UNIVERSAL PRODUCT DESIGN: TRANSFORMING USER ACTIVITY INTO PRODUCT FUNCTION

A Thesis

by

VINCENT MICHAEL KOSTOVICH

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2009

Major Subject: Mechanical Engineering

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Approved by:

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ABSTRACT

Universal Product Design: Transforming User Activity into Product Function.

(December 2009)

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Chair of Advisory Committee: Dr. Daniel A. McAdams

Many people have disabilities and would like to have all of the amenities typical of daily life. Universal product design is important in designing for the disabled and creating user-friendly products for all people. The goal of this thesis is to develop a universal product method by understanding how user activity closely resembles product function.

The research results include a twenty product pair study in which a universal and typical product were compared. An activity diagram and functional model for each product in the product pair were the design tools used for this comparison. User activities were used to cluster product function changes. In addition, design changes such as functional, morphological and parametric were identified between the universal and typical product. The result was an action-function diagram showing the clusters and design changes for all of the twenty product pairs.

An interactive GUI universal product design repository detailing the information from the action-function diagrams was created and used for eventual modification of typical products to make them universal. A universal product family was created using a user-centric universal design method developed because of the universal product design

repository. Furthermore, user disability ratings from the ICF helped to expand the database and make creation of a universal product family more focused on levels of disability.

The useful application of the research will be in developing a universal design method for product designers and engineers. This method will be broken down into a design structure matrix representation of functions from a universal product family of household kitchen appliances. In addition, an embodied concept for a product family consisting of existing accessible dispensers will be used to validate the universal design method developed from the twenty product study. Both case studies will serve as an example of how to extend universal design principles to a wide range of consumer product categories.

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Thanks also go to my friends and colleagues and the department faculty and staff for making my time at Texas A&M University a great experience. Finally, thanks to my mother and father for their encouragement and to my friends from Buffalo, New York for helping me along the way.

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CHAPTER I

INTRODUCTION: BACKGROUND AND MOTIVATION

According to the U.S. Census Bureau, 18 percent of the U.S. population has some form of a disability. Disabilities can affect individuals' access to educational and working environments. Six percent of people aged 16 to 64 years old have a disability affecting job stability and working conditions. Twenty-two percent of people 25 to 64 report that they have intellectual or cognitive disabilities that affect their ability to access information or educational services [1].

As people age, the probability of developing a disability increases. This trend is expected to increase as the life expectancy rises to 79 years for those born during the turn of the century [2]. Given this statistic it is very surprising to find that companies are very unfamiliar with applying universal design.

In a United Kingdom study of 87 design, manufacturing and retail sector companies, various responses towards barriers to universal design were statistically accumulated [3]. First of all, the various barriers were evaluated based on the companies'

This thesis follows the style of *IEEE Transactions on Education*.

awareness of universal design. In almost all of the responses, the ‘not aware’ responses were highest in percentage for each of the various barriers. Furthermore, for those ‘not aware’ the most popular answer was lack of knowledge and tools creating a barrier to implementing universal design. For those participants who were ‘extremely aware’ of the concept of universal design, their most popular answer was thinking that universal design is too hard to implement.

Clearly, there are barriers to universal design because people do not really know what it is in practice and what tools can be used to develop a universal product. While these barriers do exist, there are companies and products that have achieved success while implementing universal design strategies. In addition, there are principles and rules developed by researchers and companies explaining what a universal product does however there is not a direct universal method for implementation.

Two examples of successful companies that have implemented universal design concepts are O.X.O and Toyota. O.X.O with their Goodgrip product-line initially designed for an accessible line of kitchen tools with comfortable grips for arthritic customers [4]. As years went by, the market segment shifted to younger users interested in cooking with ergonomically friendly peelers, bottle openers and other cooking utensils. What O.X.O really developed was both an accessible and universal product. The accessibility aspect was in the ergonomic adjustment for the elderly while the universal aspect took this into consideration in addition to the distinct style and repeatability of the santoprene handgrip in all of its various kitchen tools (refer to Figure 1).

Figure 1. O.X.O Goodgrip Serrated Vegetable Peeler.

The Universal Design showcase in Japan is another success story using universal design [5]. In this case, universal design was implemented from the ground up while developing minivans and sedans. For instance, the chairs, knob placement and trunk configurations all became stock items in vehicles rather than after market add-ons. For example, the Toyota Crown Comfort has a mechanical handle that will pull out and swivel a rear seat towards the entering passenger as shown in Figure 2. Aside from this pull out handle, the configuration of the seat is very similar to any other sedan. Often these modifications are adaptable but implemented early on in the design process in order to become mainstream.

Figure 2. Toyota Crown Comfort Swivel Chair Sequence [6].

As described so far, there are rules for universal design and success stories, but the goal of this paper is to suggest a prototypical tool or strategy for supporting universal product design and showing how a universal product family can be created. This goal does have gaps due to the many human factors and social influences difficult to quantify. Nonetheless, these human factor elements have been incorporated into a design process and evaluated closely by Keates [7]. This existing method for designing universal products will be discussed in the next section.

This paper focuses on applying traditional design techniques to design universal products. Particularly, product design methods and product platforming principles are used to systematically develop a universal product during a conceptual design phase. These product design methods and platforming principles following a sequence starting with looking at the sequence of user interactions known as an activity diagram and visually representing the sequence of product functions known as functional modeling.

The remainder of this paper is organized as follows. Chapter II reviews related literature and background for traditional design and universal design. Chapter III describes the proposed design method for supporting universal design. Chapter IV gives a case study using twenty products. Chapters V describes disability terminology and methods for creating a universal product for different disability levels. In Chapter VI, limitations and future work are discussed. A conclusion and insights gained overall are presented in Chapter VII.

CHAPTER II

LITERATURE REVIEW

AND BACKGROUND

Universal design has many closely related types of design. For example, transgenerational design focuses on design for older people and rehabilitation design focuses on design for the handicap. These are closely related designs because they focus on a specific segment of the population that requires the easiest means of using a product. This ease of use idea is similar to principles of universal design [8];[9];[10].There are also existing traditional and universal design methods that have been thoroughly documented and explained by others [11];[12].

Universal Design

A universal design is a design that can be used equally as well by people of any ability. It also does not discriminate users based on their ability. Accessible design achieves the same goal as universal design but is often regulated by rules or governmental intervention. Adaptable design can also be universal in the sense that it changes an existing product by merely modifying a part or component to make it easier to use [13]. As a result, the stigma of using an accessible or adaptable product may still be prevalent despite its ease of use. For example, Figure 3 shows how accessible, universal, and adaptable designs vary across the design space [13].

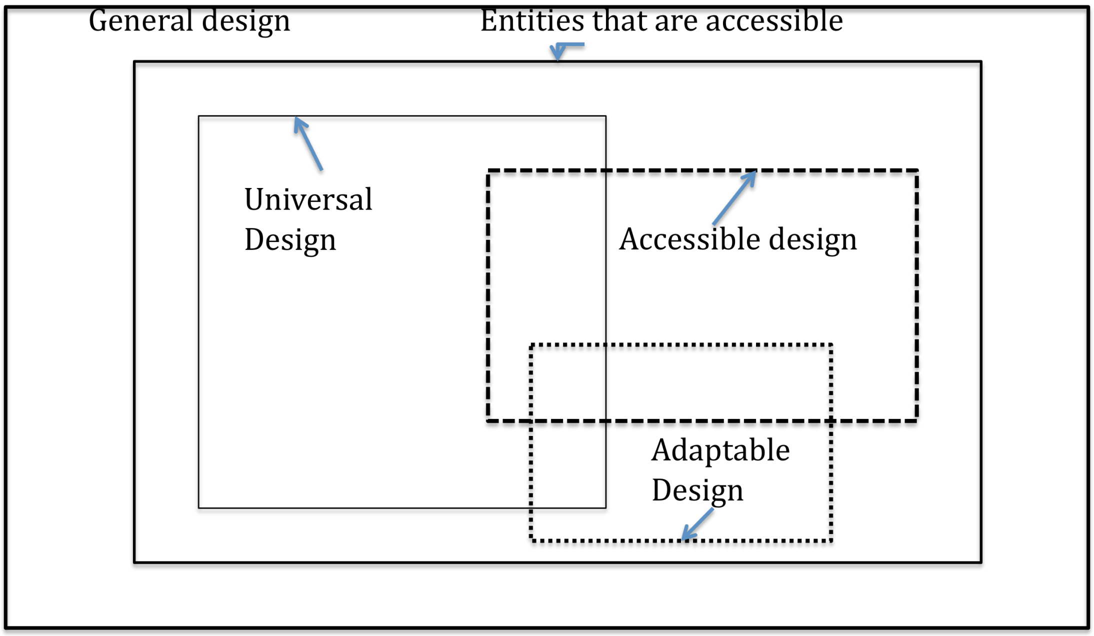

Figure 3. Design Venn Diagram. Overlap shows designs that are in more than one category [13].

As shown in Figure 3, there is an opportunity to create a universal design from more commonplace adaptable or general designs. However, as a designer, there is a tendency to focus on adaptable or merely general designs because of cost, market or time constraints. These constraints are associated with product assessment techniques and are believed to be the most common problem with universal design because of extra design steps [11]. In addition, it is often the lack of education and tooling that prevents a company from reaching the overlapping areas of universal design. Companies want quick, visual and an easy to understand tool with product examples and case studies in order to feel more comfortable implementing universal design techniques [12]. Designers want to know how to use the plethora of information about universal design in a more systematic way [14].

Furthermore, designers often focus purely on functionality unaware of users with different capabilities. The designer is not sure how to incorporate universal design into the design process [15]. Moreover, designers work reactively rather than proactively. For instance, a designer will react to a definite set of customer needs and focus on satisfying them. Rather a designer should proactively design to focus on the product's capabilities and ability to work with a variety of consumers [16]. Reactive design focuses more on redesigning a specific part of an existing device to satisfy a customer. However, if the user is redefined at the front end of the design process, the designer will produce a more universal product.

A designer cannot purely design for a disabled person and assume the product will be universal. The eventual outcome will be a technical improvement of the product and usability will be overlooked [17]. What will eventually happen is consumers will rebel and the stigma of universal design will occur.

Interpreting universal design delays creation of a universal design tool. For example, there are shortcomings with designs that either focus too much on specific market segments such as transgenerational design. Transgenerational design theory describes how older adults are the focus for design often misinterpreted as universal [8]. People may also get this type of design confused with rehabilitation design dealing with impairments [9].

Traditional Design Method

The traditional design method is important in establishing a framework for a universal design method. Various methods such as activity diagrams and functional models are important when implementing a traditional design method in product creation. A brief background of the three phases of design will provide an outline for how a universal design method can expand three design phases and focus on the user of a product. The expansion of the traditional design method for universal design is explained in the Universal Design Method section.

Figure 5 is a flow chart of a traditional design process [18]. The first step in the design process is to clarify the task or identify the potential for creating a marketable product. At this stage, marketing, surveying, and some basic customer requirements are accumulated in order to completely understand a product opportunity.

The next step is to develop the concept by using customer requirements to begin preliminary concept modeling. Modeling a product is developing a process description. By focusing on preparation, execution, and conclusion the sequence of user interactions with a product allows a designer to focus on and assemble a sequence of product functions. At this stage, activity diagrams and functional models can be used in addition to quality function deployment. Quality function deployment aims at matching customer needs with engineering specifications. Often a House of Quality is used to organize and evaluate the correlation between the needs and specifications [18].

The third and final phase of traditional engineering design is actually implementing a concept. At this phase, detailed sketches are created and components for a product are gathered. Furthermore, embodiment modeling may include numerical or physical means of testing a concept.

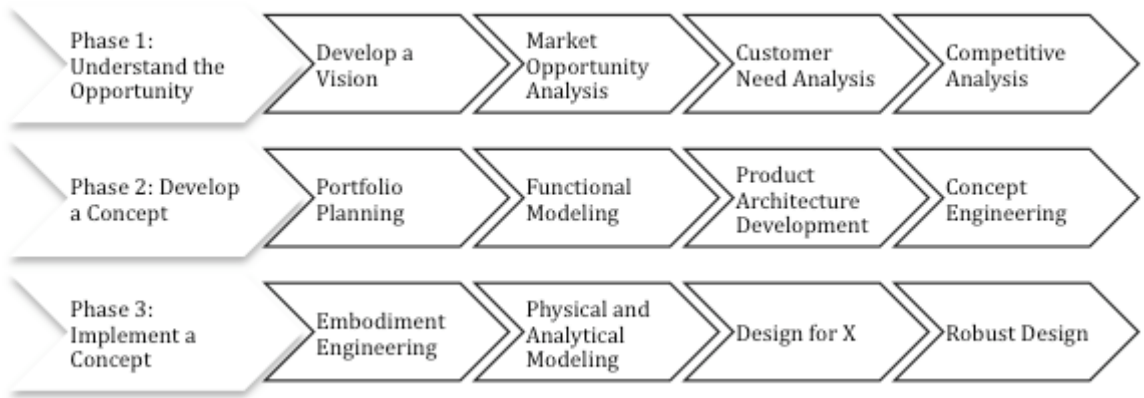

Figure 4. Tradition Design Process [18].

The traditional methods used to develop my universal design method are shown in Phase 2: Develop a Concept. Functional modeling, product architecture development, and concept engineering are important while creating a universal product for a specific user because these methods provide a concept that not only focuses on the product functions but how to reuse product functions for product platforms. These platforms can be customized for the user of a product and shown in a solid model while doing concept engineering. I use Phase 2 methods in my case studies and demonstrate how the end user of a product influences the product design for not only individual universal products but universal product families.

Universal Design Method

There are principles that help someone understand universal design philosophy. Codified by researchers at NC State, the seven principles of universal design are: 1.) Equitable Use, 2.) Flexible in Use, 3.) Simple and Intuitive, 4.) Perceptible Information, 5.) Tolerance for Error, 6.) Low Physical Effort , 7.) Size and Space for Approach and Use [10]. A specific product that contains these seven principles is a universal product. These principles do not directly state how to create a universal product but rather help someone determine if a product is universal.

Equitable use refers to useful design for people with a diverse set of abilities. The principle avoids stigmatizing users of a product. An example of applying equitable use in design is a curb cut out or an entrance ramp.

Figure 5. Curb Cutout.

Flexible in use allows a design to accommodate a wide variety of abilities and preferences. The user can adapt to using a product at his or her unique pace. An example is the Fiskars Softouch scissors that can accommodate left or right-handed use.

Figure 6. Fiskars Softouch Scissors.

Simple and intuitive refers to being able to understand a product's function. For example, a person could understand operation of the product without needing to acquire a new skill. An example, is whenever, a person assembles or uses an office chair. The instructions clearly show how to assemble a chair. In addition, the shape and adjustment lever are intuitive for a person to operate.

Figure 7. Neutral Posture 8600 Office Chair [19].

Perceptible information informs the user how to use a product. For example, tactile, visual, and pictorial representations allow for suitable contrast of important information and its surroundings. An example, is a washer and dryer knob (Figure 8) or thermostat interface.

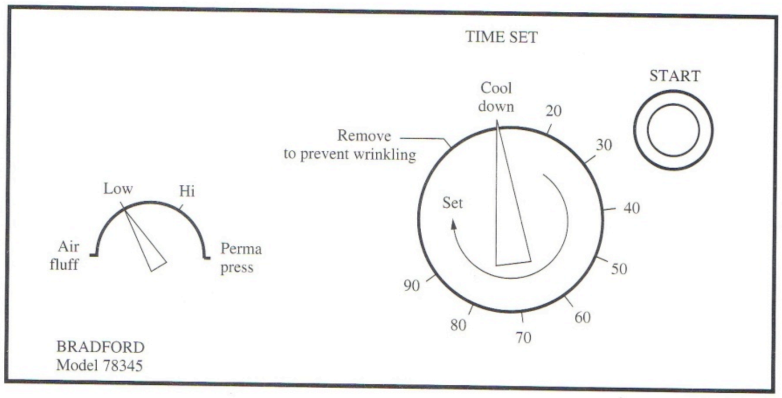

Figure 8. Redesigned Dryer Control Panel [20].

Tolerance for error takes into account accidental actions taken by the user resulting in no adverse consequence. An example is the 'undo' feature of most word processing software. If a typo is made, just click undo and the user gets another opportunity to revise a document.

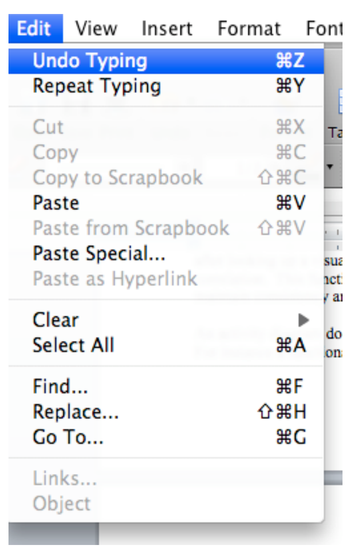

Figure 9. Undo Feature on Word Processing Program.

Low Physical effort refers to minimizing the amount of physical fatigue a person feels while using a product. An example is a lever door handle instead of a traditional knob. A person may open a door with a closed fist or finger rather than using all fingers to grasp a knob and open a door.

Figure 10. Lever Door Handle.

Size and space for approach and use refers to allowing enough space for reaching and interacting with a product regardless of mobility, posture or body size constraints. An example of this implementation is an entrance gate (Figure 11) or an airport check station where scanners and checkpoints are designed for different sized people with and without luggage.

Figure 11. Entrance Gate [10].

Another set of design principles and guidelines for product design focuses more on functions of a product and how to fulfill these guidelines in order to cover as many disabilities a possible. The five function areas are: output/displays, input/controls, manipulations, documentation, and safety. For each function area five disabilities are addressed by stating problems and example solutions [21]. To take this approach one step further, another means for evaluating the universality of a product is by associating exclusion scores for various human attributes. If the score is low, a user with a disability similar to the five areas addressed in the previous approach will have difficulty using the device. This product assessment method includes: product description, context of use, sequence of use, capability, score and justification [22].

However, other researchers have more systematically modified the traditional three-step design process and expanded it to account for universal design aspects [11]. One example is Clarkson's seven-step approach to design as shown in Figure 12 [11]. The first two levels of Clarkson's universal design method parallel the first two phases of a traditional design method. However, phase two is actually broken down into levels 3 through 5 in the 7-level design approach.

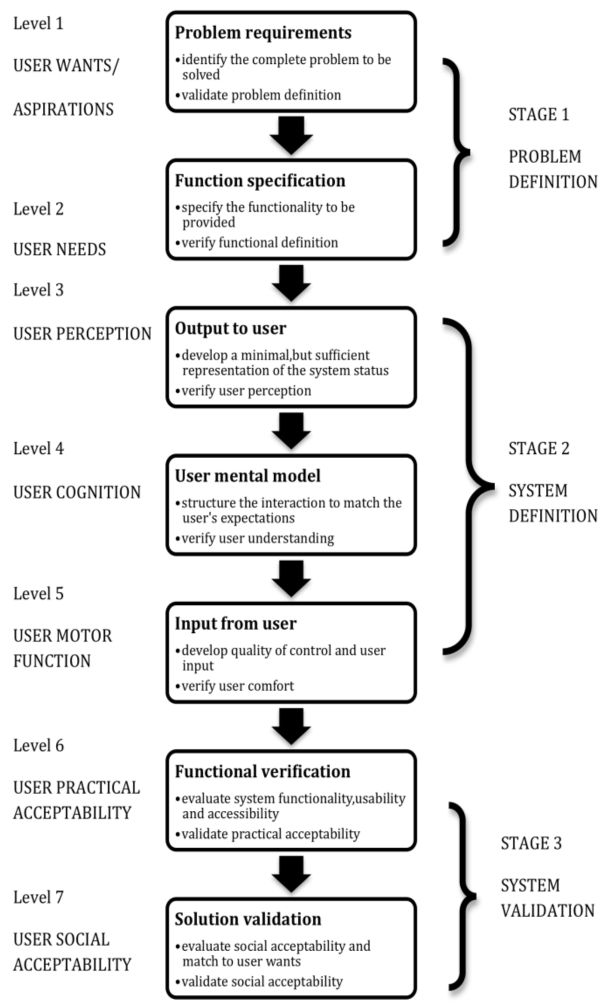

Figure 12. The 7-level Design Approach [11].

