A General Design Analysis of Cobot Manipulators

ME6101 Final

Shubh Raval

A History of Cobot Development

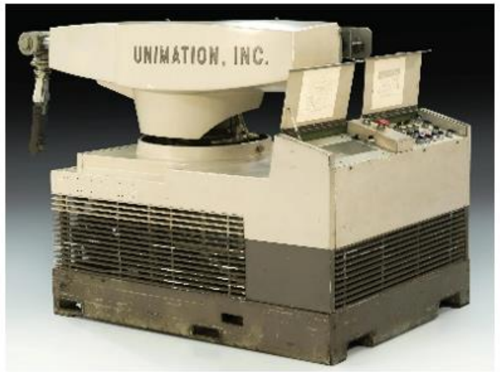


FIGURE 1: THE UNIMATION ROBOT ARM

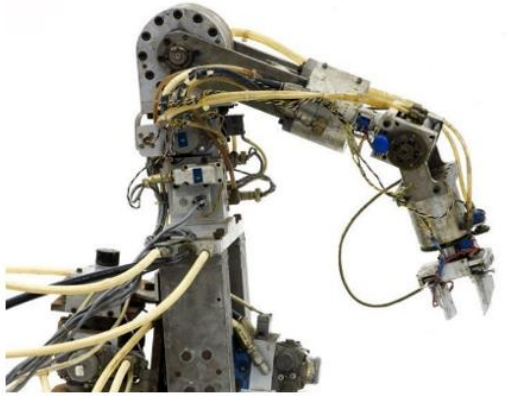


FIGURE 2: THE STANFORD ARM

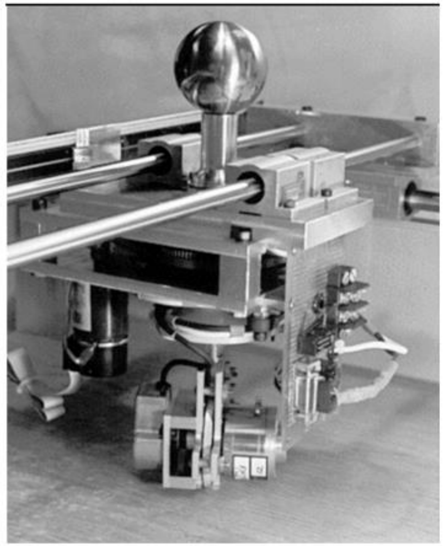


FIGURE 3: FIRST "COBOT" DEVELOPED BY NORTHWESTERN

FIGURE 4: FIRST COBOT MANIPULATOR KUKA LBR III

FIGURE 5: UR5 TENDING A CNC MACHINE

Overall Goal of Analysis

- Understand the design of a cobot on a fundamental level
  - Why certain components are needed, what functions do they serve and how does that impact customers
- Conduct functional modeling to develop a general cobot
- Use Axiomatic Modeling to further develop general cobot
- Qualify the Universal Robot as a good reference point for a general cobot's design
- Understand how a product line of cobots is thus created

Tabularized CNs

- Determined by evaluating top priorities from some customers/ robotic arm resellers
- Determined by what the topic marketing topics were from cobot makers

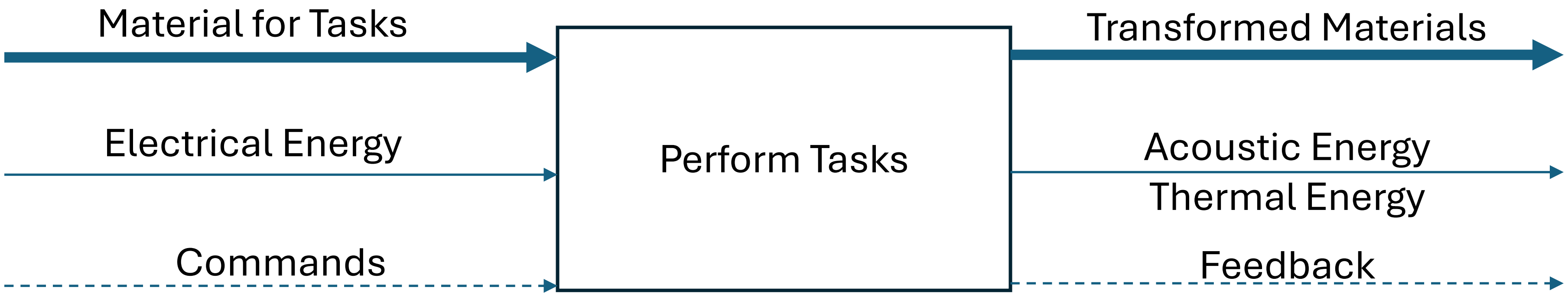
Surveyed Customer Needs	Label (CN#)
Task Adaptability	CN1
Safe Operations Next to Humans	CN2
Particular Reach in Workspace	CN3
Particular Speed	CN4
Particular Accuracy	CN5
High Load to Weight Ratio	CN6
Easy and Robust Integration	CN7
Programmability	CN8
Task Completion Autonomy	CN9

