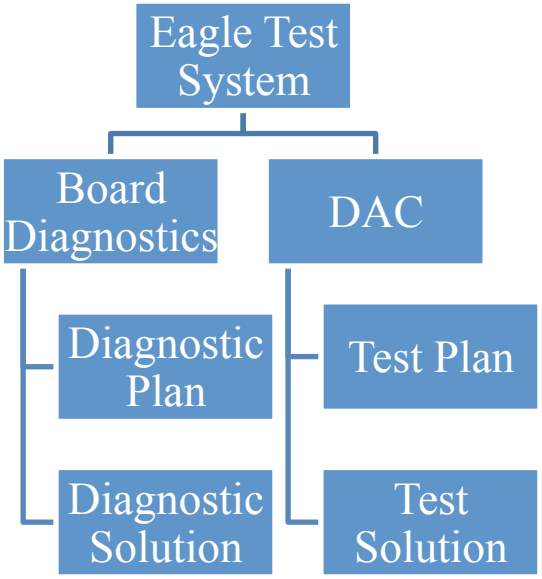
- Common framework for all projects
- Minimize overhead and workload
- Explicitly aid in learning design

Here are some of the many different courses at Rose-Hulman in which systems perspectives are being used.

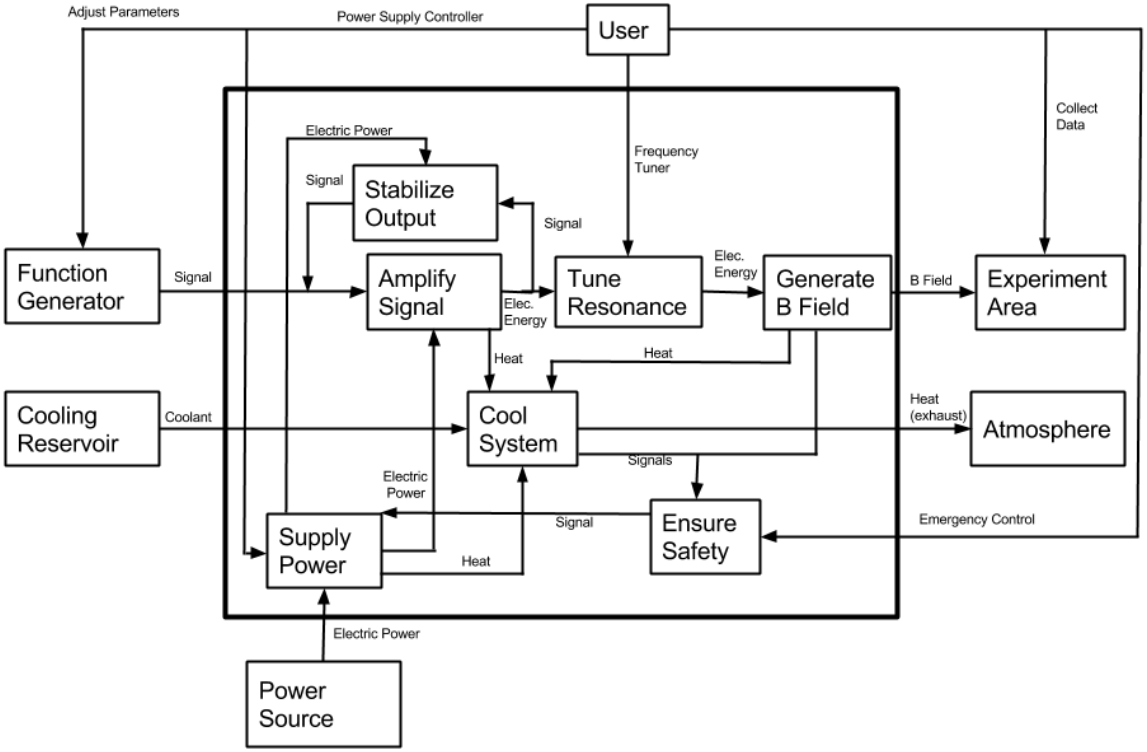
- **ECE Senior design and Junior Design**
- **ME Intro to design**
- **Engineering Grand Challenges Course**
- **Engineering Physics and Optical Engineering Senior Design**
- **Biomedical Engineering Senior Design**
- **Engineering Management Courses**
- **Principles of Optics Course**
- **Neuroprocessor research project**

ECE Senior Design students did not know how to make a block diagram and we didn't know how to teach them