In the 7-level design approach, user perception, cognition, and motor function are additional elements introduced into a traditional design method to make it universal. Level 3 describes user's perception of the product or how the physical layout of the product affects the user interaction. Often anthropometric, ergonomic and empirical data from trials are needed to complete design at this level. Level 4 focuses on the user's mental or cognitive interaction. Cognitive walkthroughs are used to correlate user system behavior to user expectations. Thirdly, level 5 focuses on user input or interaction with the product and relies on similar techniques as those used at level 3 to address design at this level [11]. These three additional elements will help explain how a universal design tool composed of traditional methods can fit into an existing framework for universal design. This is further explained in Chapter III.

CHAPTER III

UNIVERSAL DESIGN TOOL

In this chapter, 20 product pairs are compared to explore the differences between typical and universal products. The term product pair denotes two products that provide the same overall usage, such as cutting or peeling vegetables, but differ in their final implementation. Specifically, one product is designed for users with some disability and the other product is intended primarily for a typical user. The product pairs are compared in the context of user action and product functionality to understand changes needed in a typical product to make it universal. To facilitate the understanding of product difference, a new representation framework is used called the actionfunction diagram. The actionfunction diagram combines an activity diagram and a functional model providing a single framework to model user activity and product function.

In this chapter, the product pairs are briefly reviewed, background and explanation of activity diagrams and functional models is given, and the actionfunction diagram is introduced. Then, the actionfunction diagram is used to analyze the product pairs. Results are presented and discussed in terms of the type of product difference and the interaction between product function and user activity and disability.

Figure 13 shows the proposed method for developing a universal design tool by integrating traditional design methods, universal design principles, and product family design. The proposed method (IED method) consists of three phases: (1) Identify, (2) Evaluate, and (3) Determine and thus will be referred to as the IED method. Phase 1 is identifying universal and non-universal product pairs. Identifying product pairs is finding two products with similar overall functionality but different in the type of design changes.

Design changes are functional,morphological or parametric. Design changes were created while doing research for a consistent method of identifying differences and similarities among different product pairs. In Phase 2, the selected product pairs are evaluated based on actionfunction diagrams. Actionfunction diagrams are new diagrams developed in my research for understanding the interaction between product function and user activity. Phase 3 is to determine general design knowledge that can be used in product family assembly. Modules reveal the general design knowledge. Module identification during Phase 3, using the actionfunction diagram, uncovers reusable modules for universal product design and product family assembly. Modules with acitivites grouping product functions in a user centric context from the actionfunction diagrams are similar to components grouping product functions in a product centric context.

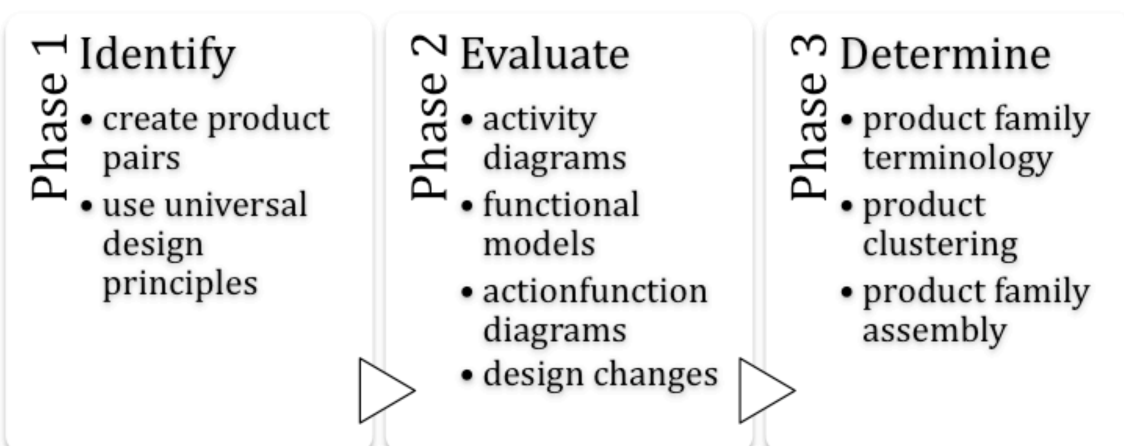

Figure 13. The Proposed Universal Design Tool Flowchart (IED Method).

Phase 1- Identify Universal and Non-Universal Product Pairs

In Phase 1 the designer identifies universal and non-universal product pairs and describes their differences in terms of user feedback and the principles of universal design. Product pairs are products with similar overall functionality but different in the type of design changes. In order to understand the effect of differences between product pairs testing of two utility cutters by cutting paper and cardboard was completed. In addition, principles of universal design developed by North Carolina State School of Design were used to understand why the rotary cutter was more universal than the typical utility cutter. Table 1 shows how the rotary cutter satisfies the seven principles of universal design.

I illustrate the design and analysis framework and approach through an example of a paper and cardboard cutter product pair, in this case the Fiskars rotary cutter and standard box cutter as shown in Figure 14. Both products provide the same overall usage of cutting but are different in their embodiment.

Figure 14. Picture of Fiskars Rotary Cutter (above) and Standard Box Cutter (below).

To start, the rotary cutter has a more ergonomic handle. In this example, the handle which provides the secure hand function is based on the same basic principle, but was shaped differently, specifically more ergonomically, for the universal cutter. Thus, this difference is shown as a parametric change in the actionfunction comparison shown in Table 2.

The rotary cutter has a circular blade with a guard whereas the standard box cutter has a retractable angled blade. The difference in blade shape and motion impacted the effort needed to cut. The rotation of the circular blade naturally added a little sawing motion to the material-blade interface reducing the total pushing force needed to cut paper and cardboard as the user pulled the cutter across paper or cardboard. Also, the rotary cutter can cut with a pushing away motion by the user whereas the traditional utility knife only works well with a pulling toward the user motion. This is a morphological difference as rotating is a different principle for cutting than just pulling the blade through the material to be cut. The actionfunction diagram shown in Figure 4 represents this morphological difference in the solution of the convert human to mechanical energy function.

The blade extension and retraction design of the cutters is significantly different. There are two switches to lock and unlock the blade for the rotary cutter whereas only one switch is for both extending and retracting the blade for the standard box cutter. In the case of the rotary cutter, the blade extensions and retraction switches are both activated with a simple pushing in, or pushing down, motions on a single axis of travel. The blade on the rotary cutter is spring loaded to snap back into place when the retraction switch is pushed. For the traditional utility knife, the user pushes the switch into the knife to release a lock, then forward along the length of the knife to extract the blade. The simple pushing in is easier then the push in then push forward motion. Additionally, the actual force to push the switches on the rotary cutter was less then the force needed to either push in or forward on the utility knife.

Both the typical utility knife and the rotary cutter provide the function of transferring human energy into the device to move the blade. The difference is categorized as morphological as there is no clear parametric representation that encompasses both concepts.

Table 1. Universal Design Principles for the Rotary Cutter

Universal Design Principle	**How Principle is Satisfied**
Equitable Use	same model, style, and means of gripping the object
Flexible in Use	right or left hands can grip the handle just as easily
Simple and Intuitive	release and locking switches are conveniently placed
Perceptible Information	switch to release the blade makes a clicking noise to indicate when the blade is safe to use
Tolerance for Error	blade guard and easy to retract push button make adjusting the blade easy for perfect or misaligned cuts
Low Physical Effort	circular wheel reduces the amount of

Table 1. Continued

Low Physical Effort	resisting cutting frictional force
Size and Space for Approach and Use	very slim head with thick enough handle to account for precision cuts and alignment

Phase 2-Evaluate Product Pairs

Activity diagrams and functional models from traditional design are applied in this phase to evaluate product pairs. The relationship between these two methods will help create actionfunction diagrams that cluster universal product functions. Clustering refers to an activity overlapping function(s) in an actionfunction diagram. The premise is that universal product functions, which are related to user activities, occasionally differ between universal and typical product pairs. The designer can uncover universal product functions, when an activity overlaps with design change function(s) in an actionfunction diagram.

Activity Diagrams

An activity diagram is a sequence of user interactions from purchase to recycling or disposal [18]. This sequence may include parallel or series actions. A series of actions implies that one action must occur before another. An example includes turning on a computer before you can log onto the internet. Conversely, a parallel interaction implies that two user activities can occur at the same time. An example of a parallel interaction is simultaneously holding a cup of yogurt and using a spoon to scoop out the yogurt. The relevance of activity diagrams in product design is to provide an outline for a functional model and even suggest product family principles. For example, parallel or series arrangements in an activity diagram may correlate to parallel or series modules [18]. These device functions will be subsystems or assemblies used in establishing product families. An example activity diagram for the rotary cutter and the box cutter is shown in Figure 15. The activity diagram shows the user interaction process from purchasing and unpackaging the cutters to cutting cardboard with them.

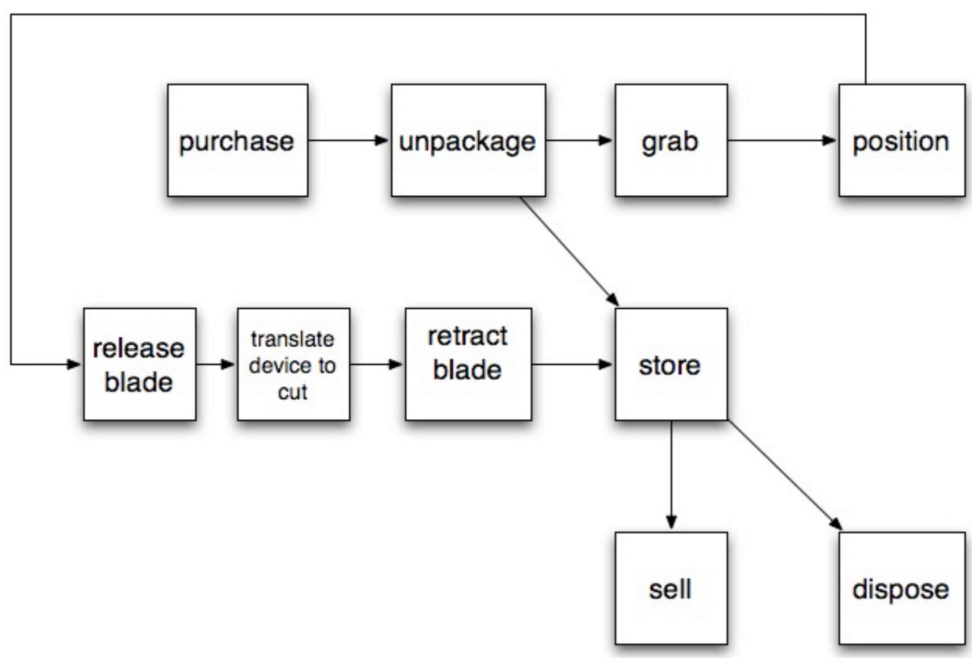

Figure 15. Activity diagram of Rotary and Standard Cutter.

Functional Models

A functional model is a visual tool representing a sequence of product functions. This model consists of functions or what a device does and flows such as material, energy or signal flows that enter and exit each function. These models are created during the "developing a concept phase" after which customer requirements and engineering specifications are realized [18]. Functional models use function and flow terminology from a Functional Basis in order to maintain consistency from one product to another [23]. This basis lends itself to database creation and function-component or design structure matrices in which components and functions are mapped in matrix format. The design repository Missouri S&T contains many functional models of consumer products and how components are related to the functions [24]. A functional model of the rotary cutter was developed focusing on the functionality of the universal product as shown in Figure 16.

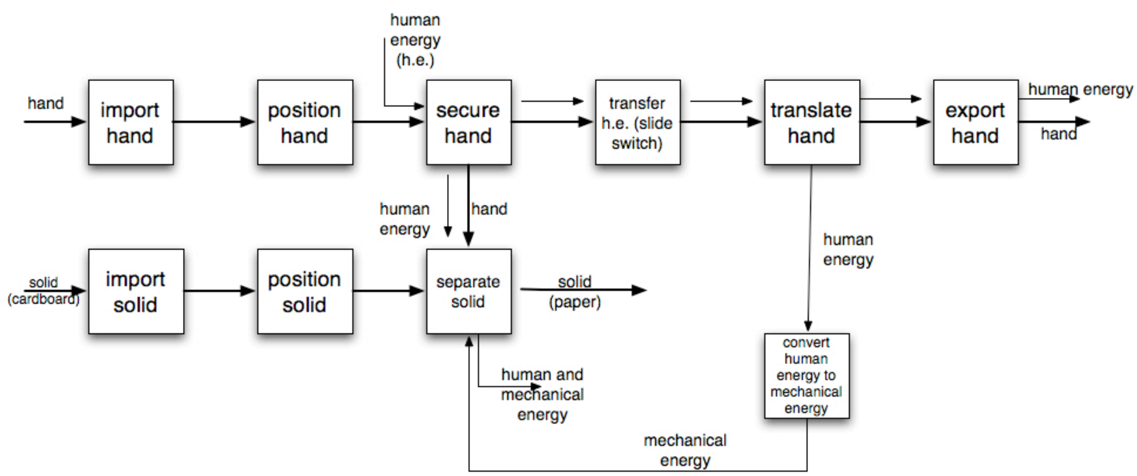

Figure 16. Functional Model of the Universal Rotary Cutter.

As mentioned previously, activity diagrams serve as an outline for functional modeling. By starting with how a user interacts with a product the designer can abstract functions for a functional model. This serves as the first task in decomposing a universal product and providing insight into designing for universality. Take for instance a vegetable peeler. The standard and universal O.X.O branded peelers have a similar procedure for operation and identical functional models. From the onset, this overlapping seems to hide what is truly universal about the O.X.O peeler. However, after physical testing and feedback about what is great about the product, the grip is on the top of the list. Hence, there is a direct mapping between physically grabbing the product from the activity diagram and "securing hand" in the functional model. This simple example shows a one-to-one mapping of user activity to function. However, a sequence of functions or user activities maybe mapped to one user activity or function respectively.

Actionfunction Diagrams

To reflect the specific functions that differ between the universal and non-universal functional models, we introduce three design changes that are categorized into function, parametric or morphological changes. These three changes are used to provide a clear categorization of how a universal product differs from a non-universal product. Definitions and examples for each of these changes are shown in Table 2.

Table 2. Design Change Definitions and Examples

Type of Change	Definition	Function; Example of change
Function Change	A new or different function.	Export hand; In the case of the signage studied in the twenty product study, the Braille exported the hand while the typical sign did not have any braille
Parametric Change	A scalable difference between the same functions for both the universal and non-universal product	Secure hand; Physically the hand grip of an object is either bigger or more ergonomically designed
Morphological Change	Same function but different component.	Allow DOF (degree of freedom); A way to allow DOF would be to have either mechanical linkages or springs. Both alternatives can provide a similar motion but their component makeup is different.

In Figure 17, an actionfunction diagram is represented by the dashed rectangles which group function(s) that pertain to a specific activity from the activity diagram. From the results of the actionfunction diagram, we can obtain two features of the cutter products. First, a basic functional model is shown with the functions, boxes connected by arrows or flows. The non-universal functional model differs only in the parametric and morphological change boxes in Figure 17. In the rotary cutter case, convert human energy to mechanical energy is a morphological change by having a circular disk rather than a rigid blade. The transfer human energy function is also a morphological change because the switches are different in form. For example, the rotary cutter has a button and a switch to transfer human energy whereas the utility cutter only has a switch for both retracting and releasing the blade. A parametric change, secure hand, refers to the physical differences in actually gripping the cutter handle for the universal and non-universal case. In short, the second feature shows how design changes are created from the functional models.

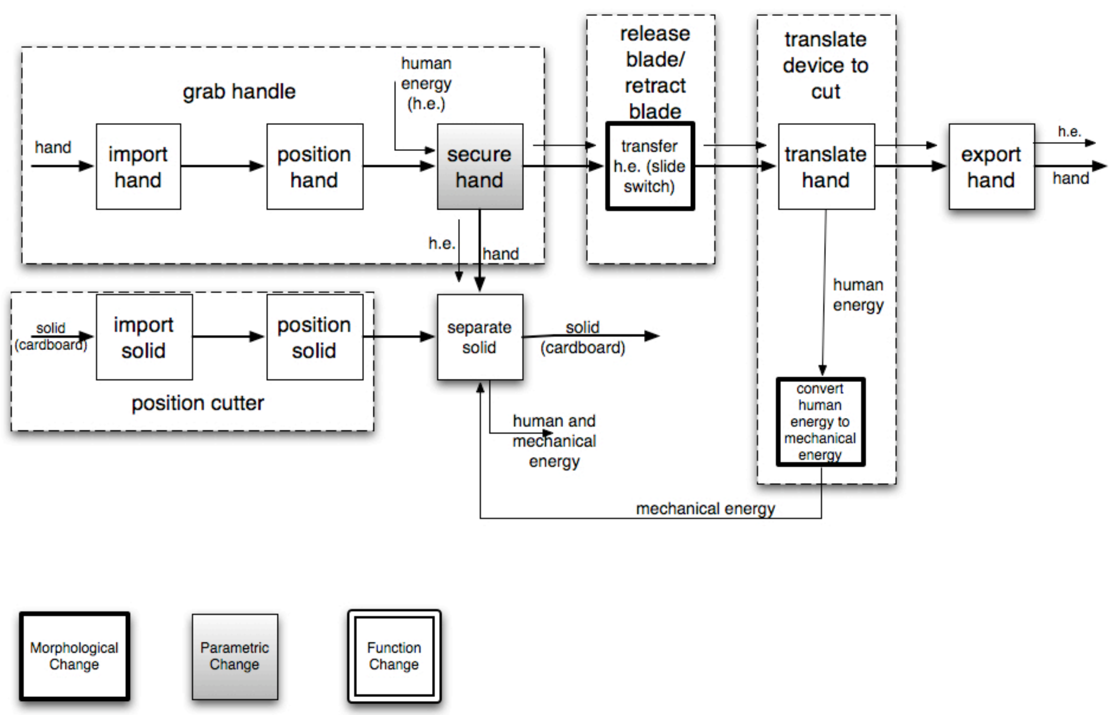

Figure 17. Actionfunction Diagram of Rotary Cutter.

Phase 3: Determine General Design Knowledge

The previous two IED phases are brought together through product platforming by creating new terminology that categorizes universal product pairs, actionfunction diagrams and more specifically design changes for universal product design. Product platforming terminology such as product platforms, common parts, variant parts, unique parts and individual products and clustering methods provide a way to not only assemble a universal product family but help improve the accuracy of the universal design tool and database.

Product Platforming

A product family is a group of products with features, functions, or subsystems in common. The common element within the product family is the product platform. Individual products are the products customers purchase at retail stores or online and use in their lives [25]. For example, Black and Decker created a product family consisting of a drill, flashlight, and saw in their VersaPak family [26]. This product family included the same battery pack that is considered as a platform. The drill, flashlight and saw are the individual products within the family.

Parts in a product family can be categorized into variant, unique and common parts. Variant parts provide the same function within a family but differ in shape or material. Unique parts are unique to one product within a family and common parts are the same from one product to another within a family. With this terminology, a percent commonality index shows how similar or different products within a family are in relation to their components [27]. The commonality index is defined as follows.

$$C_c = \frac{100 * common\ components}{common\ components + unique\ components}$$

A high value of the commonality index implies that many parts are being shared. In a universal design context, this equation relates to common,variant, and unique functions between functional models of both universal and non-universal product pairs. For the utility cutter comparison, commonality indices can be calculated for functions rather than components. In the case of functions, a morphological change or a parametric change corresponds to a variant function. A function change corresponds to a unique function and no design change corresponds to a common function. However, the commonality percentage could be 100% if there are only variant and common functions. This is where the terminology differs between part commonality and function terminology used in this thesis. The purpose of using the product platform equation is to demonstrate that a highly common product pair family implies that the universal product is a low cost improvement of the typical product yet still deemed to be universal. Whereas, a unique function or function change in a product would imply having to add a feature to a product to make it universal which is typically higher in cost than changing a parameter or shape of an object typical of a parametric or morphological change. Table 3 shows the functions of both the utility and rotary cutter along with the type of function and the ratios for common and variant functions.