TABLE A: CUSTOMER NEEDS

Functional Modeling

This is a look at what is a general cobot and how can that be defined

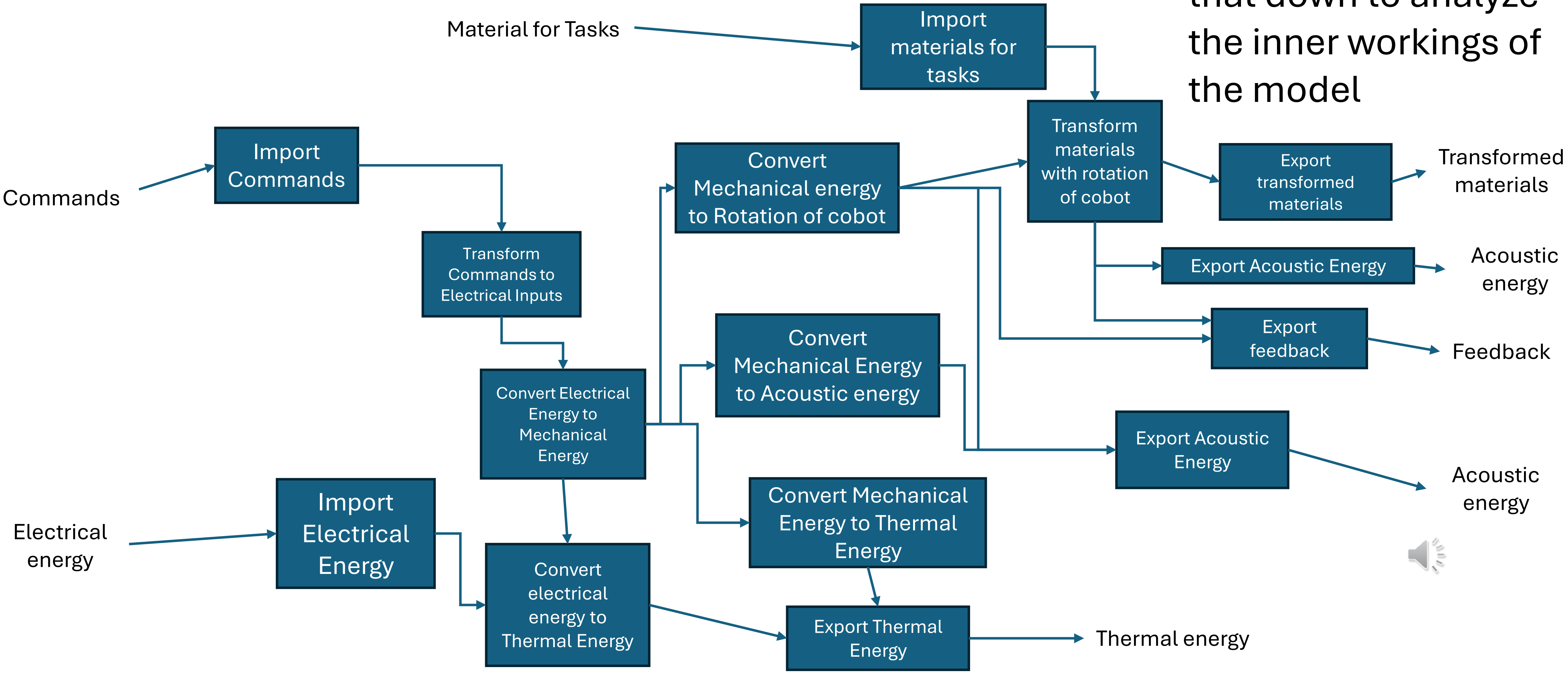
Black Box Model



- This is to show the most basic level that a cobot can be
- At any point for any customer this is the basic model of what goes in, happens, and comes out of cobot

Function Structure Diagram

- With the black box model created there is an ability to break that down to analyze the inner workings of the model



Modern Cobot Components Review

ONBOARD COMPUTER

POWER SUPPLY UNIT

LINKAGES STRUCTURE

SAFETY SUITE/BRAKE

MOTOR CONTROLLER BOARD

MOTOR

SOFTWARE SUITE

ROS

SENSOR SUITE

GEARBOX

END EFFECTOR

Morphological Matrix

- After having completed the functional modeling, it comes time to assign components to those functions
- For this initial point of reference the top cobot manufacturers were investigated to understand their component choice
- What was found is that for major components as seen here they are largely the same
- Thus completes the general cobot model which is essentially what the Universal Robotics Platform is