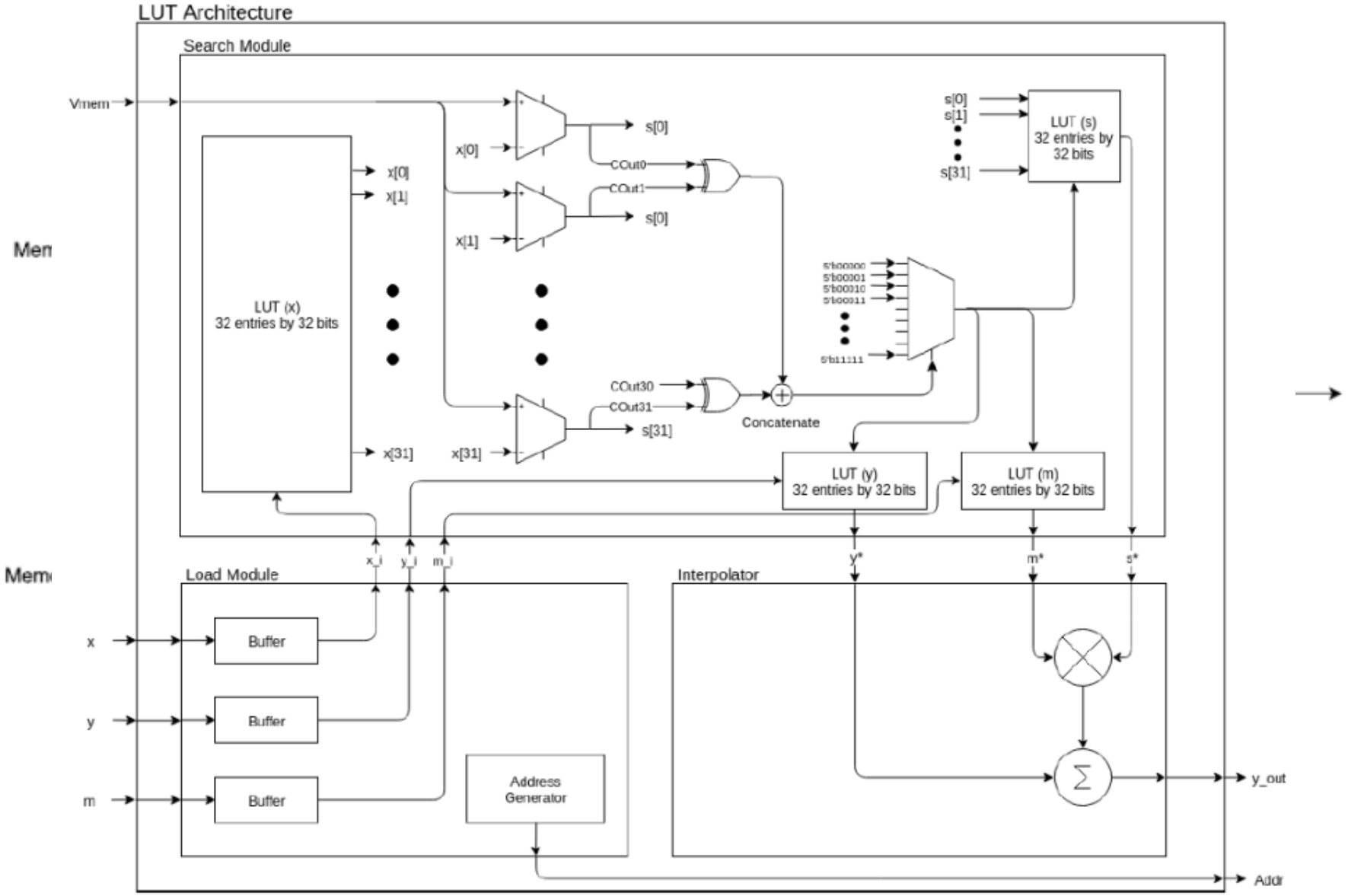
Without Systems Competencies



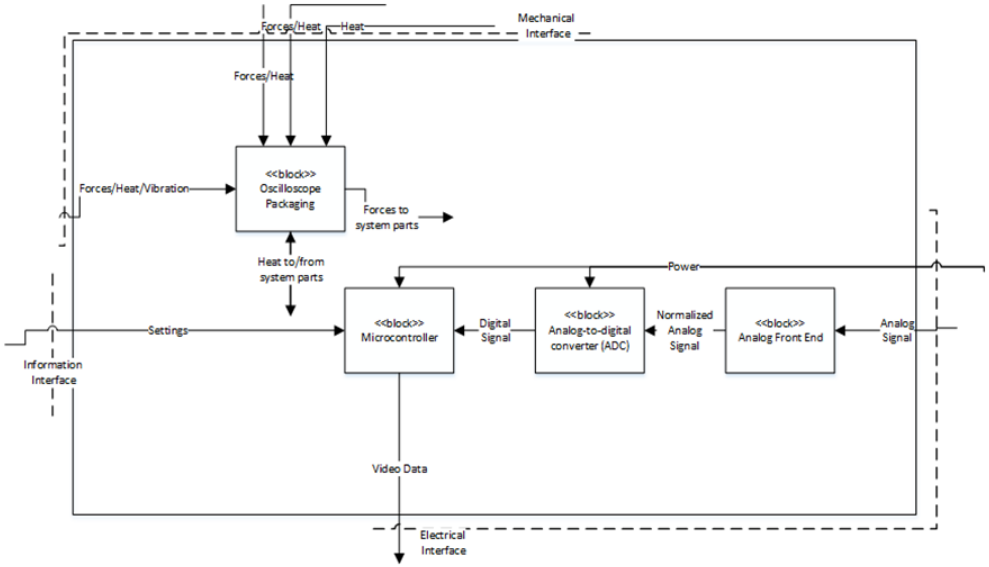
With Systems Competencies

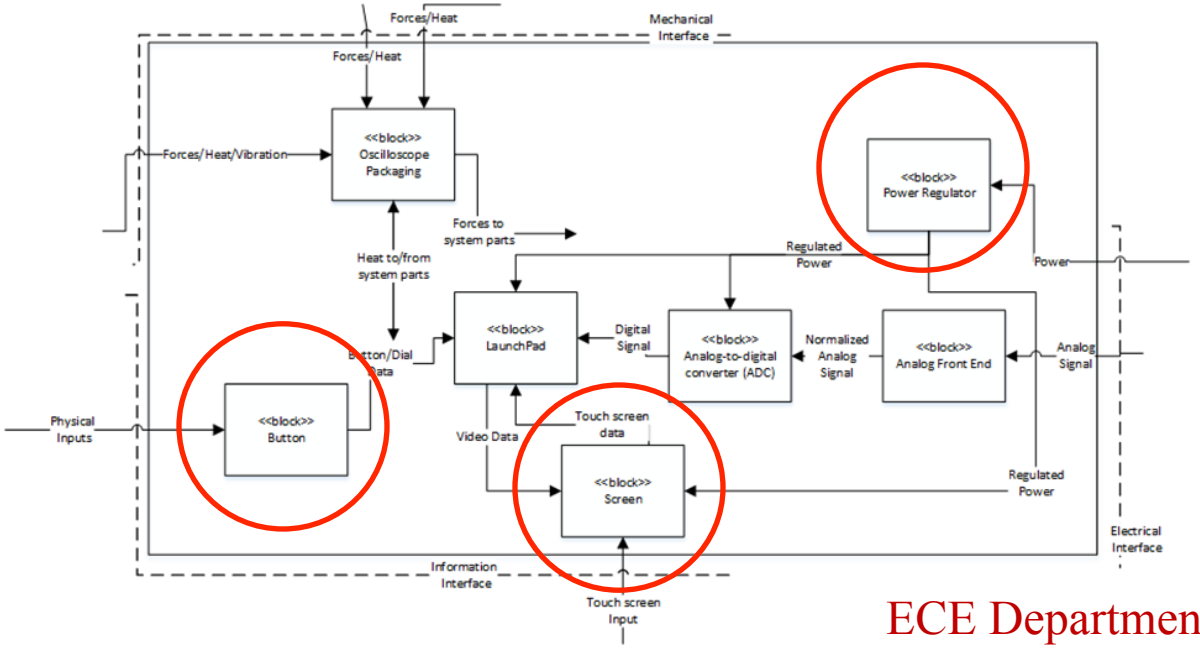


Students who went through senior design were able to apply modeling concepts to find the right level of detail



Students are understanding the need for revision and improvement of their models.





Students are learning how to write requirements that have more meaning and significance to the design process.