Table 3. Function Comparison Between a Typical and Universal Rotary Cutter

Function	**Utility Cutter**	**Rotary Cutter**	**Function Type**	**Design Change**
import hand	1	1	common	none
position hand	1	1	common	none
secure hand	1	1	variant	parametric
transfer h.e.	1	1	variant	morphological
translate hand	1	1	common	none
export hand	1	1	common	none
convert h.e. to m.e.	1	1	variant	morphological
import solid	1	1	common	none
position solid	1	1	common	none
separate solid	1	1	common	none
Total # of functions	10			
Cc (commonality index)=	100			
% variant	30			
%common	70			

For example, a minimum metric or cutoff value of variant, common or unique function percentages may indicate which universal product pairs are cost effective or practical. For instance, having common or variant functions just like having common or variant components in a product family can be lower in cost than a unique function or unique component. In the case of the rotary cutter, all of the functions are shared between the two products and there is enough difference in the parametric and morphological changes to distinguish the universal rotary cutter from the typical utility cutter. Hence, the rotary cutter can be considered a cost effective and practical universal product. The assumption is left for further research and investigation. However, the purpose of presenting the product platforming rotary cutter example is to show how existing product clustering and platforming principles could be used directly for universal design without considering the use of actionfunction diagrams. Actionfunction diagrams depend on previous clustering and platforming principles as a basis for focusing on a user centric design method. As a result, showing a platforming equation reinforces the connection between universal design and product family creation.

Product Platforming is related to other forms of functional model decomposition. For example, Holtta and Otto used functional models for evaluating redesign complexity in a product family of drills [28]. They investigated a common platform, which was a partial functional model, and proposed a redesign metric based on weighing the flows in proportion to this complexity. This research not only relates to product clustering involvement in product platforming but how to incorporate a subjective and qualitative factor of redesign and numerically incorporate it into product platforming.

This incorporation may relate to customer feedback and requirements necessary when designing a universal product. In other words, there is a potential to include a customer's opinion and voice in creating a universal family and viable universal product tool. User opinion and voice is left for future universal product design research.

Product Clustering

Product clustering is defined as grouping functions in a functional model based on their intuitive arrangement. For instance, an inkjet printer with ink, paper handling and electronics systems are clustered based on functions and flows related to these systems. Generally, the purpose of clustering in design is to modularize design and manufacturing tasks. This helps form a rough geometric layout of the clusters that aids in communicating the design to people involved in the process [18].

Product clustering is very similar to creating an actionfunction diagram. However, an actionfunction diagram does not directly consider flow arrangement like some clustering does. Both methods do rely on an intuitive arrangement. For example, mechanical and electrical subsystems can be identified by functions and flows related to these domains with clustering. Similarly, user activities have similar language as the product functions that they group. For example, the activity grab correlates with the product function secure. The product flow is exactly the same as the body part that the person uses called hand.

Other clustering methods include dominant flows, branching flows, and conversion-transmission modules. Each of these methods relates the function and flow interactions in a different way to separate modules. Furthermore, these methods become necessary when a functional model is not intuitively decomposed like an inkjet printer.

The dominant flow method tracks a single flow and clusters functions that it passes through. When the flow either exits or is converted, a module's boundaries are created. Branching flows is a method that clusters functions based on their sequential arrangement in a parallel layout within the functional model. In other words, parallel function chains become clusters. Finally, conversion-transmission modules are convert functions that take an input flow and output a different flow. This different flow is traced through until it no longer appears at which point a cluster is formed [18]. For example, some conversion-transmission modules refer to motor or energy converting components.

In designing for universality, ergonomics and human interaction with the product are very important. As a result, hand, human energy and signal flows can be clustered according to the dominant flow heuristic in order to isolate potentially ergonomic or user-friendly features of a product [18]. In the case of the rotary cutter, instead of merely relying on intuition to group functions with user activity, an advanced clustering method can be used. The new clustering arrangement of the rotary cutter is shown in Figure 18.

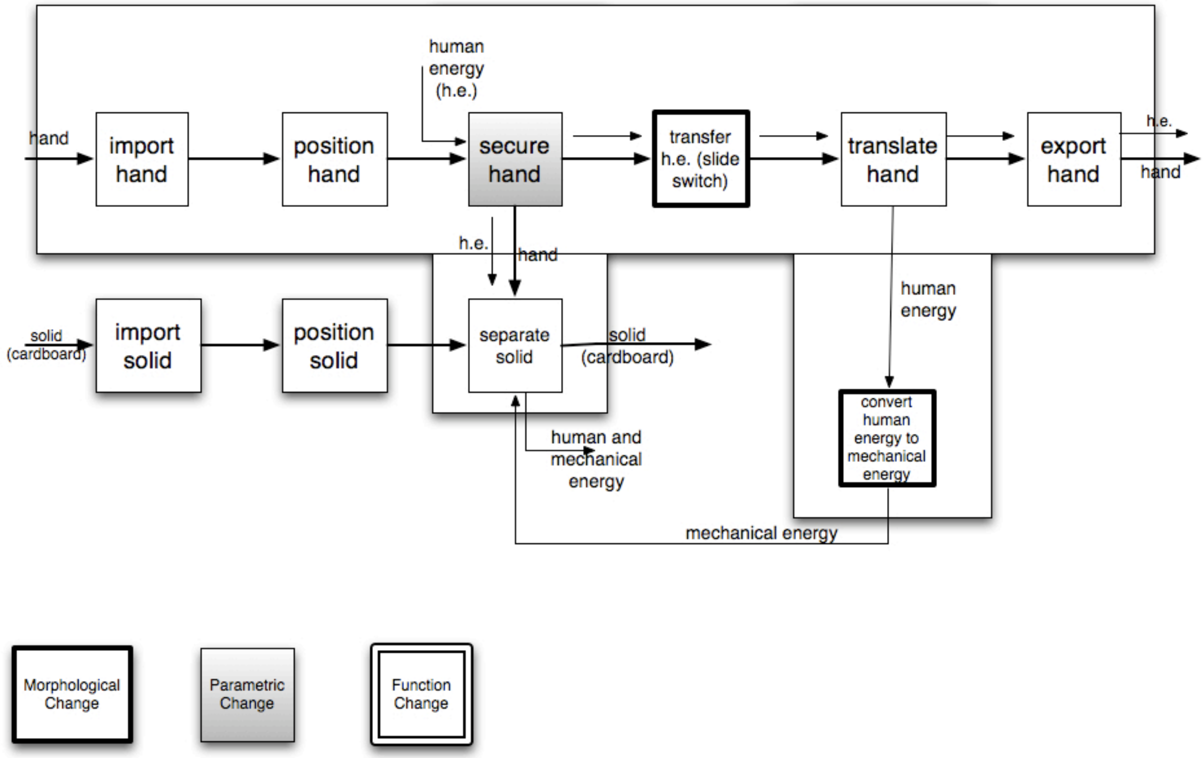

Figure 18. Clustered Rotary Cutter.

Using traditional advanced clustering methods, the dominant flow, branching flow and energy conversion flow heuristics identify different function chains. Table 4 shows the number of chains for each of the three advanced clustering methods and the number of modules for both the utility cutter and the rotary cutter.

Product	Dominant Flow	Branching Flow	Energy Conversion	# of modules in the device	*Modules*
Rotary Cutter	4	4	1	4	blade, shleld, handle,switch
Utility Cutter	4	4	1	3	handle, blade,switch

Dominant Flow Modules

1 import hand, position hand,secure hand,separate solid
2 import hand, position hand,secure hand, transfer h.e., translate hand,export hand
3 secure hand,transfer h.e.,translate hand,export hand
4 secure hand,separate solid

Branching Flow Modules

1 separate solid
2 transfer h.e., translate hand, export hand
3 convert human energy to mechanical energy
4 translate hand, export hand

Hub

import hand,position hand, secure hand

Energy Conversion Modules

1 convert human energy to mechanical energy

Figure 19. Number of Potential Modules Using Three Different Clustering Heuristics.

The dominant and branching flow chains are the greatest in number and are greater than the number of modules in the typical devices and equal to the number of modules in the rotary cutter. This shows that creating a more modular product can correlate with a more universal product. The association is presented to demonstrate how strictly applying modular heuristics can lead to a universal design. However, this study was only done for the rotary cutter and is presented as a future avenue of research for universal product design. What modular heuristics does present is a motivation for creating actionfunction diagrams. Since actionfunction diagrams are very similar to modular heuristics, an example case study using modular heuristics was presented to show that previous clustering methods could be applied to universal product design and distinguishing between a universal and typical product. Since the flows are human based more modules may imply greater potential for a more universal product. The branching flow number explains how bus modularity or a snap-in part module could result in either the rotary cutter or utility cutter. An example would be how the blade snaps into the handle or housing of the cutter. Finally, the energy conversion modules are exemplified in the rotary and stationary cutting blades for the rotary and utility cutters.

Extension to a Design Repository

There is a progression from understanding how the seven principles of universal design apply to a universal product and how the product is unique in its user activity and functional arrangement. The uniqueness in the product is how the clusters created in an actionfunction diagram are connected to one another. Furthermore, by taking different modules from different universal products, a new universal product could be created. Storing these modules along with what functions are design changes in a database is important in creating a tool for a designer interested in creating a universal product or universal product family that has common, variant and unique modules.

The database could resemble design databases already created such as the Missouri S&T design repository in which functional models for products, DSMs and FCMs are easily available to the designer [29]. An example from this database is shown in Figure 20 [24].

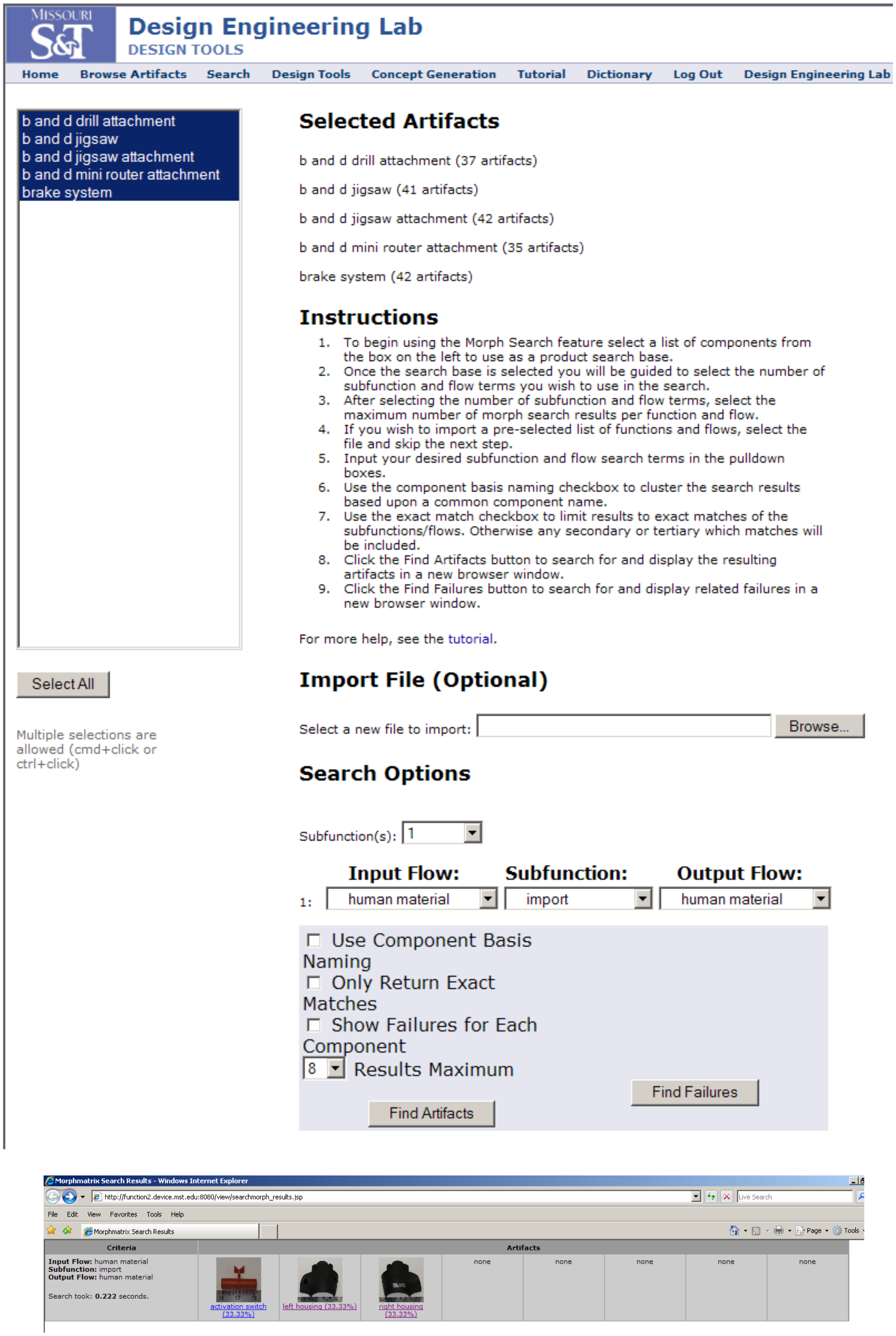

Figure 20. FFDM Search and Results [24].

Figure 20 shows how a database can be used to pictorially represent a function and flow pair. By searching the database for archived products and their functions, the designer can quickly generate a morphological matrix of options for his or her design. This also has applications to universal design and current database development for universal product generation. For example, activity clusters instead of function component matrices are used to uncover the archived data. In other words, the current morph matrix generation on the UMR design repository website depends on a mapping between product components and product functions (FCM-function component matrix). However, in this thesis, a method for creating a new product from scratch is more directly investigated by uncovering archived functions and activities instead of components.

Figure 20 also provides a statistic of the frequency of a function-flow pair appearing in the database. A similar approach is shown IED method database. For instance, a statistic for the frequency of functional appearances is calculated and displayed to the designer. In some sense, the IED method database can be used as a precursor to the morph matrix tool while creating functional models. As a result, an existing component could be attributed to the universal function. However, this correlation is beyond the scope of this thesis and is left for future work.

CHAPTER IV

CASE STUDY

To demonstrate implementation of the proposed method, twenty products were investigated. Twenty products ranging from automobile interiors to scissors were compared in both their universal and non-universal cases. Appendix A shows a table of the twenty products and IED terminology for each product. The IED method prototype was built using MATLAB 7.6 (R2008a) GUIDE (GUI builder). A similar exercise for the cutter case was carried out for the 20 products, and the design changes were archived in a database. This case study will focus on collecting design changes that appear in activity clusters and calculating the frequency of each design change. This will provide data for any trends in the types of functions used in the twenty universal products.

Early Phase of Universal Design Tool

As stated in the introduction, there are barriers to implementing universal design because few know how to implement the principles using a viable tool. A solution to this problem is expressed in a collection of universal product pairs stored in a graphical database. A snapshot of the GUI is shown in Figure 21.

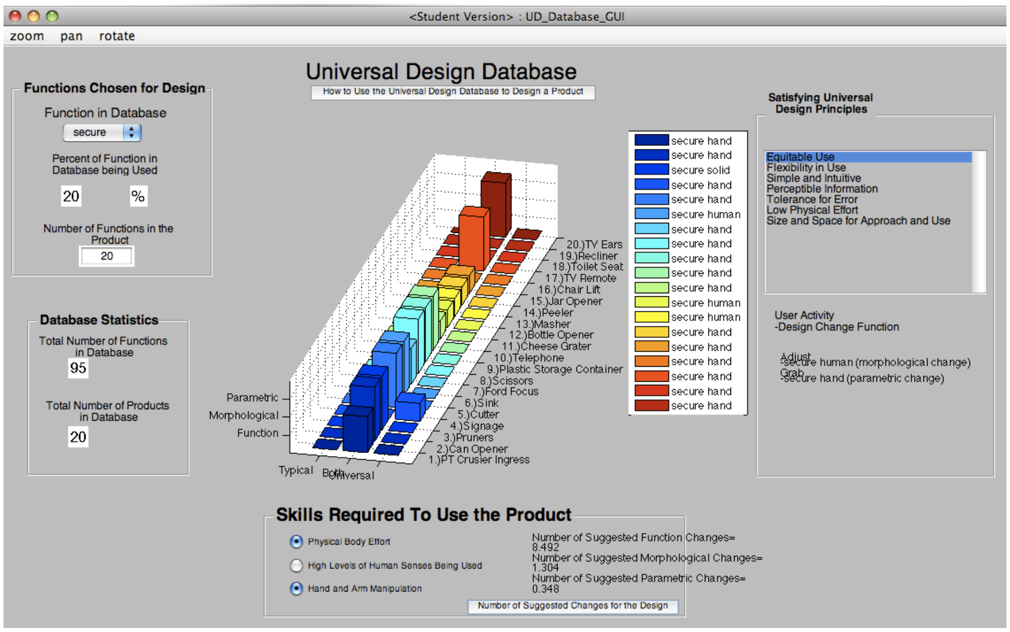

Figure 21. Early Phase of the IED Method Database.

Figure 21 shows a 3D graph containing universal products, and two other axes for their product pairs. One axis shows whether the universal, typical (non-universal), or both products in a pair contain the selected function in design. The second category displays whether the function in design is a parametric, morphological or function change. The user can click the drop down arrow to select from functions in the database. MATLAB GUI builder was used to create Figure 21. Each bar represents coordinates as expressed (product name, universal:both:typical, design change). A design change such as function change was given a value of one, morphological change was given a value of two, and parametric change was given a value of three. 'Universal' was given a value of one, 'both' a value of two and 'typical' a value of three. Starting with the PT Crusier to TV Ears the x-axis values ranged from 1 to 20. These data points were plotted whenever a design change appeared in the activity cluster and the function name was expressed in the legend. In addition, a zoom and pan option allow the user to distinguish between the bars. In the GUI there is a universal design principle table where the user can select a specific universal design principle. When selected, an activity and functions associated with that activity are displayed. The designer can reuse these function chains with specific focus on functions that are design changes.

There is also a panel with three disabilities listed for the designer. Three categories were created based on the key skills needed to operate the product by focusing on the product functions in its functional model. Depending on the product, one or many of the three skill categories may be selected. The designer can estimate the number of design changes in his universal design based on the percentages accumulated and the specific number of functions typed in by the designer. The percentages for each of these design changes are shown in Appendix C.

Results

The results from analyzing the twenty universal products provide knowledge for universal design and statistics about the trends in function, parametric and morphological changes. Appendix C shows the percentages for the three types of changes in the twenty universal products.

Function, Morphological and Parametric Change Percentages

The most frequent design change was a function change as shown at 68 percent of the total number of functions in the results. This correlates with a person's intuition about an improved product in general needing different parts to make it easier to use. This is especially the case for universal products where innovation and new concepts or functions are necessary in order to satisfy more of the principles of universal design.

Parametric changes were the second most frequent design change. Since there were many kitchen and small consumer products in the database, grips and the handling of the product in general were distinctly different for the universal product. For example, the OXO Goodgrip products had a standardized santoprene grip that was not only visually distinct but ergonomically pleasing to the consumer. As a result, a size or comfort change identified by many 'secure hand' functions led to this design change coming in second place at about 18 percent.

Finally, morphological changes only categorized about 14 percent of the functions in the results. This may be because there were relatively few complex consumer products that really depended on existing devices and mechanisms as a foundation. For example, the PT Crusier and its ingress functions were modeled after an existing door hinge mechanism. However, to create more room and directly satisfy the seventh principle of universal design, an actuator or spring mechanism was used instead. This product along with the can opener and the Ford Focus were only three complex products among the 20 in the database. The study did also show that a very simple consumer product such as the gardening tool had a morphological change. In its functional model, a 'allow Degree Of

Freedom (DOF)' function relied on a linkage rather than spring to reduce the amount of physical effort needed to operate the product. These were the two most popular examples of a morphological change.

Combination Change Percentages

The most popular combination change correlation was between function and parametric changes. So for every function change there exhibited a parametric change. Many of the products, included a popular 'secure hand' function or parametric change function and a conversion function (function change) often electromechanical in nature.

Function and morphological changes occurred with 35 percent of the products. This was the second strongest connection between design changes because of the electromechanical nature of most of the consumer products in operation and their functional models. For example, the PT Crusier, can opener and Ford Focus had both changes often occurring in separate subsystems of the device. In the can opener case, the morphological change of removing the lid and the function addition of an electrical element to aid in transferring human energy to electrical and eventually to mechanical energy represented the separate magnetic clamp and power systems respectively.

Finally, parametric and morphological changes were approximately exhibited by 30 percent of the products in the results. Since there were not as many morphological changes as functional changes, this statistic was relatively low. There is a connection between the 'secure hand' and some mechanical alternative that would help with securing the user's hand. For example, the gardening tool had a morphological change of a linkage for the universal case while also containing a change in the grip or handle of the object.