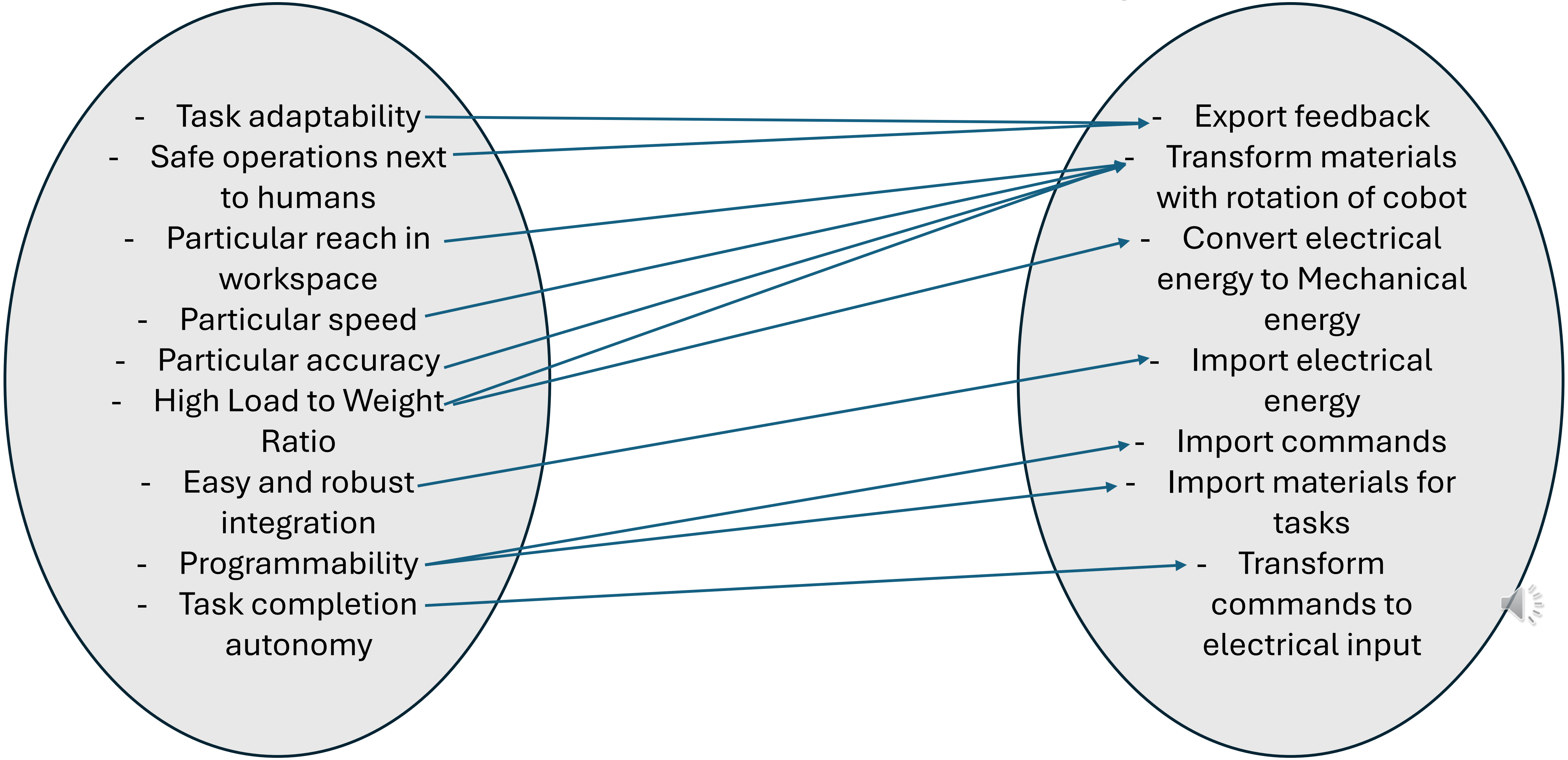
Morphological Matrix of a Cobot	
Function	**Component(s)**
Signal	
Import Commands	Onboard Computer (Generally Using Linux)
Transform Commands to Electrical Input	Motor Controller Board
Export Feedback	-Commutation -Hall Effect -Force Torque Sensors
Energy	
Import Electrical Energy	Power Supply Unit
Convert Electrical Energy to Mechanical Energy	Frameless Motor
Convert Mechanical Energy to Rotation of Cobot	-Gearbox -Linkages Structure
Material	
Import materials for tasks	Software Suite
General	
Transform materials with rotation of cobot	-Software Suite -End Effector -Safety Suite -Brake

Axiomatic Analysis

This is essentially analyzing that same general cobot, which is qualified as the UR10e, from an axiomatic perspective to see if the same conclusions are drawn on the selected components