Before Systems Competencies

TLV5616 DAC Tests

Test	Measurement	Min	Max	Units
Continuity	$\|V_m\|$	0.2	1.8	V
Leakage Current	I_{IH}	-1	1	µA
	I_{IL}			
Supply Current	I_{DD} (V_{DD}=5V, Fast)		1.35	mA
	I_{DD} (V_{DD}=5V, Slow)		0.6	
	I_{DD} (V_{DD}=3V, Fast)		1.1	
	I_{DD} (V_{DD}=3V,		0.45	

Performance and Capacity

The product should function to the same capacity and performance as the NI myDAQ. It must perform reliably and consistently. It should have the same accuracy in measurement as the myDAQ.

After Systems Competencies

Interaction	Block	ID	Requirement	Stakeholder Features
Generates Analog Output	Signal transmitter	ST-1	The **signal transmitter** must output an analog waveform at [the fastest the AD9914 can attain—1.4 GHz]	*RF transmission*

Introducing Systems Competencies During Undergraduate Design

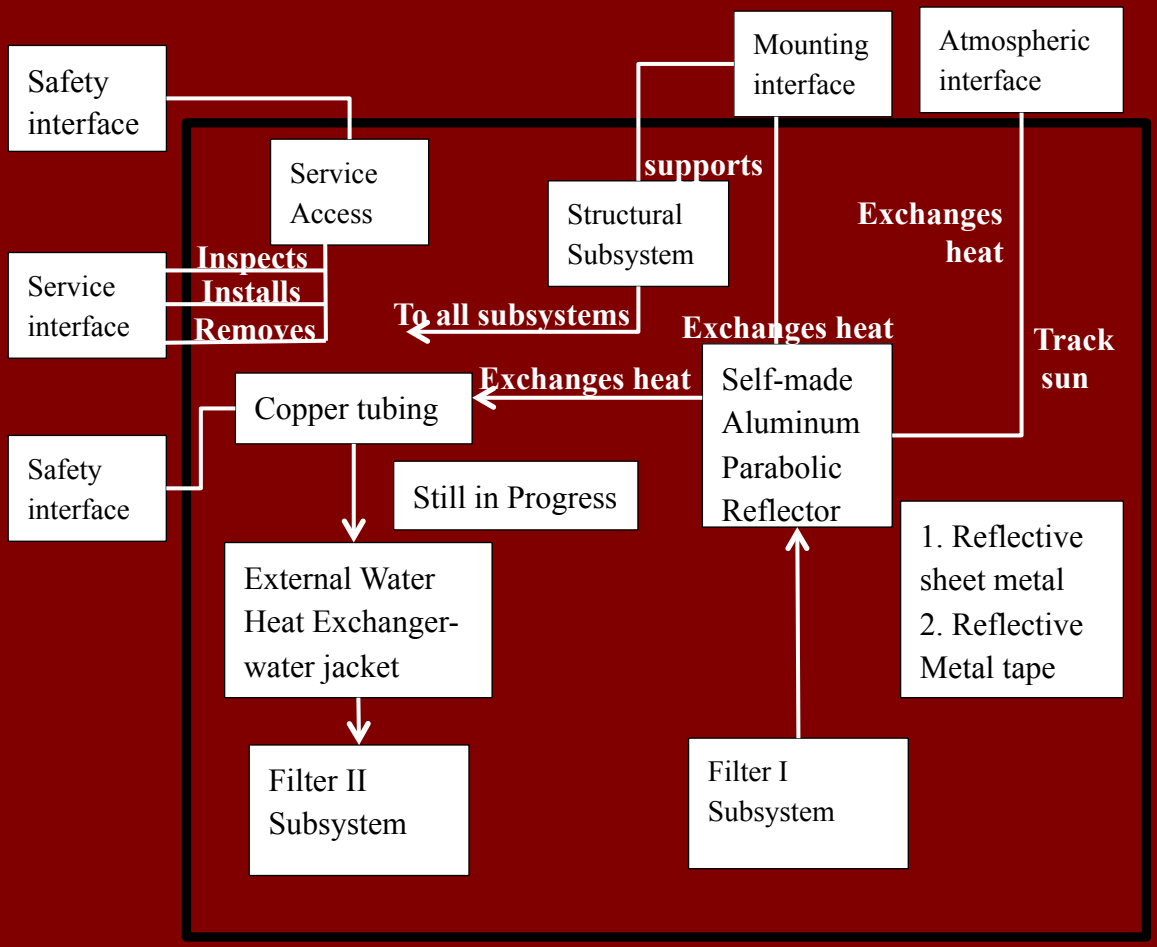
2014 Annual ASEE Conference

Ashley Bernal
Scott Kirkpatrick
Bill Schindel

Grand Challenge: Solar Energy

Summer 2013

The “heating” team’s physical model recognized interaction with other subsystems



This is the diagram produced by the team last summer for the grand challenges course to create roofing tiles made out of melted plastic.