Bathroom Dispenser Product Family

A bathroom dispenser product family case study will be presented to demonstrate how to use an actionfunction diagram for a universal product family.
In order to create a product family of existing dispenser designs, actionfunction diagrams were used to create three different modules: universal, transferring and typical. These modules were used to provide an outline for the Solidworks models of the bathroom dispensers. For example, each functional model for the different soap dispensers was created and modules were designed using the actionfunction diagrams of each dispenser. The functions that were not clustered by activities were considered typical functions that could be grouped together into a typical module or component. Furthermore, similar energy transferring modules such as the pipe and plunger system for transferring the material:soap, shaving cream or shampoo was broken into another module or subsystem.

Abledata.com was the website used to find various dispensers used in the bathroom. A toothpaste dispenser, shaving cream dispenser, automatic soap dispenser and spraying container were the dispensers collected for a product family. The objective was to create actionfunction diagrams for each dispenser and redesign them into a product family. Table 5 shows clusters for the four dispensers. Each cluster is either labeled as a universal, transferring, or typical module.

Table 5. Cluster Table for Dispensers

Product	Activity	Functions	Cluster Type
Toothpaste Dispenser	Grab, Twist	import hand,import h.e.,position hand,secure hand,rotate hand,convert human energy to mechanical energy	Universal (activity cluster)
	Twist,Remove	import hand,import human energy.,position hand,rotate hand	Universal (activity cluster)
	None	transfer mechanical energy	Transferring
	None	store toothpaste,supply toothpaste export toothpaste	Typical
Shaving Cream Dispenser	Grab	import hand,position hand,secure hand, import human energy	Universal (activity cluster)
	Squeeze,Release	allow DOF,convert h.e. to m.e.	Universal (activity cluster)
	Remove	Export hand	Universal (activity cluster)
	None	Transfer m.e.,convert m.e. to pneu. Energy,transfer pneu. Energy	Transferring
	None	Store shaving cream,supply shaving cream,export shaving cream	Typical
	None	Store air,supply air,export air	Typical
	Adjust	Import hand,position hand, secure hand, translate hand	Universal (activity cluster)
Spray Container	Grab	import hand,position hand,secure hand, import human energy	Universal (activity cluster)
	Squeeze,Release	allow DOF,convert h.e. to m.e.	Universal (activity cluster)
	Remove	Export hand	Universal (activity cluster)
	None	Transfer m.e.,convert m.e. to pneu. Energy,transfer pneu. Energy	Transferring

Table 5. Continued

Spray Container	None	Store liquid,supply liquid, export liquid	Typical
	None	Store air,supply air,export air	Typical
Automatic Soap Dispenser	Position	Import hand,position hand,convert hand to c.s.	Universal (activity cluster)
	Remove	Export hand	Universal (activity cluster)
	None	Store e.e.,actuate e.e.,transfer e.e.,convert e.e. to m.e.	Universal (activity cluster)
	None	Transfer m.e.,convert m.e. to pneu. Energy,transfer pneu. energy	Transferring
	None	Store soap,supply soap,export soap	Typical
	None	Store air,supply air,export air	Typical

The universal module is the module that makes the product universal. This module was known before the actionfunction diagram was made because of the product description from abledata.com. All but one universal module was related to a user activity. The exception was the battery or electrical energy universal module in the automatic soap dispenser. Since this makes the product more automated, user activity is replaced by the product functions. This is typically why there are so many automatic dispenser aids in bathrooms and restrooms, for accessibility.

The transferring module is a cluster of functions that transfer either mechanical or pneumatic energy. This module is typically invisible to the user and is a pump or cylindrical tube attached to a nozzle for a soap dispenser. Finally, the typical module is a module in almost any dispenser being sold. These two modules were the liquid, soap, or shaving cream module and the air storage module. All the dispensers from abledata.com had both modules combined into a storage container.

All in all, the actionfunction diagrams provided a great starting point for identifying what features of each product to keep the same, which features to vary, and which ones to change for a specific dispenser. The features to keep the same include the body shape of the dispenser. The body would hold a container with either soap, shaving cream, liquid, or toothpaste. These containers would be variant from one product to another within the family. In addition, the transferring module would be variant for the respective dispensed liquids as well. Finally, the interface between the user's hand and the actual dispensed liquid would be the universal (unique) module. Figure 22 shows a three product family of dispensers for the bathroom. A morphological matrix in Figure 22 shows what functions correspond to specific product components.

Functions	Components
import hand	nozzle
position hand	nozzle
secure hand	button
export hand	button/nozzle
convert hand to c.s.	sensor
import material	storage container
store material	storage container
supply material	storage container
export material	storage container
import human energy	button
convert h.e. to pneu. energy	pipes connected to plunger attached to button
import electrical energy	battery
store electrical energy	battery
actuate electrical energy	battery
convert e.e. to m.e.	actuator
transfer m.e.	actuator

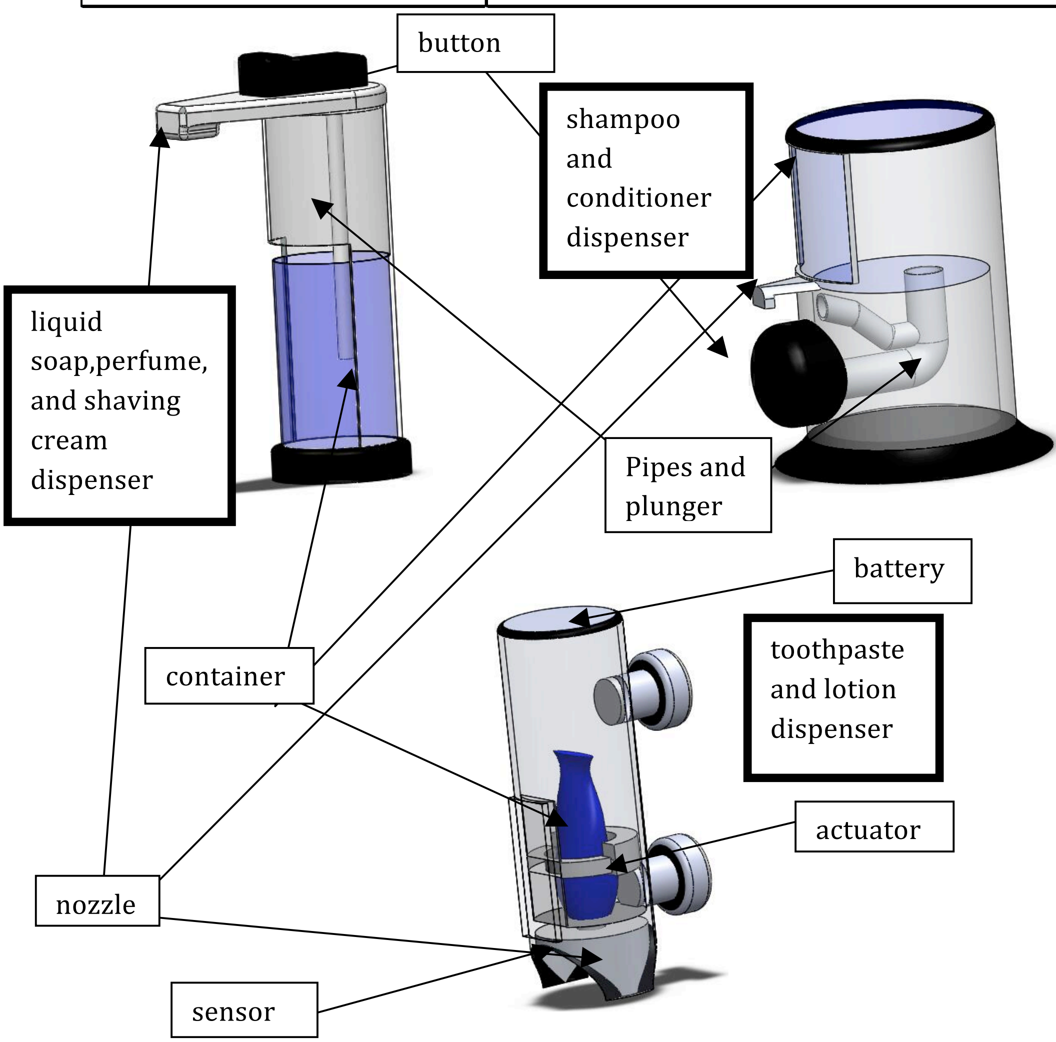

Figure 22. Bathroom Dispenser Family.

The common features among the dispensers in Figure 22 are the dispenser shapes and the clear containers to let the user know when to refill the liquid containers or replace the toothpaste container. The nozzle for the shaving cream dispenser was put on the top of the dispenser while it was placed below the liquid container for the shampoo dispenser. The shampoo dispenser was designed with a wider base to accommodate a greater amount of liquid soap being stored. In addition, the removal of the liquid container from the top of the shampoo dispenser is easier than the bottom level container like that for the shaving cream dispenser. The wall mount toothpaste dispenser will save space and not need to be moved around like the shaving cream dispenser. This dispenser will be automatic and the user just needs to open the clear front door to slide out the inverted toothpaste container when it needs to be replaced.

CHAPTER V

CUSTOMIZATION OF A PRODUCT BASED ON USER ABILITY

With a proof-of-concept universal design tool in place and bathroom dispenser product family design, the next question to ask is how do I associate user activity with specific body structures and functions. From a designer's perspective, product conception may start from understanding user limitation from a biological rather than functional perspective. In order to address this approach to design, the International Classification of Functioning Disability and Health categories will be compared to user activity and product function mappings archived in the proof-of-concept database.

International Classification of Functioning, Disability and Health

International Classification of Functioning, Disability and Health (ICF) Terminology is broken down into four categories: Activities and Participation, Body Structures, Body Functions and Environmental Factors. A code is used for each specific ICF term in every category. The first entry is a letter followed by three or four numbers and a decimal point and a number. The number after the decimal point corresponds to the severity of the disability [30]. An example code is shown in Table 6 for an Activity and Participation typical of the ability needed to use the Fiskars rotary cutter.

Table 6. D440 Fine Hand Use

D	**4**	**4**	**0**	**.**	**2**

Column one indicates the letter D corresponding to an activity and participation. For a body function the letter is S and for a body structure the letter is B. The 2 corresponds to a medium level of disability typical of someone with arthritis. Table 7 below shows the number corresponding to the level of disability as indicated by the ICF.

Table 7. ICF Levels of Disability

Number	**Level of Disability**
0	**No Disability**
1	**Low Disability**
2	**Medium Disability**
3	**High Disability**

In order to consider these levels of disability while creating a universal product, the design changes occurring inside activity clusters will be used in Chapter VI to generate ideas for a universal product family of kitchen appliances. There will be three versions of the universal product family corresponding to low, medium and high disability.

Grouping User Activity with ICF Terminology

The first step in addressing levels of universality include grouping user activity, activities and participation, body structure and body functions. A brief survey of the distinct ICF and associated design changes from the Twenty-Product Study are shown in Table 8.

Table 8. Distinct ICF Activities and Design Changes from Twenty Product Study

ACTIVITIES AND PARTICIPATION	MORPHOLOGICAL DIFFERENCE	PARAMETRIC DIFFERENCE	FUNCTION DIFFERENCE
d4208-transferring oneself, other specified			X
d410-changing basic body position	X		
d440-fine hand use	X	X	X
d445-hand & arm use	X	X	X
d160-focusing attention			X
d4751.-driving motorized vehicles			X
d330-speaking			X
d4200-transfer oneself while sitting	X		

The table identifies a more user centric connection between the design changes and activity. The fine hand and hand and arm use activities have all three changes because they were most prevalent among the small hand-held user products studied. Conversely, the PT Cruiser and the Ford Focus, focused on activities d4208, d410,and d4751. These activities correlated with more complex products that required added functionality or different morphology when comparing the universal and typical versions of both automobiles.

For all twenty-products, the activity clusters were inspected and organized according to activity and participation, body function and body structure. The activity clusters corresponding to the ICF activity are highlighted in black (see Appendix C). An example breakdown for the fine hand use activity and participation is shown in Table 9.

Table 9. Fine Hand Use Divided into User Activity, Body Function and Body Structure

User Activity: *Grab,Rotate,Squeeze,Press,Attach,Remove,Touch,Turn*
ICF Activity: d440-fine hand use
ICF Body Function: B710-mobility of joint functions B715-stability of joint functions B720-mobility of bone functions B730-muscle power functions B735-muscle tone functions B740-muscle endurance functions B760-control of voluntary movement functions B780-sensations related to muscles and movement functions
ICF Body Structure: S7302-structure of the hand

The user activites correspond to the activities (taken from activity diagrams) in all of the twenty products that incorporate fine hand use when using the product. The ICF activity is labeled according to the letter-numeric system codified by the World Health Organization. Also, ICF body functions and related body structure were collected from the International Classification of Functioning, Disability and Health [30] . Table 9 provides a concept generation tool when considering a person's body parts needed and similar sensory and reaction abilities when designing a universal product. This may correlate with product signal and material flows. Similarly, the product function may closely resemble the body function or structure. For example, the grip on the Fiskars rotary cutter is curved in shape resembling how the fingers in the structure of the hand curve around the rotary cutter handle. The fingers require mobility and stability of joint functions just as the rotary cutter 'secures hand' and 'imports human energy'. These functions are typical of a user grabbing a product.

The next connection to ICF will be through using the results from the twenty-product study to create levels of disability built into the product function. This will be embodied in a product family of kitchen appliances.

Product Family Creation Based on Level of Disability

After associating activity clusters with specific ICF Activities, a more focused repository of design changes based on ICF Activity was assembled in Table 10. The fine hand use and hand and arm use sections are shown in Table 10. This repository was used as a design tool for creating product families based on activity clusters. For example, an actionfunction diagram for each product in a product family would correlate with a specific design change and ICF activity. The designer could use these connections to design a product more focused on a specific user ability.

Table 10. Universal Product Family Design Repository-Hand and Arms Uses

ICF Activity	***Function***	***Design Change***
D445-Hand and Arm Use	import solid	none,none,none,none,none
	position solid	none,none,none
	import hand	none,function
	position hand	none,function
	secure solid	parametric
	translate hand,guide hand,rotate hand,allow DOF	none
	convert h.e. to m.e.	morphological
	translate hand,guide hand,rotate hand,allow DOF	none,none
	remove solid,separate solid,divide solid,extract solid	none
	join hand,couple hand,link hand	none,none
	rotate hand,translate hand,guide hand,allow DOF	none,morphological
	allow DOF,rotate object,translate object,guide object	function
	remove object,extract object,divide object,separate object	function
	remove hand,extract hand,divide hand,separate hand	function
	convert h.e. to c.s.	function
	translate solid,guide solid,rotate solid,allow DOF	none

Table 10. Continued

ICF Activity	Function	Design Change
D440-Fine Hand Use	import h.e.	none
	export h.e.	none
	convert h.e. to c.s.	function,parametric
	export hand	none,none,function,none
	couple solid,join solid,link solid	none
	separate solid,divide solid,extract solid, remove solid	morphological
	export solid	morphological
	secure hand	parametric,function,parametric,parametric ,parametric,parametric
	convert h.e. to m.e.	none
	allow DOF,guide object,translate object,rotate object	morphological,morphological
	change m.e.,increment m.e.,decrement m.e.,shape m.e.,condition m.e.	morphological
	import hand	function,none,none,none,none,function
	position hand	function,none,none,none,none,function
	transfer h.e.,transport h.e.,transmit h.e.	morphological
	rotate hand,guide hand,translate hand,allow DOF	parametric
	secure human	parametric
	export human	none
	remove object,separate object,divide object,extract object	none

Table 10 shows the instances of design changes for each group of functions. For example, some products had the same functions as others but were not design changes. This is shown by the word none under the design change. For purposes of creating a product family appropriate for the widest range of ability, the none was ignored and only the design change was chosen for the suggested universal product family.

Two appliance functional models were taken from the Missouri S&T Design Repository and two other appliance function models were created and used as typical products that could be assembled into a product family. The purpose of this case study was to demonstrate how the ICF could be used as an idea generation tool for universal product families. By including data from the universal design database and ICF terminology, an idea generation tool in the form of a design structure matrix is possible for redesigning existing typical products into a universal product family. The appliances included a microwave,electric wok, slow cooker and toaster. A 7 step process was used to develop a universal product family with three levels of disability. The steps are:

1.) Create or obtain an activity diagram and functional model for a typical product

2.) Cluster functions in the functional model with hand flows, human energy flows, visual signals, tactile signals or auditory signals

3.) Label clusters according to user activity

4.) Use Table 10 to identify corresponding ICF activity

5.) Identify design changes within the activity cluster

6.) Create DSM showing design change modules

7.) Choose type of Universal Product

-Low Disability

-Medium Disability

-High Disability

The final actionfunction diagrams showcasing the universal products for the highest level of disability are shown in Appendix D. A three level breakdown of disability and level of universality for the kitchen appliance family is represented in a Product Family DSM shown in Figure 23.

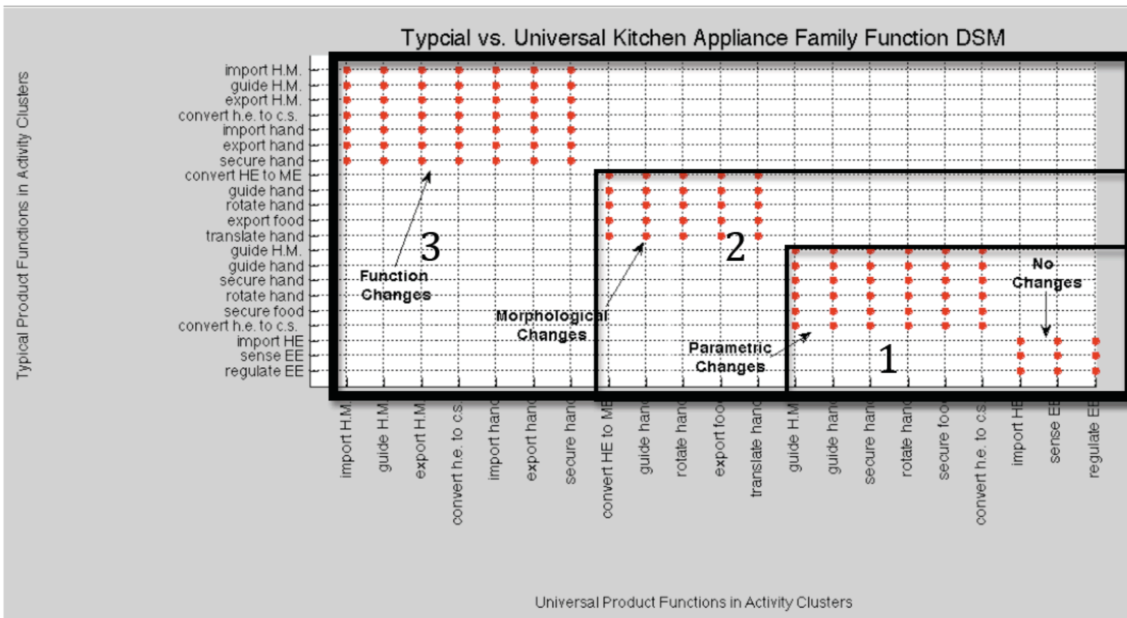

Figure 23. Kitchen Appliance Product Family DSM.

The product family DSM shows the typical and universal product functions within activity clusters grouped according to design changes. The numbers 1,2, and 3 correlate with the three ICF disability numbers. (low, medium and high disability) The parametric changes are considered to be for the lowest disabled user and hence first universal product family. In other words, the designer can focus on only these changes as indicated by box number 1. Since morphological changes are still variant functions like parametric changes but slightly more expensive to implement, these changes when used in tandem with the parametric changes will provide the designer with a second level disability product family. Finally, function changes add functionality and the most cost hence when used with parametric and morphological changes represent the highest level disability product family of kitchen appliances. This highest level of disability is expressed in the activity clusters (see Appendix D). The assumption to note is that a parametric change is cheaper and easier to implement in design than a morphological or function change.