Customer Needs to Top Level Function Requirements

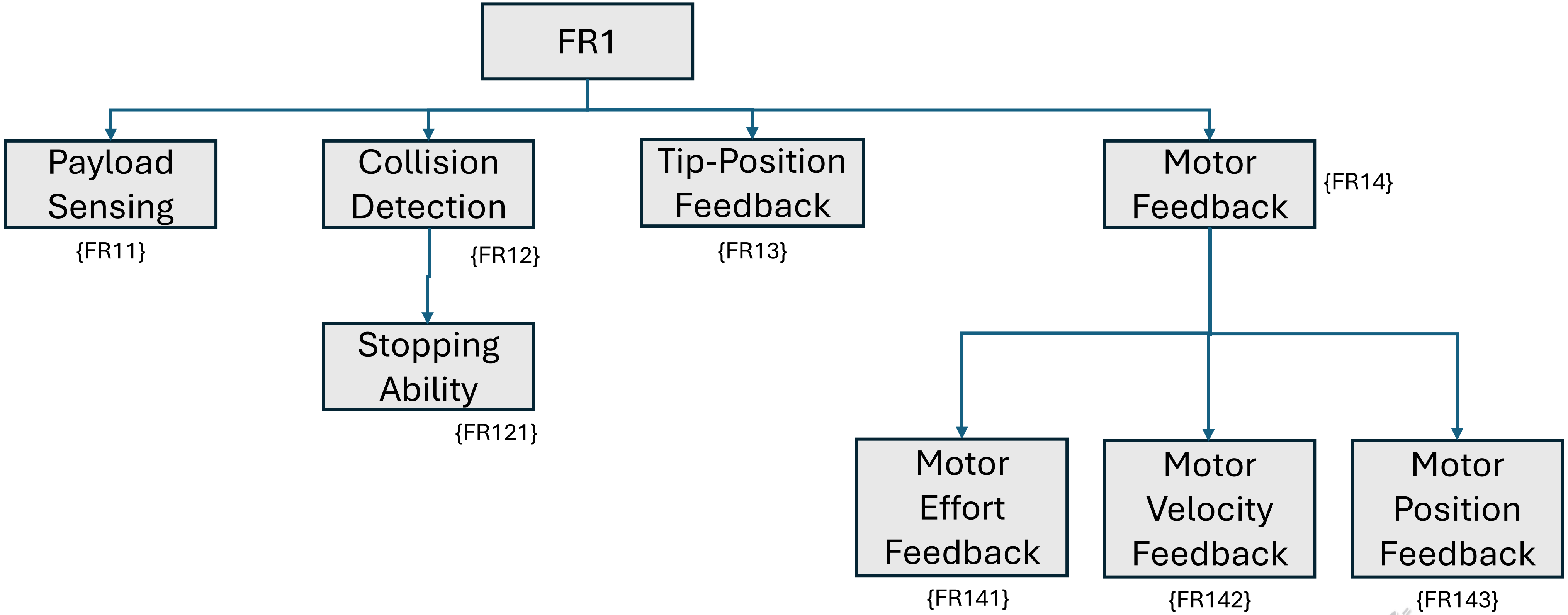
- Next the customer needs are mapped to certain functions that are based on the functional modeling



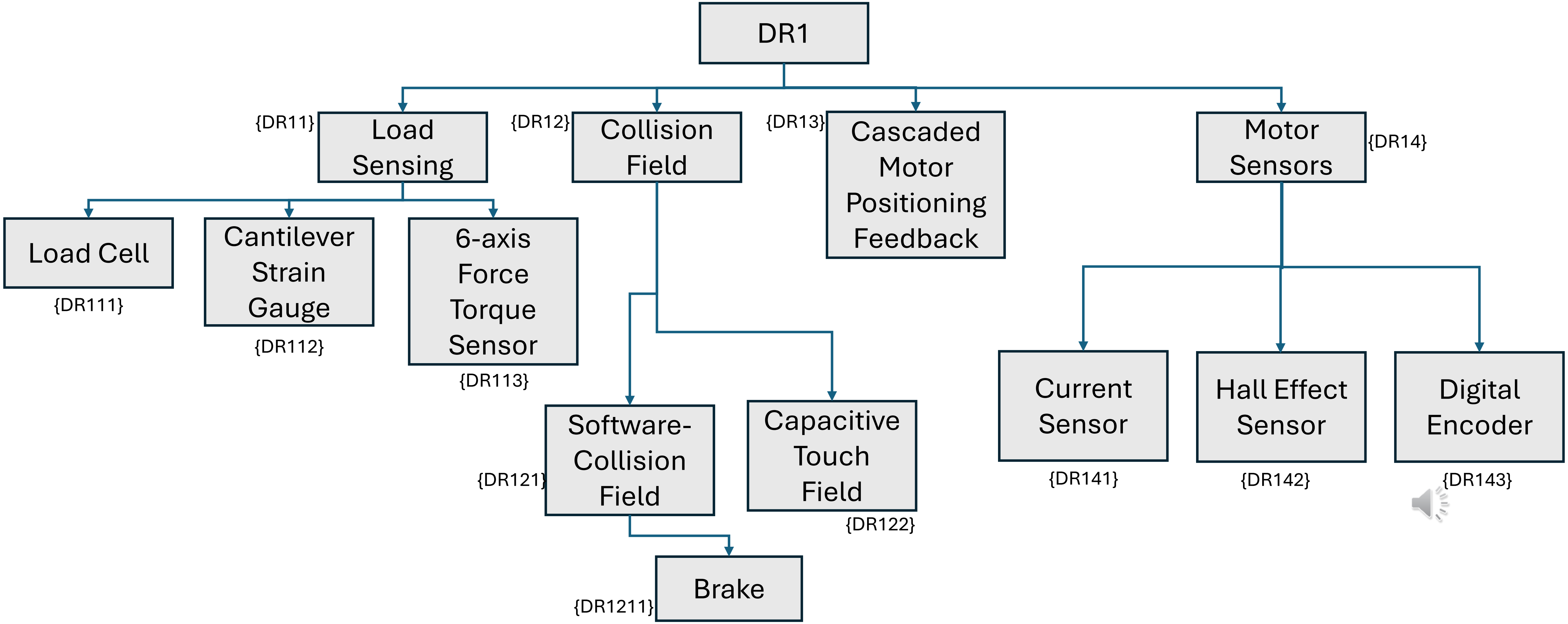
Deep Dive on the hierarchy of 2 Functional Requirements