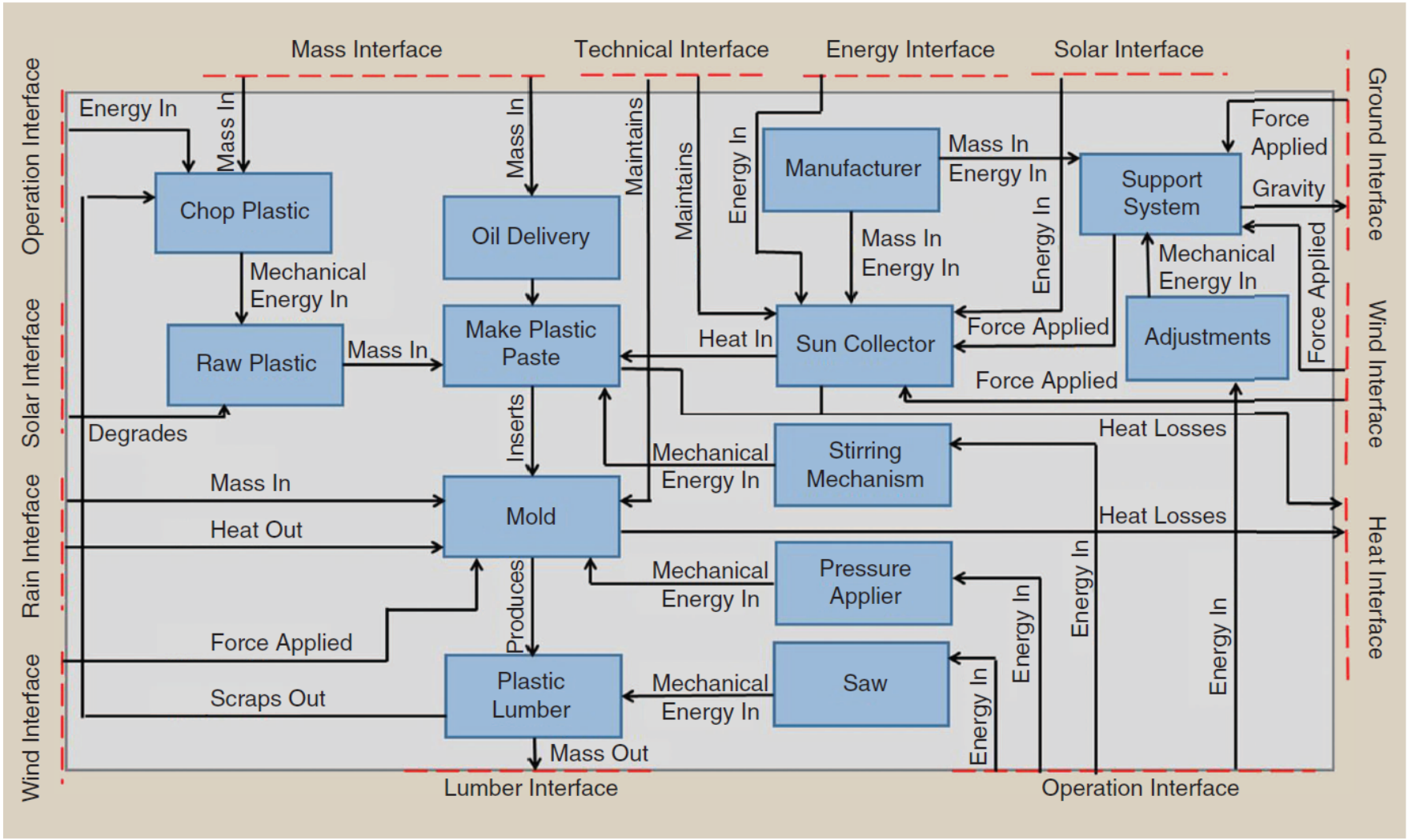


FIG5 The logical architecture of the plastic lumber process.