At a more product function specific level, say the designer chooses box 1 as the kitchen appliance product family. The no change functions will remain the same however not all parametric change functions are found in all of the typical appliances in the product family. As a result, the method mentioned in the product platforming section in which the rotary cutter was broken down into typical and universal product functions and commonality indices were implemented will have to be used. However, instead of comparing a typical with universal product, typical products within a product family will have to be compared. In this case, the designer will focus on common parametric changes among the products to be reused as modules shared among the kitchen appliances. If a parametric change is a function change from one product within the product family to another, these parametric changes could be labeled as a sublevel of disability level one. In other words a 1.2 would include parametric changes common among products within a product family and parametric changes that are unique to few products within a product family whereas level 1.1 would only include common parametric changes among the products within a universal product family. The decimal values are arbitrary at this point since the design structure matrix clusters were not actually implemented in a concept design. The concept design is left for future investigation. What is important to note is that a decimal value could be used to delineate between different levels of universality within one of the three major levels of disability corresponding to the three design changes: parametric,morphological and functional. The contribution of the kitchen appliance case study is in organizing design changes into a matrix format for easy implementation in brainstorming or concept generation phases of universal product design.

CHAPTER VI

LIMITATIONS AND FUTURE WORK

The existing design repositories and connections with other design databases will help improve the development of the universal design tool. As a result, more activity clusters will be associated with product family principles and principles of universal design. There is evidence of potential improvements of the database, future statistical investigations to expand the database, and database applications. In addition, a cost oriented approach to developing universal product families based on disability can be improved.

Potential in User Interface

There are limitations in the proposed prototype tool that will help with the future development of a universal design tool.

One of the pitfalls of Figure 21 is the limitation in showing all of the products in the database at once. Hence, a more selective option such as the results in Figure 20 would be more acceptable. In addition, a more concise grouping of similar market products would also be useful for niche companies having trouble understanding how relevant universal design is in their product development.

Positive attributes include the click and choose option when it comes to selecting a function in the design and the corresponding statistical feedback showcasing the popularity of the function choice. This helps arbitrate universal functional modeling and ease the conceptual development process for a designer. For example, a designer may be confronted with choosing whether to have their product transfer or translate something when it comes to designing universally. The GUI shows a higher percentage for ‘transfer’ rather than ‘translate’ and could spark the more general idea of transferring. As a result, the designer will then think more specifically generating a greater spectrum of ideas how to transfer rather than solely relying on translating. Essentially, the statistic allows the designer to think more creatively and carefully when designing a universal product by abstracting a function at a level appropriate for universal design.

Comparative and Statistical Results

As described in the product platforming terminology section, there are commonality indices for common components within product families. This can also help form unintuitive universal product pairs. For example, the functional models of a more universal product versus a typical one may show patterns in their formation both with series and parallel branches. These patterns relate to cluster formations and product design heuristic methods developed by Robert Stone and Katja Holtta ([31]; [32]). The developer could associate connections and count the number of common and different functions in two products (one universal and one typical) creating a metric relating their commonality and differences. A commonality index based on functions instead of components would provide the designer with a simple metric for weighing the effectiveness of a universal product family. After sufficient testing and customer involvement, a more sophisticated benchmark value could help create a universal product family. This would prove as a means to create a product family from some products that are not obviously related. The parts classification methods and modular heuristics could be investigated as a tool to start the product family developing process by more empirically identifying product pairs.

Applications in Universal Design

More customer feedback and involvement in the formation of the database will help improve the database results. One possibility of improving this metric is by including more product testing using the average consumer and translating their voice into engineering metrics for the universal design tool using any design method such as a House of Quality or surveys.

Moreover, engineers can design a complex engineering system such as an automobile by first learning to use IED for simpler subsystems within it. For instance, the IED tool can be used to design the car interior by focusing on existing modules such as seats, control panels, and other accessories. As the database grows because of case studies like that of an automobile interior; a designer can focus on more complex and interrelated subsystems such as steering, suspension. and chassis.

CHAPTERVII

CONCLUSION

In conclusion, traditional product design methods supported a universal design method and helped create universal product families based on the IED method and levels of disability. The proposed universal design method was developed by integrating activity diagrams and functional models moving towards platforming and clustering methods during conceptual design phases. The product family approach used the results from the universal design method and incorporated an analogy between unique, common and variant parts with functional changes, no changes, and morphological/parametric changes respectively.

An example case study of a rotary cutter was used to explain how a universal product pair could be analyzed using different design methods. The product pair case study helped develop an understanding of how to create a universal product family. This understanding helped develop new terminology applicable to future universal product design such as actionfunction diagrams, function, morphological and parametric changes. As a result, organizational tools such as databases were mentioned and an outline was provided for how to create one for universal products. These products were the first step in developing a family. By understanding the relationship between a typical and universal product, a more extensive product family could be formed as demonstrated by the bathroom dispenser and kitchen appliance family case studies.

Furthermore, product design databases and previous universal design methods provide insight into how to create a universal design tool. This insight relies on the correlation between component and function, changing it in the universal context to user activity and function. With this analogy, a new universal design database could be created and used in conjunction with traditional conceptual generation tools such as morph matrices, function component and design structure matrices. Furthermore, task based clustering algorithms and product platforming optimization strategies could be used in conjunction with the actionfunction diagrams to create product families.

Finally, there is a future in the universal design tool as a result of increased customer involvement and statistical tools derived from product platforming principles. These principles will help incorporate qualitative customer opinion into more universal design cluster oriented functional models. With these tools, a more thorough and in- depth comparison of universal and their non-universal sister counterparts can further develop an easy to use universal design database and help proliferate universal product families.

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APPENDIX A

TWENTY PRODUCT STUDY

 **UNIVERSAL-**Modified PT Cruiser [33]	 **TYPICAL-**Typical PT Cruiser [34]
Function Difference: transport human -Universal Description: ramp -User Activity: enter -Activities and Participation (ICF): d420 transferring oneself while sitting *Morphological Difference:* secure human -Universal Description: actuated seat -User Activity: adjust -Activities and Participation (ICF): d410 changing basic body position	No transport human function *Morphological Difference:* secure human -Typical Description: fixed seat -User Activity: adjust -Activities and Participation (ICF): d410 changing basic body position

 **UNIVERSAL**-Fiskars Softouch Scissors	 **TYPICAL**-Standard Scissors
Parametric Difference: secure human -Universal Description: ergonomic grip -User Activity: grab -Activities and Participation (ICF): d445 hand and arm use, d440 fine hand use	*Parametric Difference*: secure human -Typical Description: non-ergonomic grip -User Activity: grab -Activities and Participation (ICF): d445 hand and arm use, d440 fine hand use

 **UNIVERSAL-**Gizmo Electric Can Opener e.e.=electrical energy c.s.=control signal h.e.=human energy m.e.=mechanical energy	 **TYPICAL-**Mechanical Can Opener
Function Difference: convert h.e. to c.s.,import e.e.,store e.e.,actuate e.e.,transfer e.e.,convert e.e. to m.e.,transfer m.e. -Universal Description: button and battery -User Activity: use human force -Activities and Participation (ICF): d440 fine hand use *Morphological Difference:* separate solid, export solid -Universal Description: angled blade & electrically powered gear, magnetic spring loaded lid remover -User Activity: remove	No function differences. *Morphological Difference:* separate solid, export solid -Typical Description: angled blade & hand powered gear, hands to remove lid -User Activity: Remove -Activities and Participation (ICF): d440 fine

-Activities and Participation (ICF): d440 fine hand use, d445 hand and arm use	hand use, d445 hand and arm use

 **UNIVERSAL**-Fiskars Rotary Cutter	 **TYPICAL**-Utility Cutter
Morphological Difference: convert human energy to mechanical energy, transfer human energy -Universal Description: rotating disk blade, slider switch and button -User Activity: translate, release/retract -Activities and Participation (ICF): d445 hand and arm use, d440 fine hand use *Parametric Difference:* secure hand -Universal Description: ergonomic handle -User Activity: grab -Activities and Participation (ICF): d445 hand and arm use, d440 fine hand use	*Morphological Difference:* convert human energy to mechanical energy, transfer human energy -Typical Description: angled blade, slider switch -User Activity: translate, release/retract -Activities and Participation (ICF): d445 hand and arm use, d440 fine hand use *Parametric Difference:* secure hand -Typical Description: non-ergonomic handle -User Activity: grab -Activities and Participation (ICF): d445 hand and arm use, d440 fine hand use

 Manual Wash Basin Bracket with Sink  Electric Sink Bracket with Concealed Utilities. **UNIVERSAL-**Adjustable Sink [35]	 **TYPICAL-**Drop-In Sink
Parametric Difference: secure hand, rotate hand -Universal Description: adjustable and ergonomic faucet handle -User Activity: grab, turn -Activities and Participation (ICF): d440 fine hand use, d445 hand and arm use	*Parametric Difference:* secure hand, rotate hand -Typical Description: stationary and non-ergonomic faucet handle -User Activity: grab, turn -Activities and Participation (ICF): d440 fine hand use, d445 hand and arm use

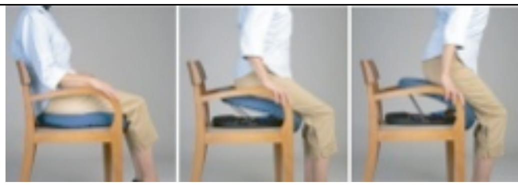
 **UNIVERSAL**-O.X.O. Masher	 **TYPICAL**-Standard Masher [36]
Parametric Difference: secure hand -Universal Description: ergonomic handle -User Activity: grab -Activities and Participation (ICF): d445 hand and arm use, d440 fine hand use	*Parametric Difference*: secure hand -Typical Description: non-ergonomic handle -User Activity: grab -Activities and Participation (ICF): d445 hand and arm use, d440 fine hand use

 **UNIVERSAL**-Voice Activated Phone [37]	 **TYPICAL**-Standard Corded Phone
Parametric Difference: secure hand -Universal Description: ergonomic receiver -User Activity: grab -Activities and Participation (ICF): d445 hand and arm use, d440 fine hand use	*Parametric Difference:* secure hand -Typical Description: non-ergonomic receiver -User Activity: grab -Activities and Participation (ICF): d445 hand and arm use, d440 fine hand use

Function Difference: convert acoustic energy to a control signal -Universal Description: voice activated dialing -User Activity: speak -Activities and Participation (ICF): d330 speaking	No voice activated dialing function

 **UNIVERSAL-**O.X.O. Serrated Peeler	 **TYPICAL-**Standard Peeler
Parametric Difference: secure hand -Universal Description: ergonomic handle -User Activity: grab -Activities and Participation (ICF): d445 hand and arm use, d440 fine hand use *Function Difference:* allow degree of freedom (DOF), remove object -Universal Description: potato eye remover -User Activity: apply force -Activities and Participation (ICF): d445 hand and arm use, d440 fine hand use	*Parametric Difference*: secure hand -Typical Description: non-ergonomic handle -User Activity: grab -Activities and Participation (ICF): d445 hand and arm use, d440 fine hand use No potato eye remover function

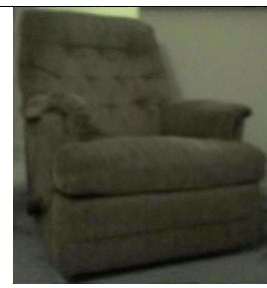
 **UNIVERSAL**-O.X.O Jar Opener	 **TYPICAL**-Standard Jar Opener [38]
Parametric Difference: secure hand -Universal Description: ergonomic handle -User Activity: grab -Activities and Participation (ICF): d445 hand and arm use, d440 fine hand use *Morphological Difference*: rotate hand -Universal Description: rotate to remove lid (different axis of rotation) -User Activity: rotate -Activities and Participation (ICF): d445 hand and arm use, d440 fine hand use	*Parametric Difference*: secure hand -Typical Description: non-ergonomic handle -User Activity: grab -Activities and Participation (ICF): d445 hand and arm use, d440 fine hand use *Morphological Difference*: rotate hand -Typical Description: pry to remove lid (different axis of rotation) -User Activity: rotate -Activities and Participation (ICF): d445 hand and arm use, d440 fine hand use

 **UNIVERSAL-**Arm chair with actuated lift assist [39]	 **TYPICAL-**Standard Chair
Function Difference: transport human -Universal Description: actuated lift -User Activity: sit -Activities and Participation (ICF): d420 transferring oneself while sitting *Morphological Difference*: export human -Universal Description: moving seat cushion -User Activity: exit -Activities and Participation (ICF): d420 transferring oneself while sitting	No actuated lift. *Morphological Difference*: export human -Typical Description: stationary seat cushion -User Activity: exit -Activities and Participation (ICF): d420 transferring oneself while sitting

 **UNIVERSAL**- Big Button Universal Control [40]	 **TYPICAL**- Standard TV Control
Parametric Difference: convert human energy to control signal, secure human -Universal Description: bigger buttons, easier to grip I-shaped handle -User Activity: press, grab -Activities and Participation (ICF): d445 hand and arm use, d440 fine hand use	*Parametric Difference*: convert human energy to control signal, secure human -Typical Description: smaller buttons, harder to grip body -User Activity: press, grab -Activities and Participation (ICF): d445 hand and arm use, d440 fine hand use

 **UNIVERSAL-** Actuated Toilet Seat Lift [41]	 **TYPICAL**-Standard Toilet Seat
Function Difference: transport human -Universal Description: actuated lift -User Activity: sit -Activities and Participation (ICF): d420	No transport human function

transferring oneself while sitting *Morphological Difference*: export human -Universal Description: moving seat with little human effort -User Activity: exit -Activities and Participation (ICF): d420 transferring oneself while sitting	*Morphological Difference*: export human -Typical Description: stationary seat -User Activity: exit -Activities and Participation (ICF): d420 transferring oneself while sitting

 **UNIVERSAL-**Park Avenue Recliner [42]	 **TYPICAL-**Standard Recliner
Function Difference: transport human -Universal Description: actuated lift -User Activity: sit -Activities and Participation (ICF): d420 transferring oneself while sitting *Morphological Difference*: export human -Universal Description: moving seat with little human effort -User Activity: exit -Activities and Participation (ICF): d420 transferring oneself while sitting	No transport human function *Morphological Difference*: export human -Typical Description: stationary seat -User Activity: exit -Activities and Participation (ICF): d420 transferring oneself while sitting

 **UNIVERSAL**-O.X.O Grater	 **TYPICAL**-Standard Grater [43]
Parametric Difference: secure hand -Universal Description: ergonomic handle -User Activity: grab -Activities and Participation (ICF): d445 hand and arm use, d440 fine hand use	*Parametric Difference*: secure hand -Typical Description: non-ergonomic handle -User Activity: grab -Activities and Participation (ICF): d445 hand and arm use, d440 fine hand use

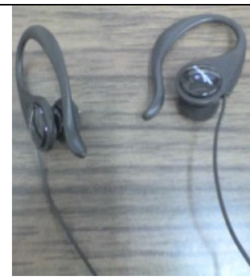
 **UNIVERSAL**- O.X.O Bottle Opener	 **TYPICAL**-Standard Bottle Opener [44]
Parametric Difference: secure hand -Universal Description: ergonomic handle -User Activity: grab -Activities and Participation (ICF): d445 hand and arm use, d440 fine hand use	*Parametric Difference*: secure hand -Typical Description: non-ergonomic handle -User Activity: grab -Activities and Participation (ICF): d445 hand and arm use, d440 fine hand use

 **UNIVERSAL-**Braille Restroom Sign [45]	 **TYPICAL-**Standard Restroom Sign [46]
Function Change: import hand, position hand, secure hand, export hand -Universal Description: braille on the sign -User Activity: touch -Activities and Participation (ICF): d445 hand and arm use, d440 fine hand use	No braille on sign

 **UNIVERSAL-**Modified 2000 Ford Focus [47]	 **TYPICAL-**Standard 2000 Ford Focus [48]
Function Difference: convert human energy to mechanical energy, transport human -Universal Description: ergonomic steering wheel, hand and foot pedal placement and gear shifter, wheelchair ingress -User Activity: drive, enter -Activities and Participation (ICF): d410 changing basic body position, d420 transferring oneself while sitting, d440 fine hand use, d445	No function differences

hand and arm use, d475 driving *Morphological Difference*: secure human -Universal Description: rotating/actuating seat -User Activity: adjust -Activities and Participation (ICF): d410 changing basic body position	*Morphological Difference*: secure human -Typical Description: fixed seat -User Activity: adjust -Activities and Participation (ICF): d410 changing basic body position

 **UNIVERSAL**-Tupperware "Wonderlier Bowls" [49]	 **TYPICAL**-Standard Food Container
Parametric Difference: secure hand -Universal Description: bigger gripping tab, more contoured lid for removal -User Activity: grab -Activities and Participation (ICF): d445 hand and arm use, d440 fine hand use	*Parametric Difference*: secure hand -Typical Description: smaller gripping tab, less contoured lid for removal -User Activity: grab -Activities and Participation (ICF): d445 hand and arm use, d440 fine hand use

 **UNIVERSAL**-TV Ears [50]	 **TYPICAL**-Standard Ear Buds
Parametric Difference: secure human -Universal Description: semi-circular rigid ear bud stems and moldable ear buds -User Activity: grab, place -Activities and Participation (ICF): d445 hand and arm use, d440 fine hand use	*Parametric Difference*: secure human -Typical Description: no ear bud stems and static ear buds -User Activity: grab, place -Activities and Participation (ICF): d445 hand and arm use, d440 fine hand use

 UNIVERSAL-American Standard Co. “Ratchet Cut Pruners”	 TYPICAL-Standard Pruning Shears [51]
Parametric Difference: secure hand -Universal Description: ergonomic grip -User Activity: position/grab -Activities and Participation (ICF): d440 fine hand use *Morphological Difference*: allow degree of freedom, change mechanical energy -Universal Description: ratcheting linkage moves when handles are squeezed -User Activity: squeeze, rotate, release -Activities and Participation (ICF): d440 fine hand use	*Parametric Difference*: secure hand -Universal Description: ergonomic grip -User Activity: position/grab -Activities and Participation (ICF): d440 fine hand use *Morphological Difference*: allow degree of freedom, change mechanical energy -Universal Description: ratcheting linkage moves when handles are squeezed -User Activity: squeeze, rotate, release -Activities and Participation (ICF): d440 fine hand use

APPENDIX B

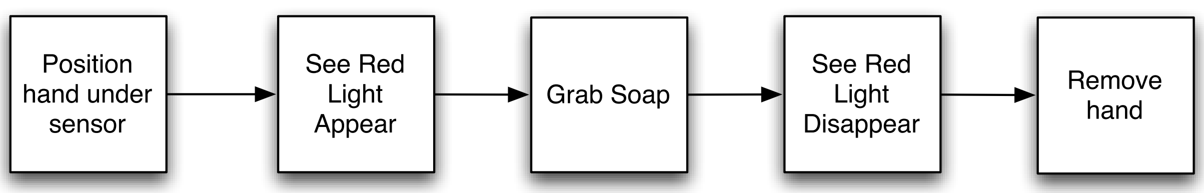
BATHROOM DISPENSER FUNCTIONAL MODELS

CREATING A PRODUCT FAMILY OF ACCESSIBLE DISPENSERS

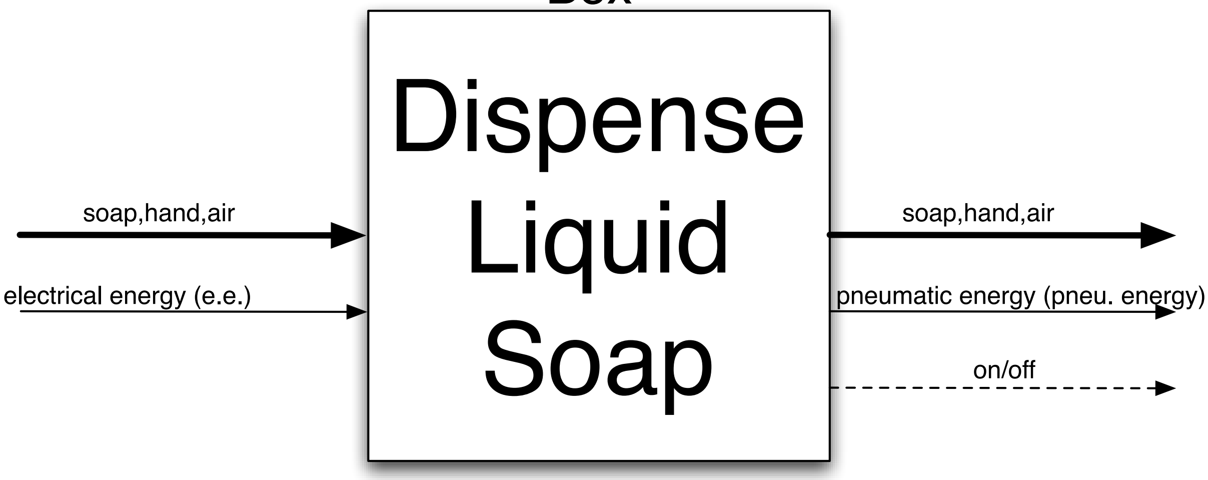
[52]