- The functional requirement of export feedback and transform materials with rotation of cobot are very complex as seen by them singularly satisfying more than half of the customer needs
- Hence it is critical to break down both functional requirements and then relative them to their respective physical domains
- This should produce the expected zigzag which is a hall mark of the hierarchical descent in axiomatic analysis

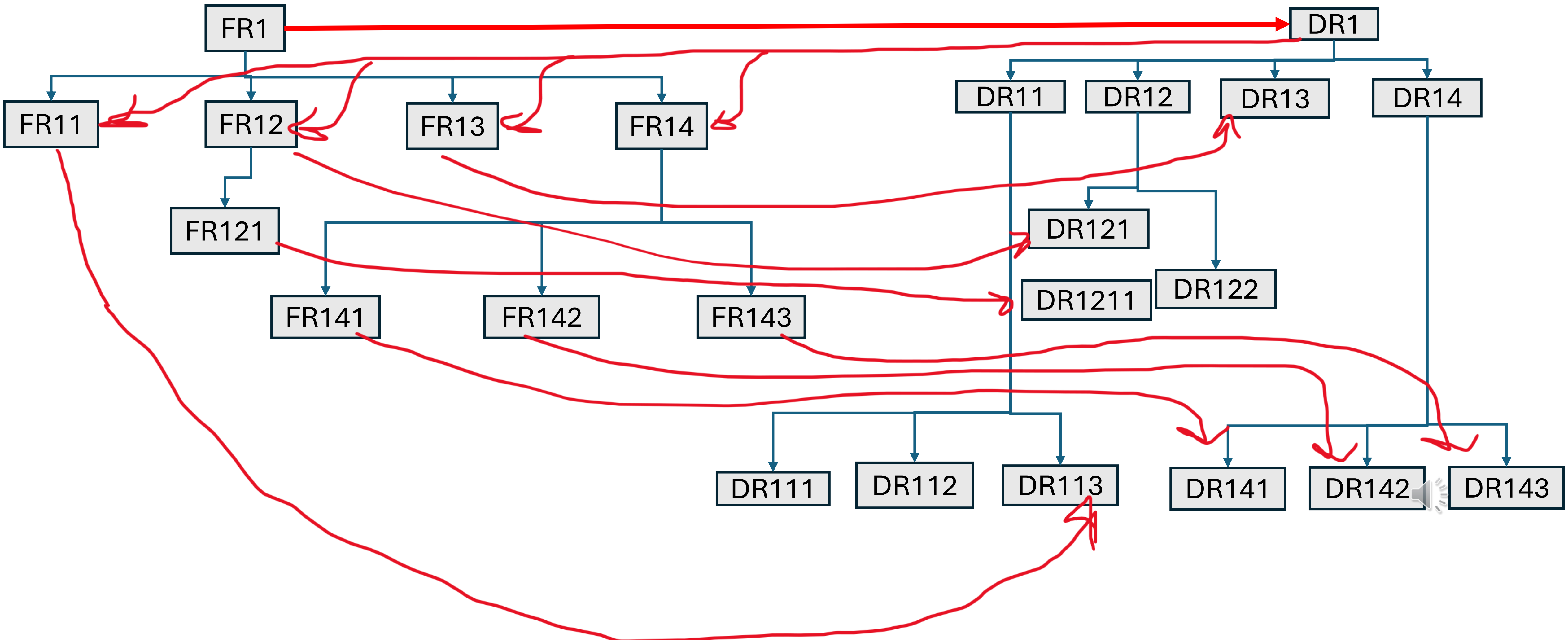
FR1 – Export Feedback



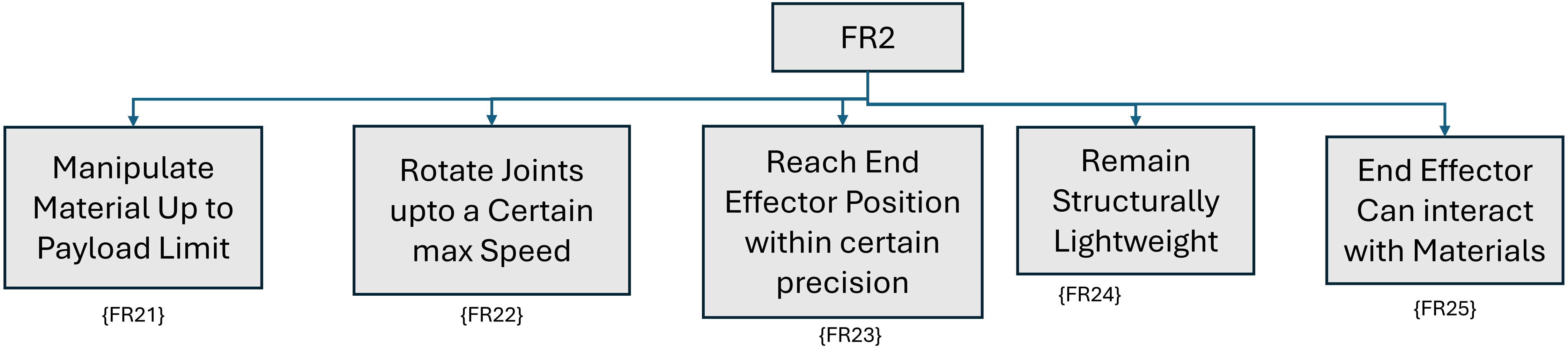
DR1 – Sensor Suite



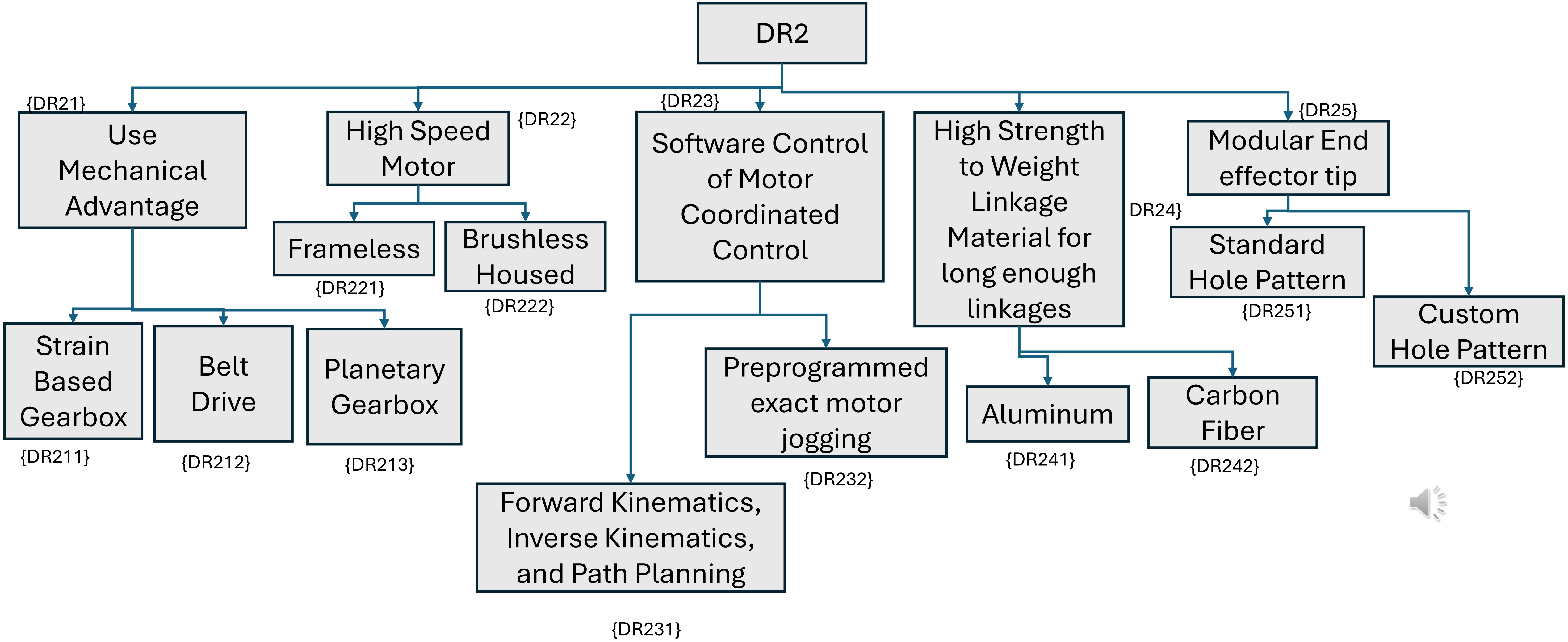
Functional Requirements to Physical Domain Mapping {FR1->DR1}