In the EMGT Systems Engineering course, students develop a systems model for a system of their choice, this is a UAV. All student projects 'look the same'…

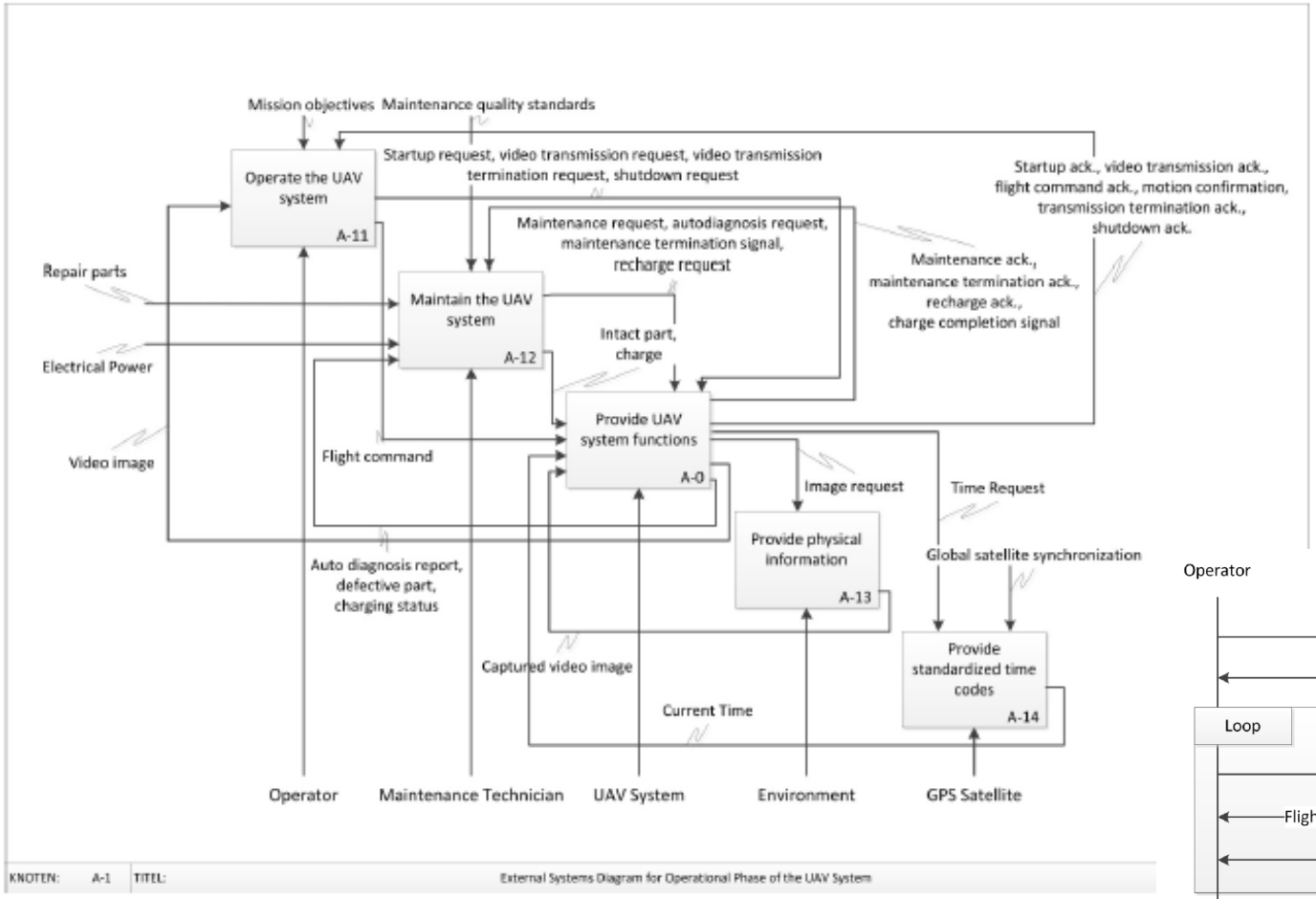


Figure 9: External Systems Diagram

idef0 model

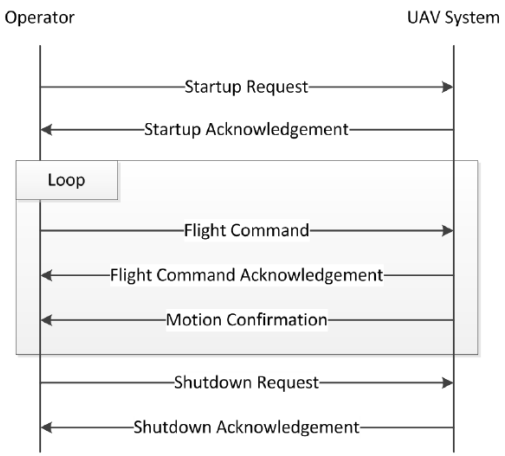


Figure 3: Normal flight