Automatic Liquid Soap Dispenser
Universal Product

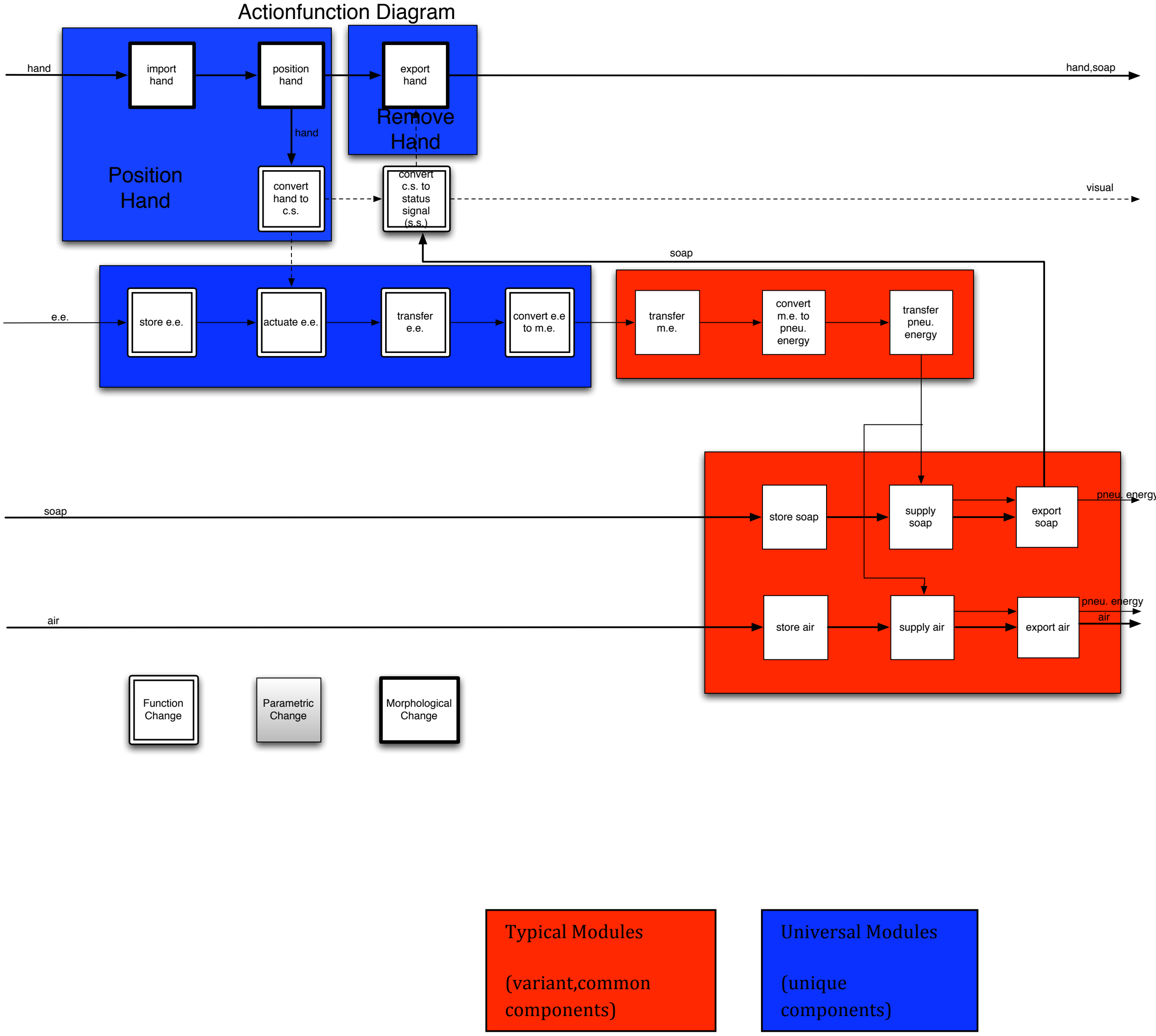
Activity Diagram

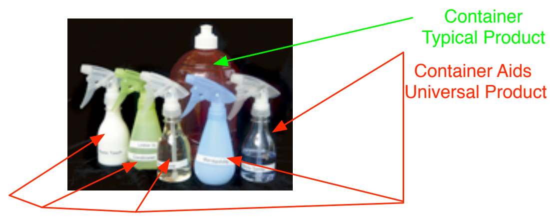


Universal Product Black Box

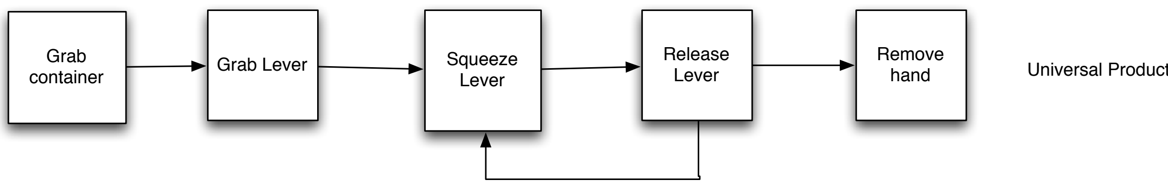


Universal Product Actionfunction Diagram



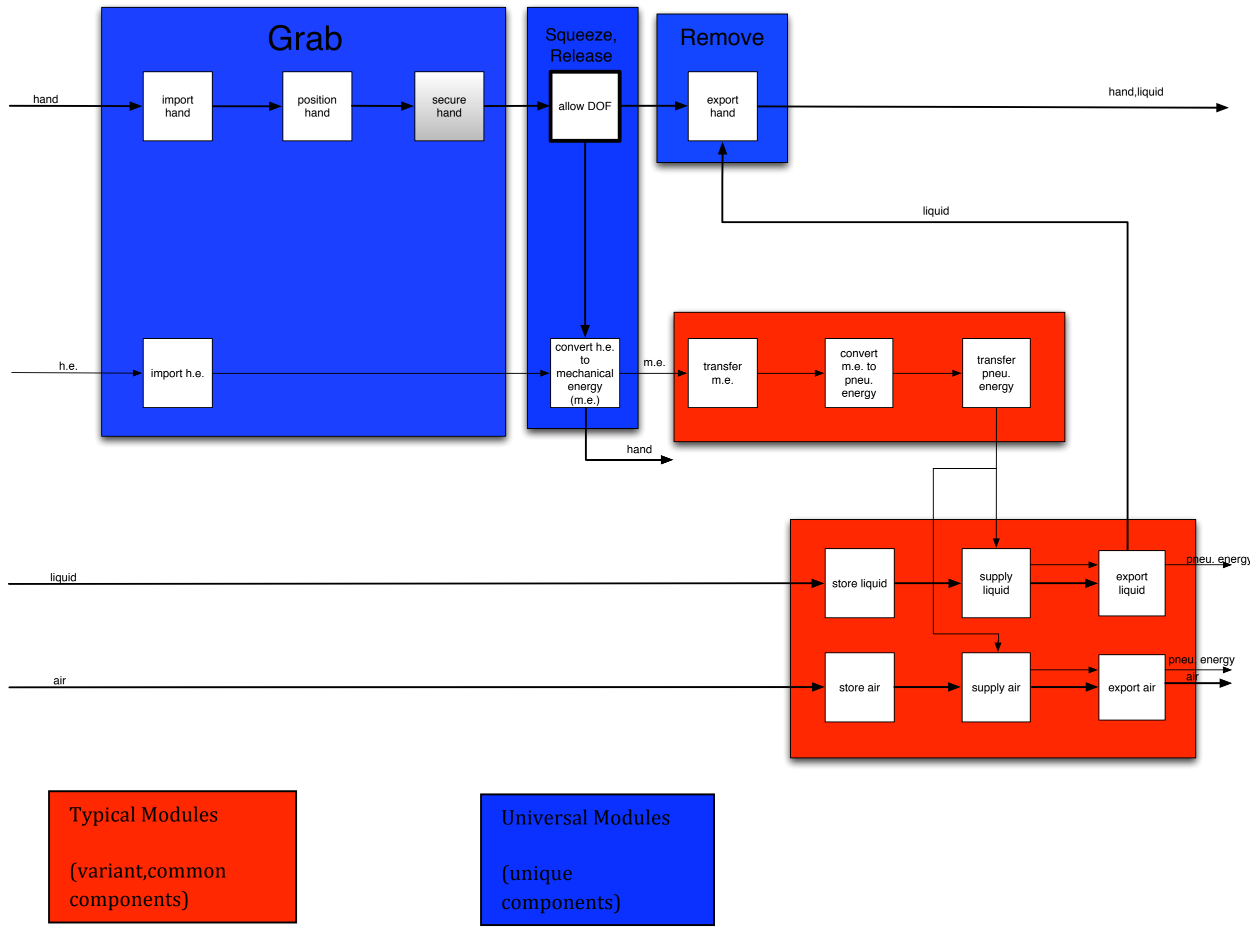


Activity Diagram



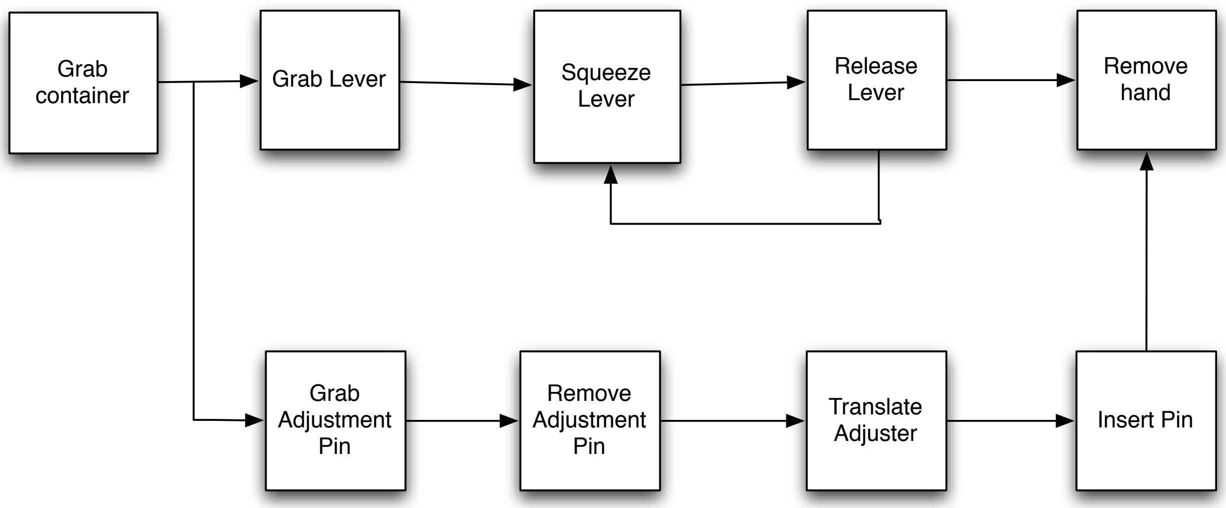
Universal Product Black Box

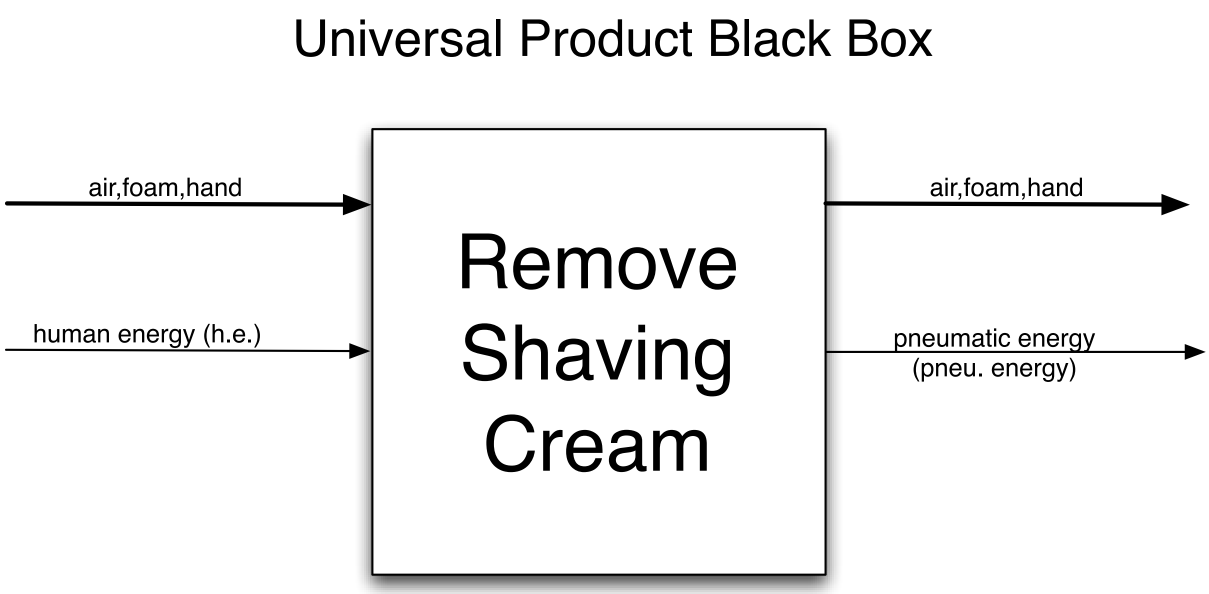
[53]

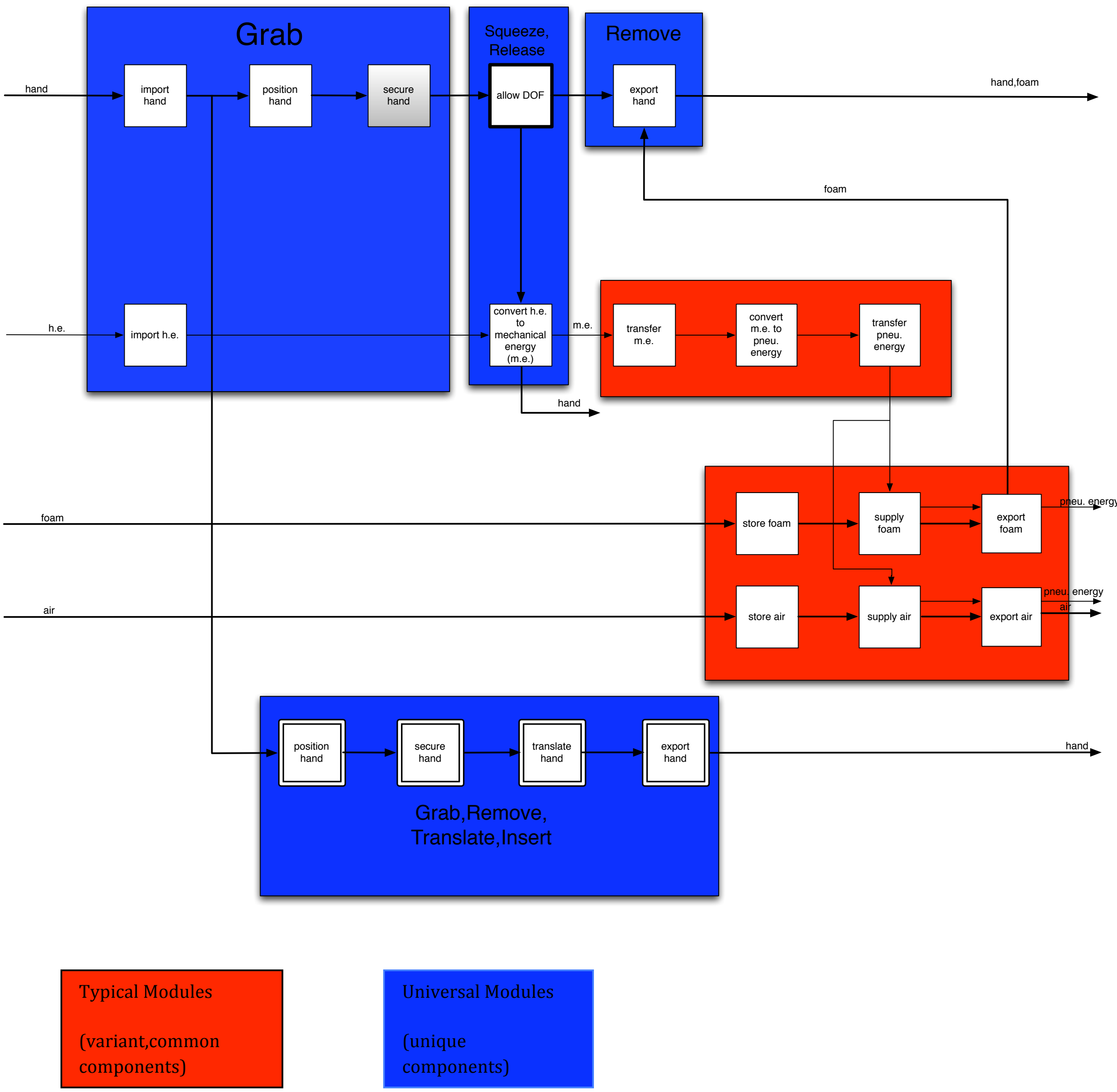

Grab
Squeeze, Release
Remove
hand
import hand
position hand
secure hand
allow DOF
export hand
hand,liquid
liquid
h.e.
import h.e.
convert h.e. to mechanical energy (m.e.)
m.e.
transfer m.e.
convert m.e. to pneu. energy
transfer pneu. energy
hand
liquid
store liquid
supply liquid
export liquid
pneu. energy
air
store air
supply air
export air
pneu. energy
air
Typical Modules
(variant,common components)
Universal Modules
(unique components)

Shaving Cream Dispenser

[54]

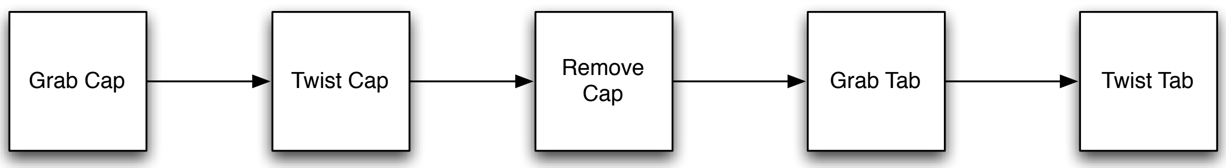




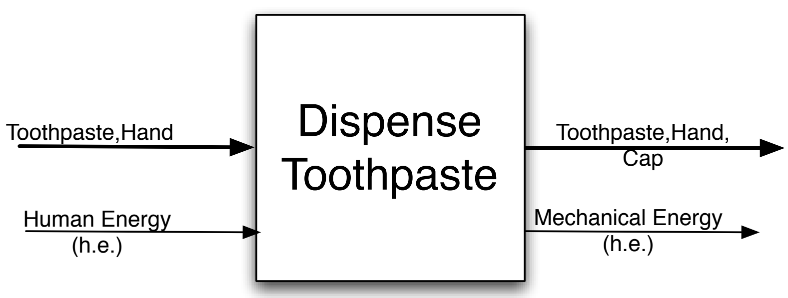

Grab
Squeeze, Release
Remove
hand
import hand
position hand
secure hand
allow DOF
export hand
hand,foam
foam
h.e.
import h.e.
convert h.e. to mechanical energy (m.e.)
m.e.
transfer m.e.
convert m.e. to pneu. energy
transfer pneu. energy
hand
foam
store foam
supply foam
export foam
pneu. energy
air
store air
supply air
export air
pneu. energy
air
position hand
secure hand
translate hand
export hand
hand
Grab,Remove, Translate,Insert
Typical Modules
(variant,common components)
Universal Modules
(unique components)