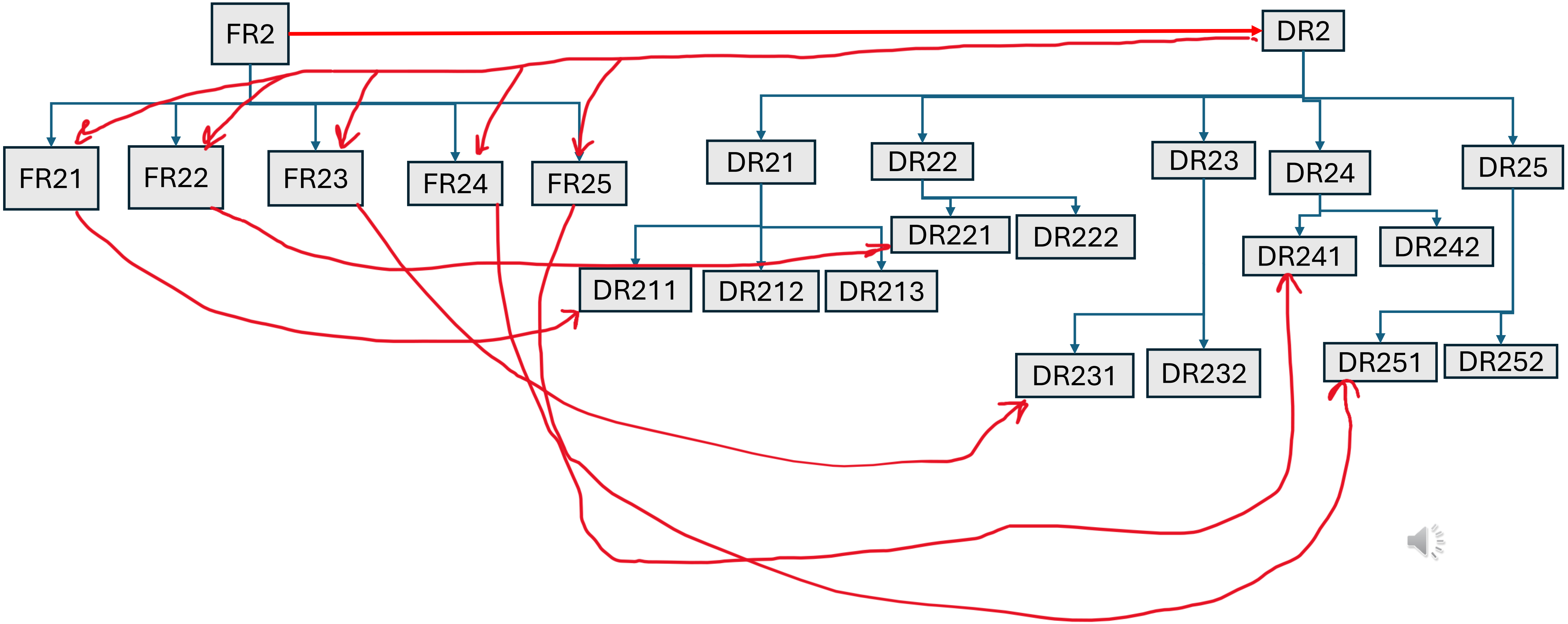
FR2 – Transform Materials with Rotation of Cobot



DR2 – Coordinated Joint Rotation



Functional Requirements to Physical Domain Mapping {FR2->DR2}



Tabularized FRs

- This is the broken-down look at the axiomatic based functional requirements
- Note the distinctions now created relative to the function structure diagram
  - Inclusion of Stopping Ability
  - Motor Feedback
  - Etc

Functional Requirements	Label (FR#)
Export Feedback	FR1
Payload Sensing	FR11
Collision Detection	FR12
Stopping Ability	FR121
Tip-Position Feedback	FR13
Motor Feedback	FR14
Motor Effort Feedback	FR141
Motor Velocity Feedback	FR142
Motor Position Feedback	FR143
Transform Materials with Rotation of Cobot	FR2
Manipulate Material upto Payload Limit	FR21
Rotate Joints upto a Certain Max Speed	FR22
Reach End effector Position within Certain precision	FR23
Remain Structurally Lightweight	FR24
End effector can interact with Materials	FR25
Convert electrical energy to Mechanical energy	FR3
Import electrical energy	FR4
Import commands	FR5
Import materials for task	FR6
Transform commands to electrical input	FR7

TABLE B: FUNCTIONAL REQUIREMENTS

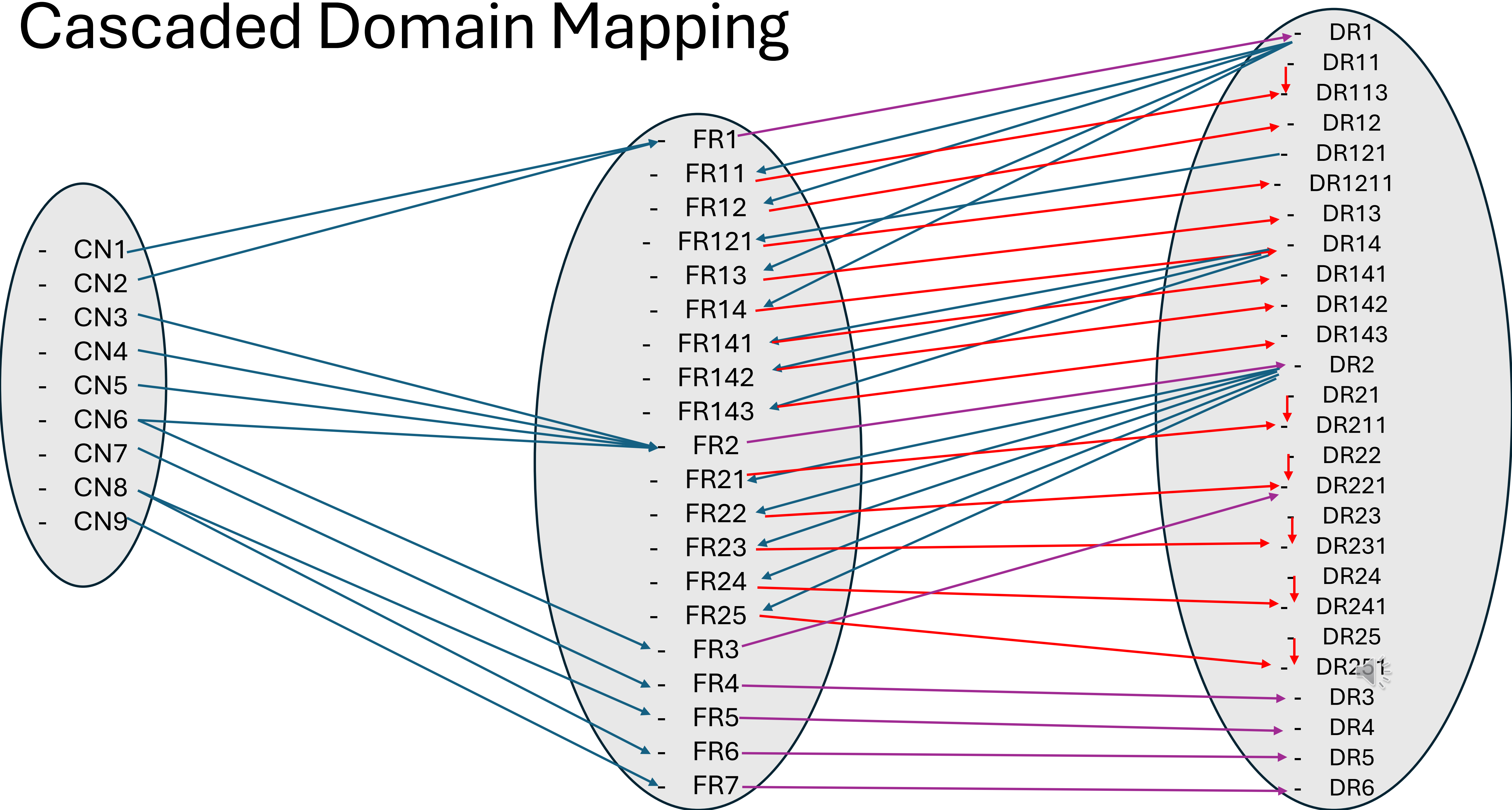
Tabularized DRs

- This is the detailed look at the various physical parameters that need to address the functional requirements
- Note the greater granularity relative to the morph matrix since this is attempting to quality that analysis' results
- Overall the components identified are largely similar just more fleshed out

Physical Domains	Label (CN#)
Sensor Suite	DR1
Load Sensing	DR11
6-axis Force Torque Sensor	DR113
Collision Field	DR12
Software Collision Field	DR121
Brake	DR1211
Cascaded Motor Positioning Feedback	DR13
Motor Sensors	DR14
Current Sensor	DR141
Hall Effect Sensor	DR142
Digital Encoder	DR143
Coordinated Joint Rotation	DR2
Use Mechanical Advantage	DR21
Strain Based Gearbox	DR211
High Speed Motor	DR22
Frameless Motor	DR221
Software Control of Motor Coordinated Control	DR23
Forward Kinematics, Inverse Kinematics, and Path Planning	DR231
High Strength to Weight Linkage Material for Long Enough Linkages	DR24
Aluminum	DR241
Modular End Effector Tip	DR25
Standard Hole Pattern	DR251
Power Supply Unit	DR3
On-board Computer	DR4
Software Suite	DR5
Motor Controller	DR6

TABLE C: PHYSICAL DOMAINS

Cascaded Domain Mapping



Independence Axiom

- Overall the design is highly independent except for one, FR3, which relates to the motors since they also serve to exchange electrical energy to mechanical energy and generate velocity
- Axiomtic Design Matrix :

$$
\begin{Bmatrix} FR11 \\ FR12 \\ FR121 \\ FR141 \\ FR142 \\ FR143 \\ FR21 \\ FR22 \\ FR23 \\ FR24 \\ FR25 \\ FR3 \\ FR4 \\ FR5 \\ FR6 \\ FR7 \end{Bmatrix} =
\begin{bmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1
\end{bmatrix}
\begin{Bmatrix} DR113 \\ DR121 \\ DR1211 \\ DR141 \\ DR142 \\ DR143 \\ DR211 \\ DR221 \\ DR231 \\ DR241 \\ DR251 \\ DR3 \\ DR4 \\ DR5 \\ DR6 \end{Bmatrix}
$$

Customized Product Line & Future Work

What can we glean from the axiomatic analysis about the Universal Robotics Product line and what more can be explored here?

Product Family Customization

- Most Important Components for Product Family Customization:
  - Frameless Motors
  - Strain-based Gearbox
  - Aluminum Linkages

- One example of the critical component variation to develop product lines
  - UR10e and UR16e
  - UR16e has same motors but higher payload since it is shorter
  - 1300mm vs 900mm and 10kgs vs 16kgs

Future Work

- Now a deeper dive can be conducted by collecting real sales/customer data
- This can be used with the information axiom to further evaluate the design
- Additionally with the design parameters and the functional requirements they can be analyzed to see which is the most critical and are there more cost-effective ways to generate the same combination of products

Thank You!

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