Tube Squeezer+Toothpaste Container-Universal Product

Universal Product Activity Diagram

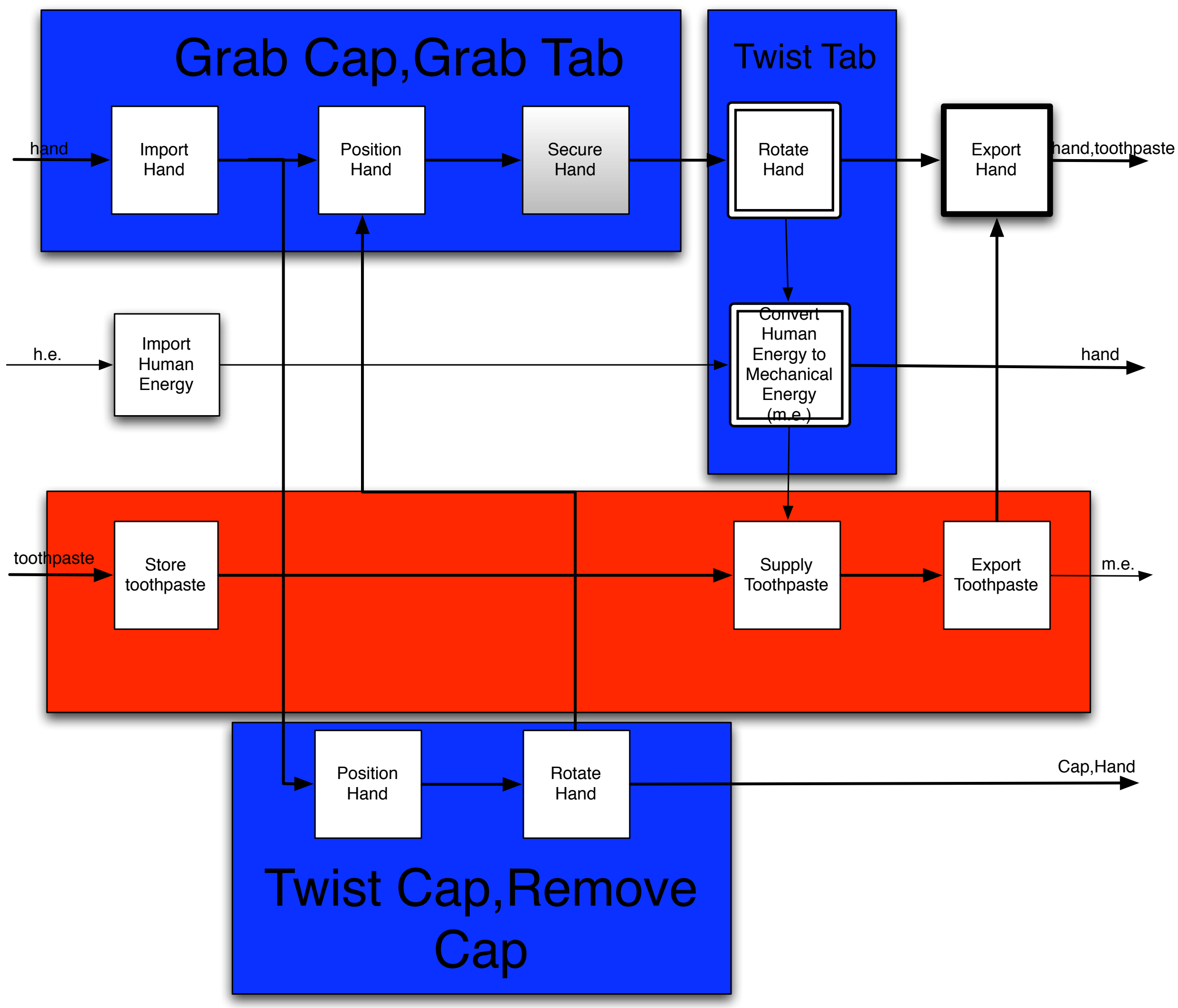


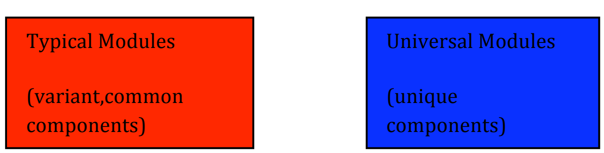
Universal Product Black Box



[55]

Universal Product Action Function Diagram





APPENDIX C

STATISTICS FOR TYPICAL AND UNIVERSAL PRODUCTS IN THE DATABASE

	# of Function Changes	*# of Morphological Changes*	*# of Parametric Changes*	*Function and Morphological (1-yes,0-no)*	*Function and Parametric (1-yes,0-no)*	*Parametric and Morphological (1-yes,0-no)*
PT Crusier	8	1	0	1	0	0
Can Opener	7	2	1	1	1	1
Pruners	0	2	1	0	0	1
Restroom Sign	4	0	0	0	0	0
Cutter	0	2	1	0	0	1
Bath Sink	10	0	2	0	1	0
Ford Focus	7	1	1	1	1	1
Scissors	2	0	1	0	1	0
Tupperware	0	0	1	0	0	0
Phone	1	0	1	0	1	0
Toilet Seat	6	1	0	1	0	0
Recliner	9	1	0	1	0	0
TV Remote	0	0	2	0	0	0
TV Ears	2	0	1	0	1	0
Arm Chair	7	1	0	1	0	0
O.X.O cheese grater	0	0	1	0	0	0
O.X.O bottle opener	0	0	1	0	0	0
O.X.O masher	0	0	1	0	0	0
O.X.O peeler	2	1	1	1	1	1
O.X.O jar opener	0	1	1	0	0	1
Total	65	13	17	7	7	6

% Function Change	68.42	% Function and Morphological	35
% Morphological Change	13.68	% Function and Parametric	35
% Parametric Change	17.89	%Morphological and Parametric	30

		# of Function Changes	*# of Morphological Changes*	*# of Parametric Changes*	*Total Number of Functions in the Functional Model*	*% Function Changes*	*% Morphological Changes*	*% Parametric Changes*	
Section 1	**Physical Body Effort**								
	PT Cruiser	8	1	0	16	50.00	6.25	0.00	
	Ford Focus	7	1	1	22	31.82	4.55	4.55	
	Arm Chair	7	1	0	14	50.00	7.14	0.00	
	Toilet Seat	6	1	0	13	46.15	7.69	0.00	
	Recliner	9	1	0	14	64.29	7.14	0.00	
	sum	**37**	**5**	**1**	**79**	**48.45**	**6.55**	**0.91**	*average*
Section 2	**High Levels of Human Sensing**								
	Tupperware	0	0	1	10	0.00	0.00	10.00	
	Restroom Sign	4	0	0	6	66.67	0.00	0.00	
	Phone	1	0	1	10	10.00	0.00	10.00	
	TV Remote	0	0	2	9	0.00	0.00	22.22	
	sum	**5**	**0**	**4**	**35**	**19.17**	**0.00**	**10.56**	*average*
Section 3	**Hand and Arm Manipulation**								
	Can Opener	7	2	1	19	36.84	10.53	5.26	
	Pruners	0	2	1	10	0.00	20.00	10.00	
	Grater	0	0	1	12	0.00	0.00	8.33	
	Peeler	2	1	1	14	14.29	7.14	7.14	
	Jar Opener	0	1	1	11	0.00	9.09	9.09	
	Bottle Opener	0	0	1	11	0.00	0.00	9.09	
	Scissors	2	0	1	12	16.67	0.00	8.33	
	TV Ears	2	0	1	13	15.38	0.00	7.69	
	Cutter	0	2	1	10	0.00	20.00	10.00	
	Masher	0	0	1	13	0.00	0.00	7.69	
	Bath Sink	10	0	2	18	55.56	0.00	11.11	
	sum	**23.00**	**8.00**	**12.00**	**143.00**	**12.61**	**6.07**	**8.52**	average

all sections	25.29	5.06	6.61
first two sections	36.84	4.39	4.39
first and third section	27.03	5.86	5.86
second and third section	15.73	4.49	8.99

APPENDIX D

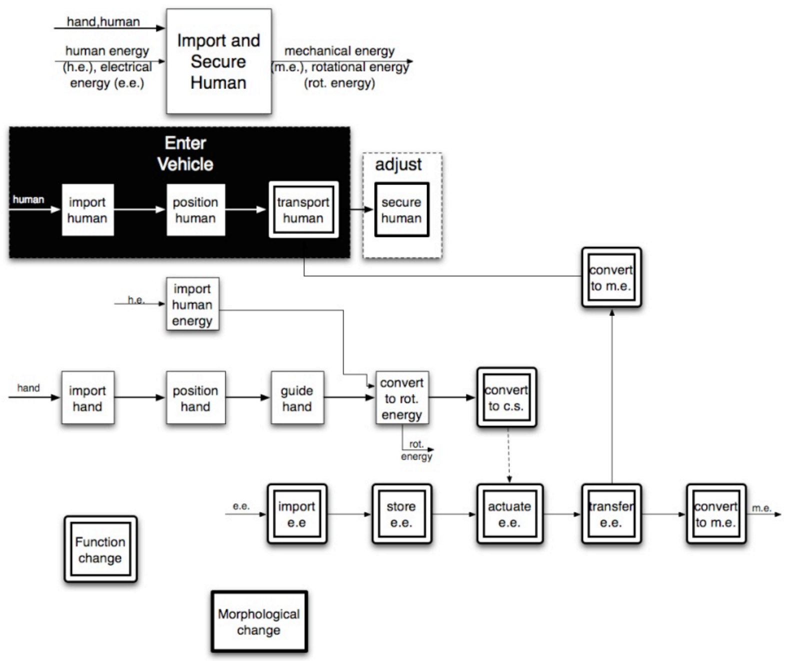
ICF ACTIVITY CLUSTERS FOR TWENTY PRODUCT STUDY

D4208-Transferring oneself, other specified

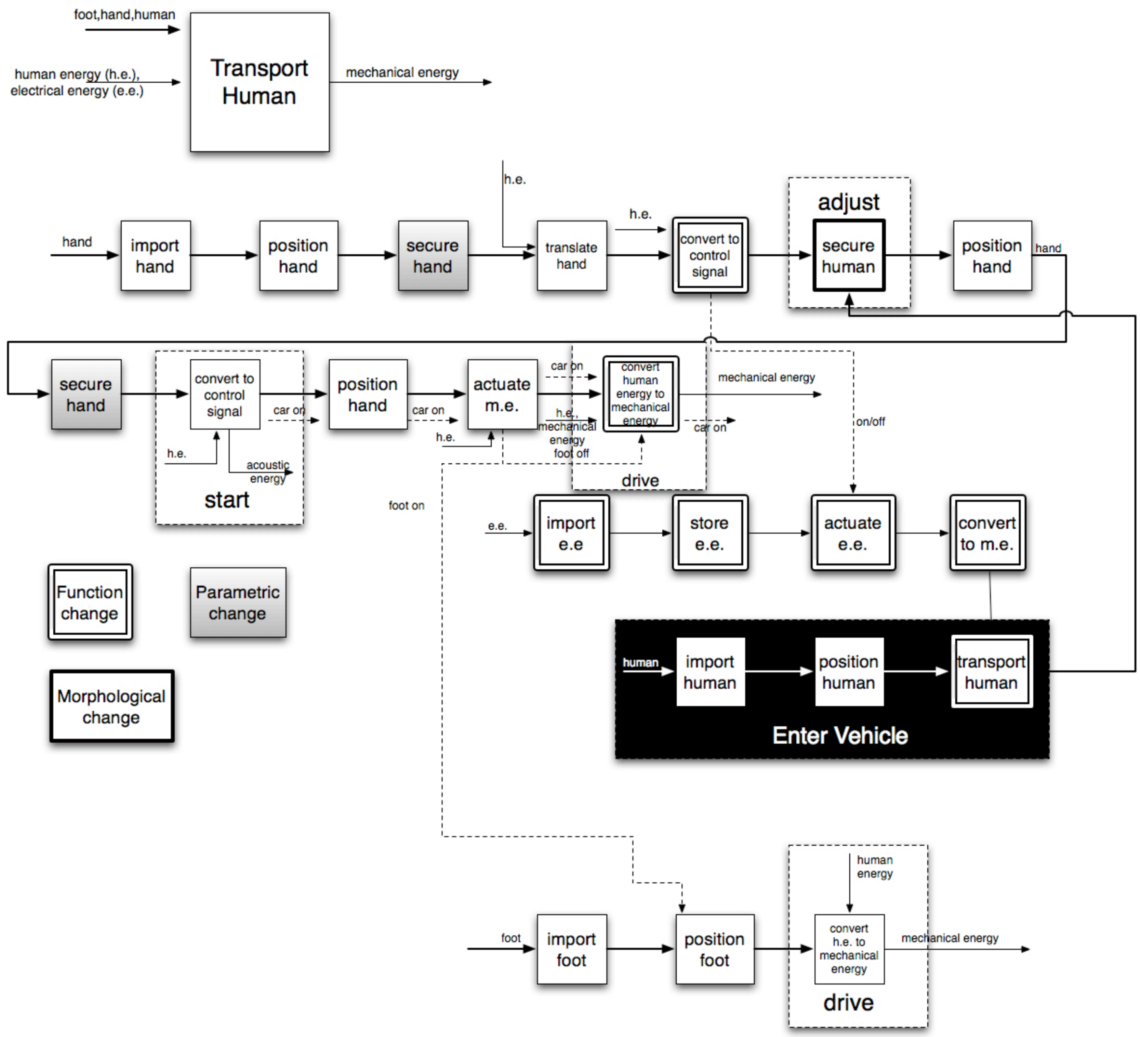
***User Activity**: Enter,Sit*
ICF Activity: D4208-transferring oneself
ICF Body Function: B710-mobility of joint functions B715-stability of joint functions B720-mobility of bone functions B730-muscle power functions B735-muscle tone functions B740-muscle endurance functions B760-control of voluntary movement functions B780-sensations related to muscles and movement functions
ICF Body Structure: S710-structure of head and neck region S720-structure of shoulder region S730-structure of upper extremity S740-structure of pelvic region S750-structure of lower extremity S760-structure of trunk

d4208	b710,b715,b720,b730,b735, b740,b760,b780	s710,s220,s730,s740,s750,s760

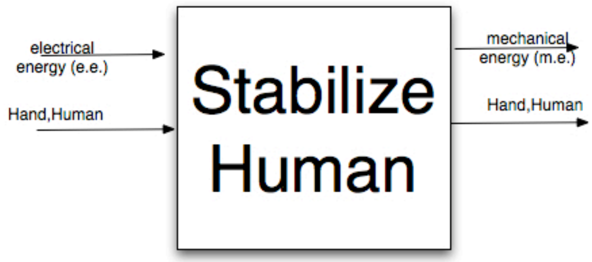
Pt Crusier Ingress/Egress:

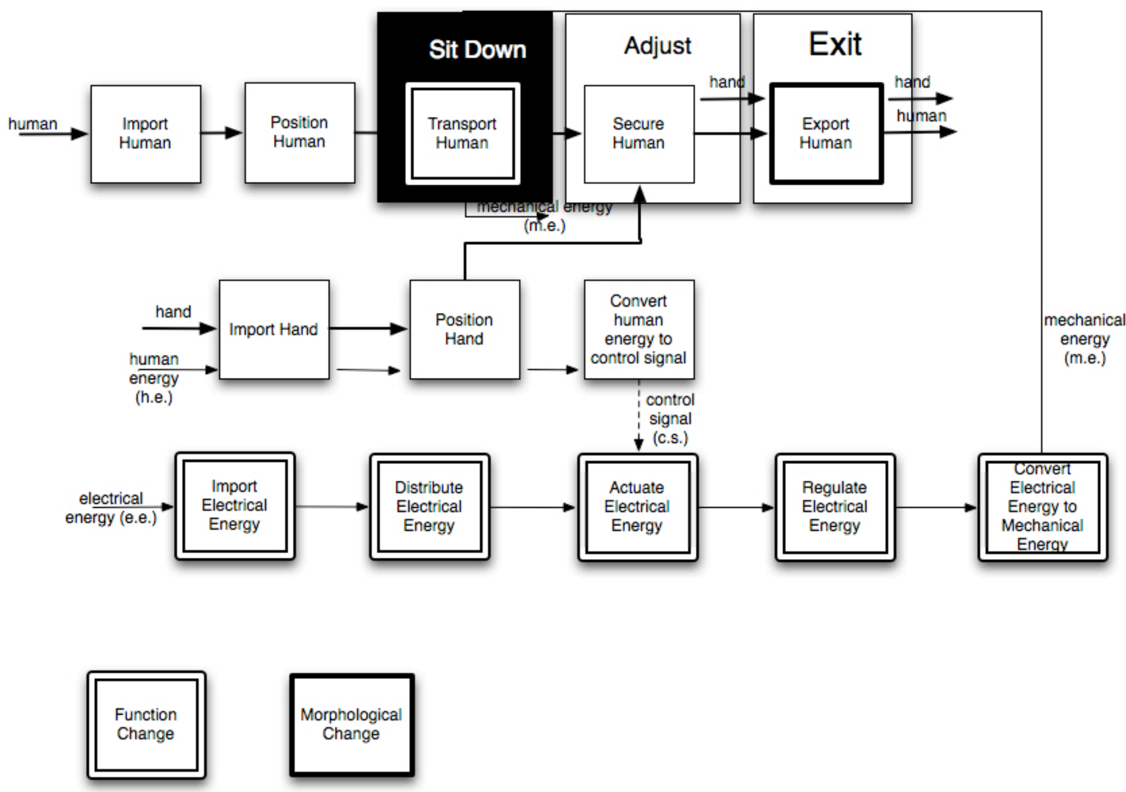


Ford Focus Ingress/Egress and Drive:

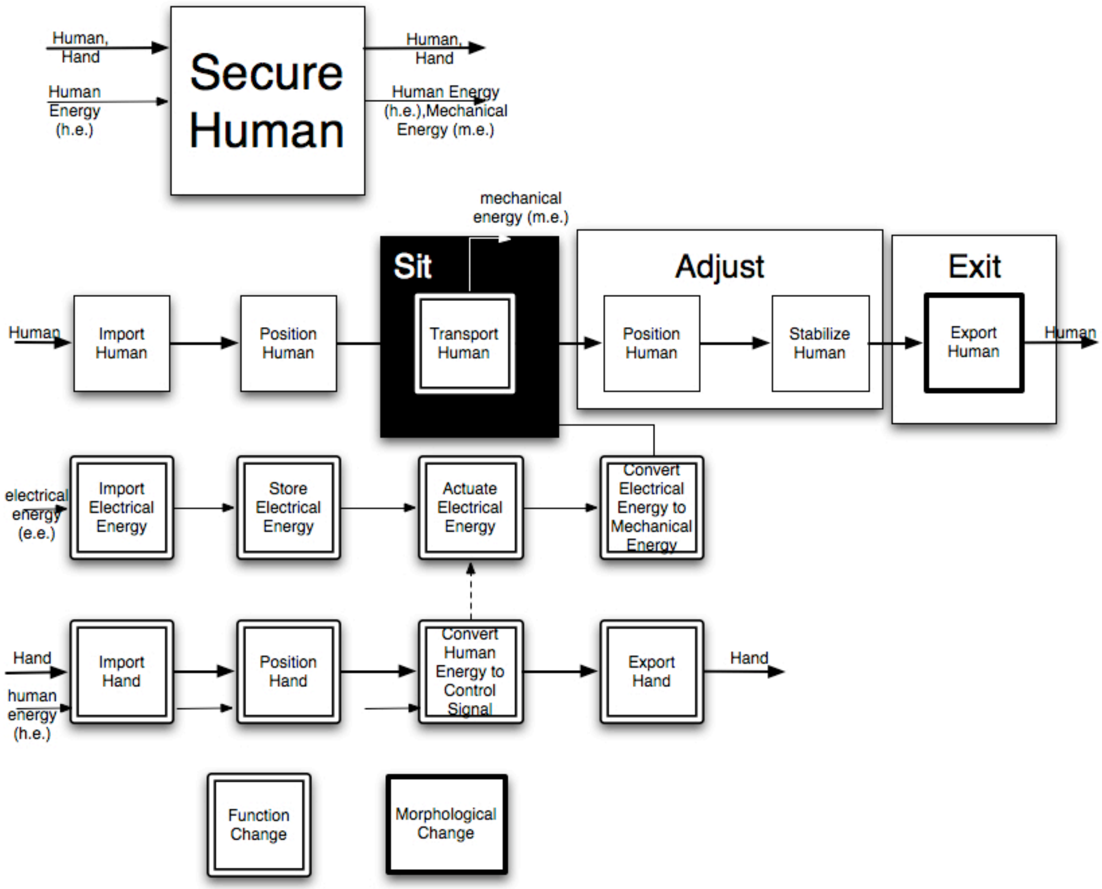


Toilet Seat:

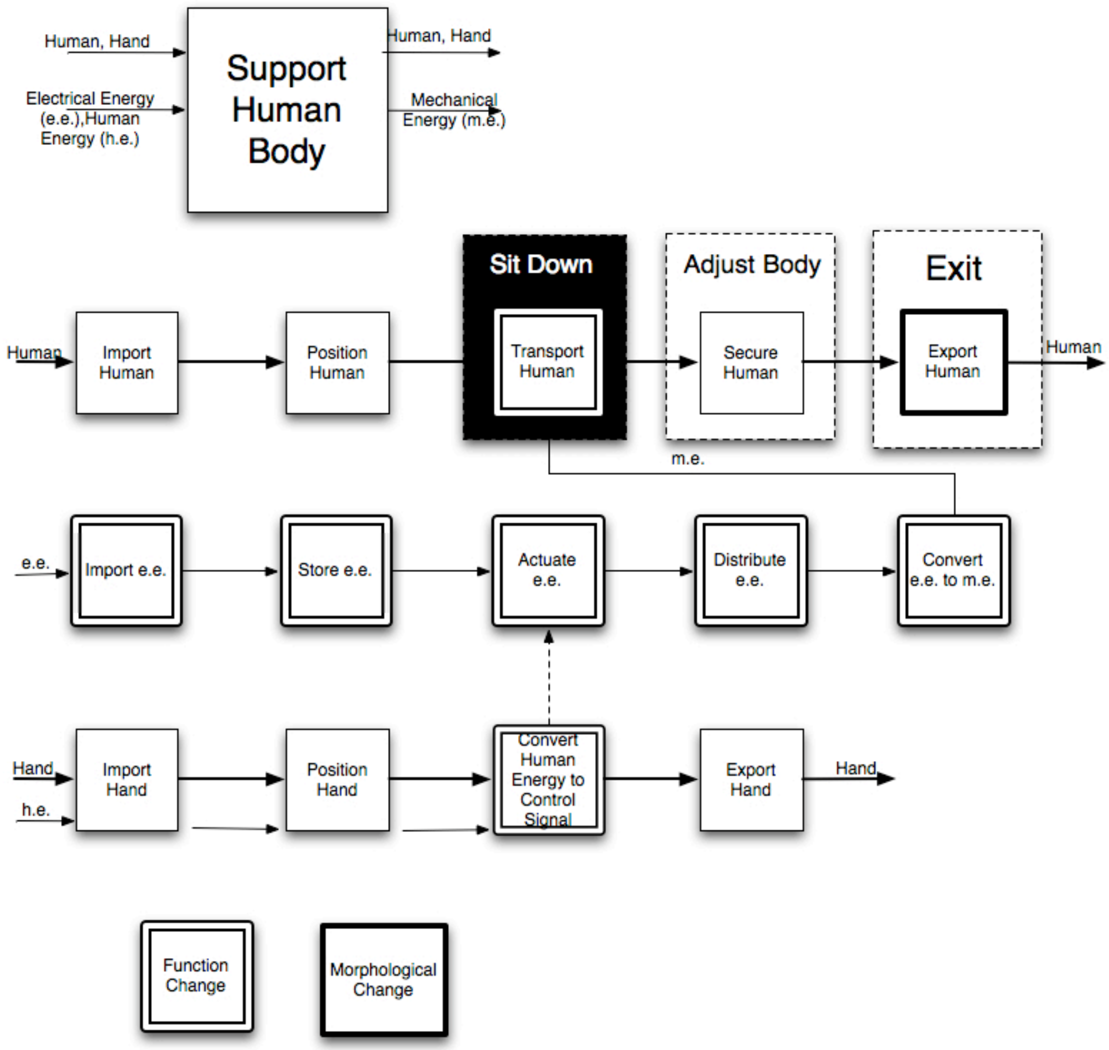

electrical
energy (e.e.)
Hand,Human
Stabilize
Human
mechanical
energy (m.e.)
Hand,Human


Sit Down
Adjust
Exit
human
Import
Human
Position
Human
Transport
Human
Secure
Human
hand
Export
Human
hand
human
mechanical energy
(m.e.)
hand
Import Hand
Position
Hand
Convert
human
energy to
control signal
human
energy
(h.e.)
control
signal
(c.s.)
mechanical
energy
(m.e.)
electrical
energy (e.e.)
Import
Electrical
Energy
Distribute
Electrical
Energy
Actuate
Electrical
Energy
Regulate
Electrical
Energy
Convert
Electrical
Energy to
Mechanical
Energy
Function
Change
Morphological
Change

Recliner:


Human, Hand
Human Energy (h.e.)
Secure Human
Human, Hand
Human Energy (h.e.),Mechanical Energy (m.e.)
mechanical energy (m.e.)
Sit
Adjust
Exit
Human
Import Human
Position Human
Transport Human
Position Human
Stabilize Human
Export Human
Human
electrical energy (e.e.)
Import Electrical Energy
Store Electrical Energy
Actuate Electrical Energy
Convert Electrical Energy to Mechanical Energy
Hand
human energy (h.e.)
Import Hand
Position Hand
Convert Human Energy to Control Signal
Export Hand
Hand
Function Change
Morphological Change

Chair Lift:



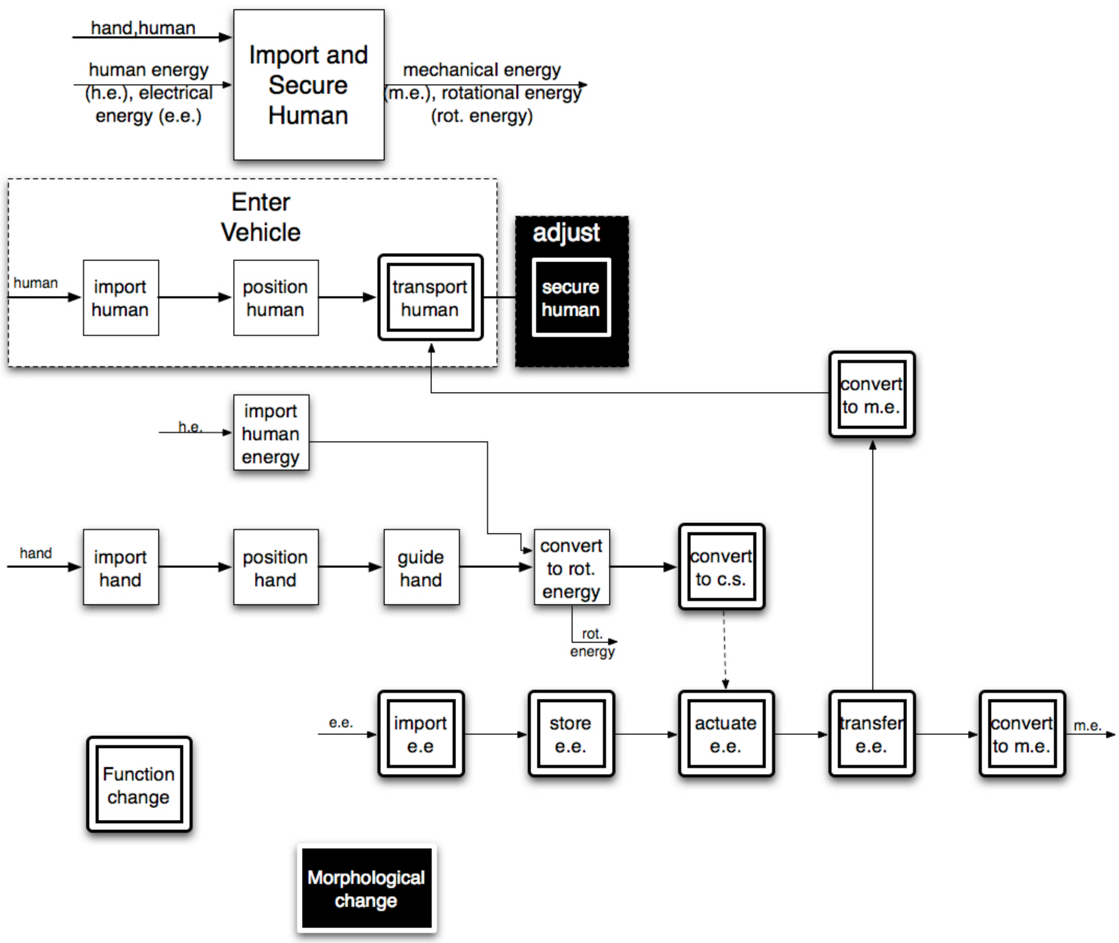
Human, Hand
Electrical Energy (e.e.),Human Energy (h.e.)
Support Human Body
Human, Hand
Mechanical Energy (m.e.)
Sit Down
Adjust Body
Exit
Human
Import Human
Position Human
Transport Human
Secure Human
Export Human
Human
m.e.
e.e.
Import e.e.
Store e.e.
Actuate e.e.
Distribute e.e.
Convert e.e. to m.e.
Hand
h.e.
Import Hand
Position Hand
Convert Human Energy to Control Signal
Export Hand
Hand
Function Change
Morphological Change

D410-Changing basic body position

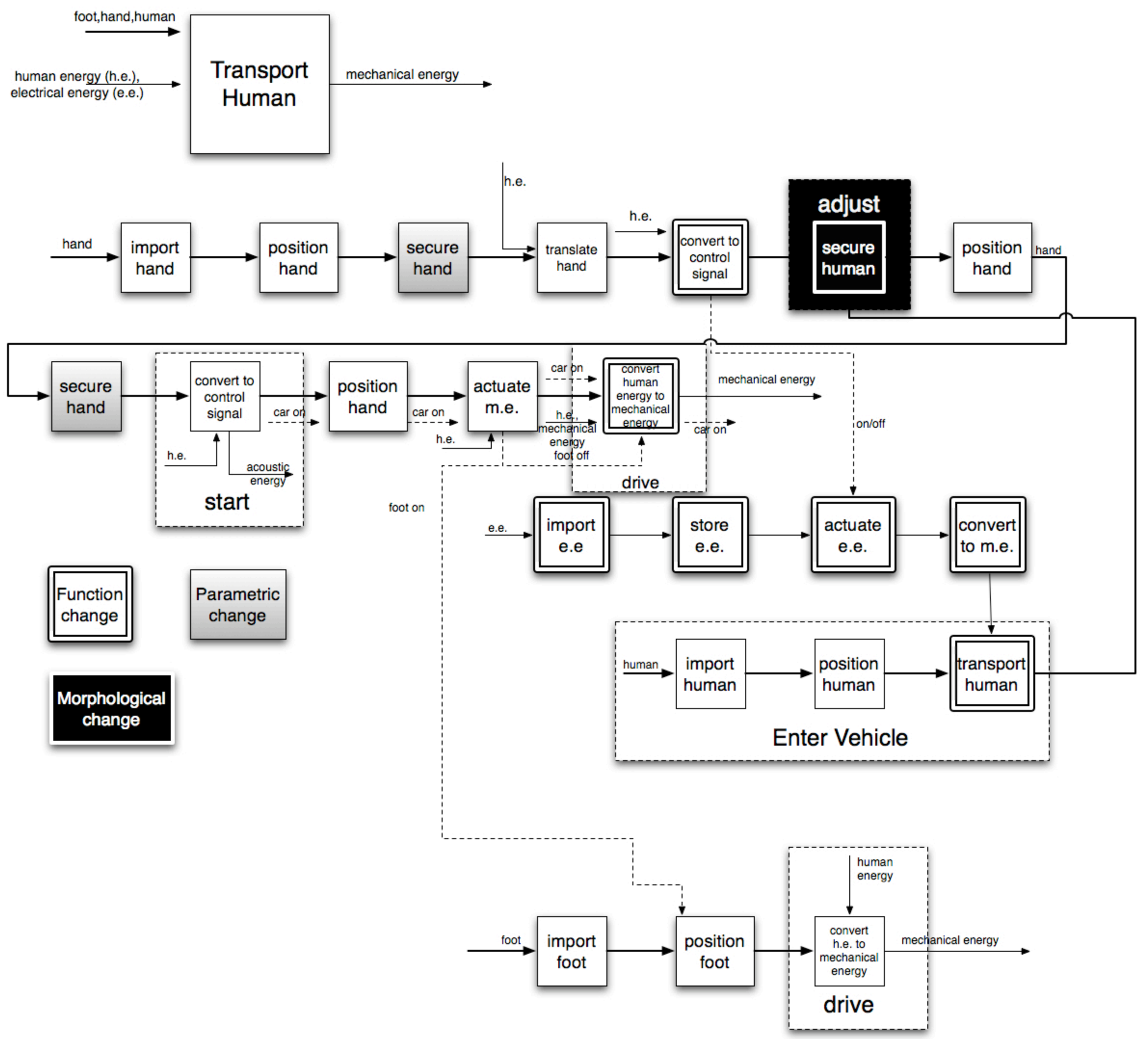
User Activity:*Adjust*
ICF Activity: D410-changing basic body position
ICF Body Function: B710-mobility of joint functions B715-stability of joint functions B720-mobility of bone functions   B730-muscle power functions B735-muscle tone functions B740-muscle endurance functions B760-control of voluntary movement functions B780-sensations related to muscles and movement functions
ICF Body Structure: S710-structure of head and neck region S720-structure of shoulder region S730-structure of upper extremity S740-structure of pelvic region S750-structure of lower extremity S760-structure of trunk

d4208	b710,b715,b720,b730,b735, b740,b760,b780	s710,s220,s730,s740,s750,s760

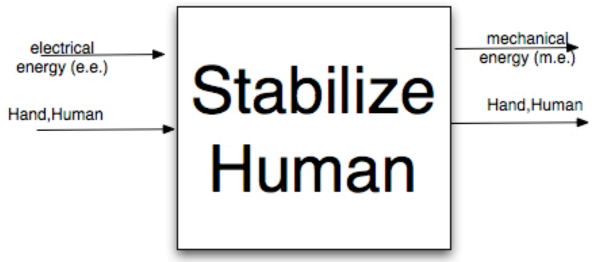
Pt Crusier Ingress/Egress:

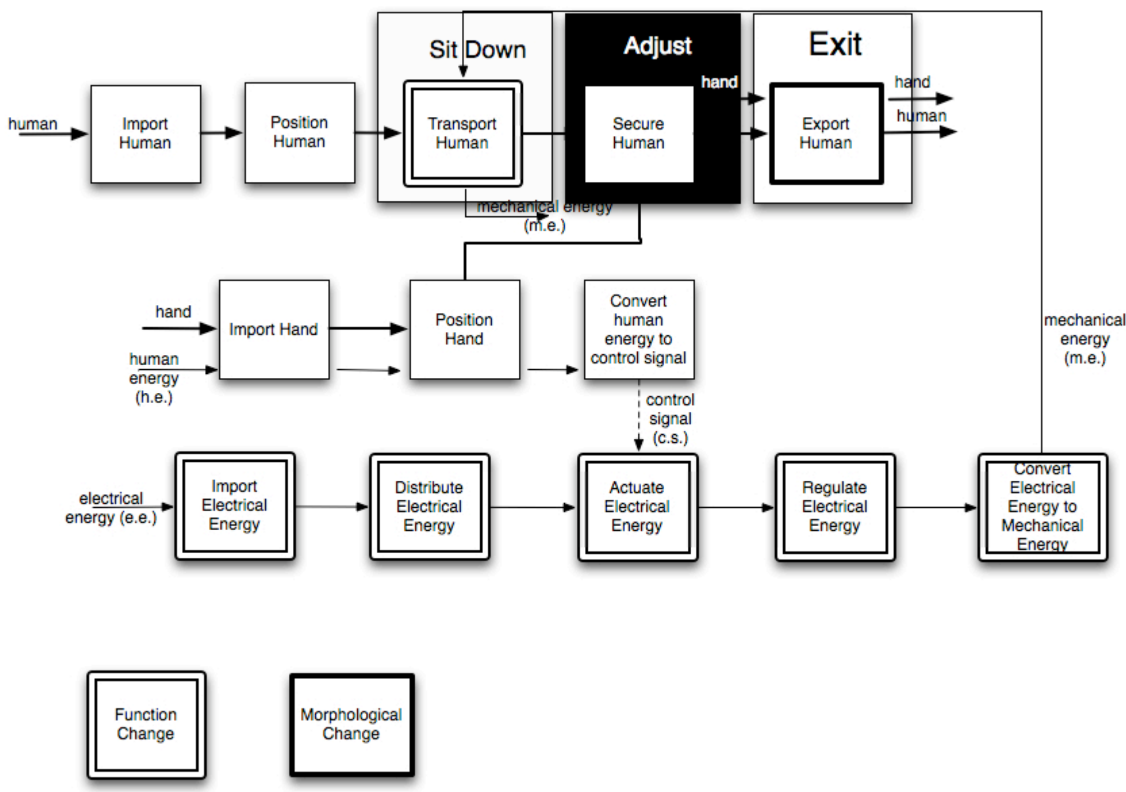


Ford Focus Ingress/Egress and Drive:

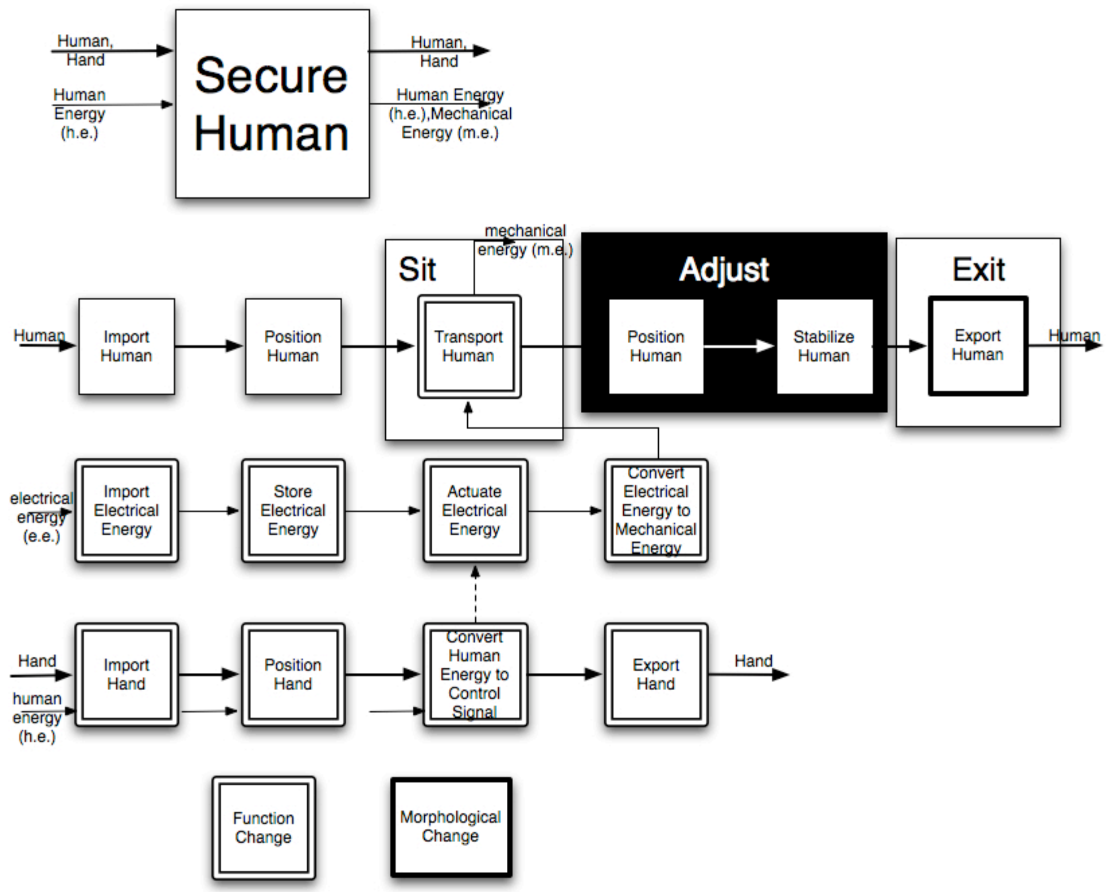


Toilet Seat:


electrical
energy (e.e.)
Hand,Human
Stabilize
Human
mechanical
energy (m.e.)
Hand,Human

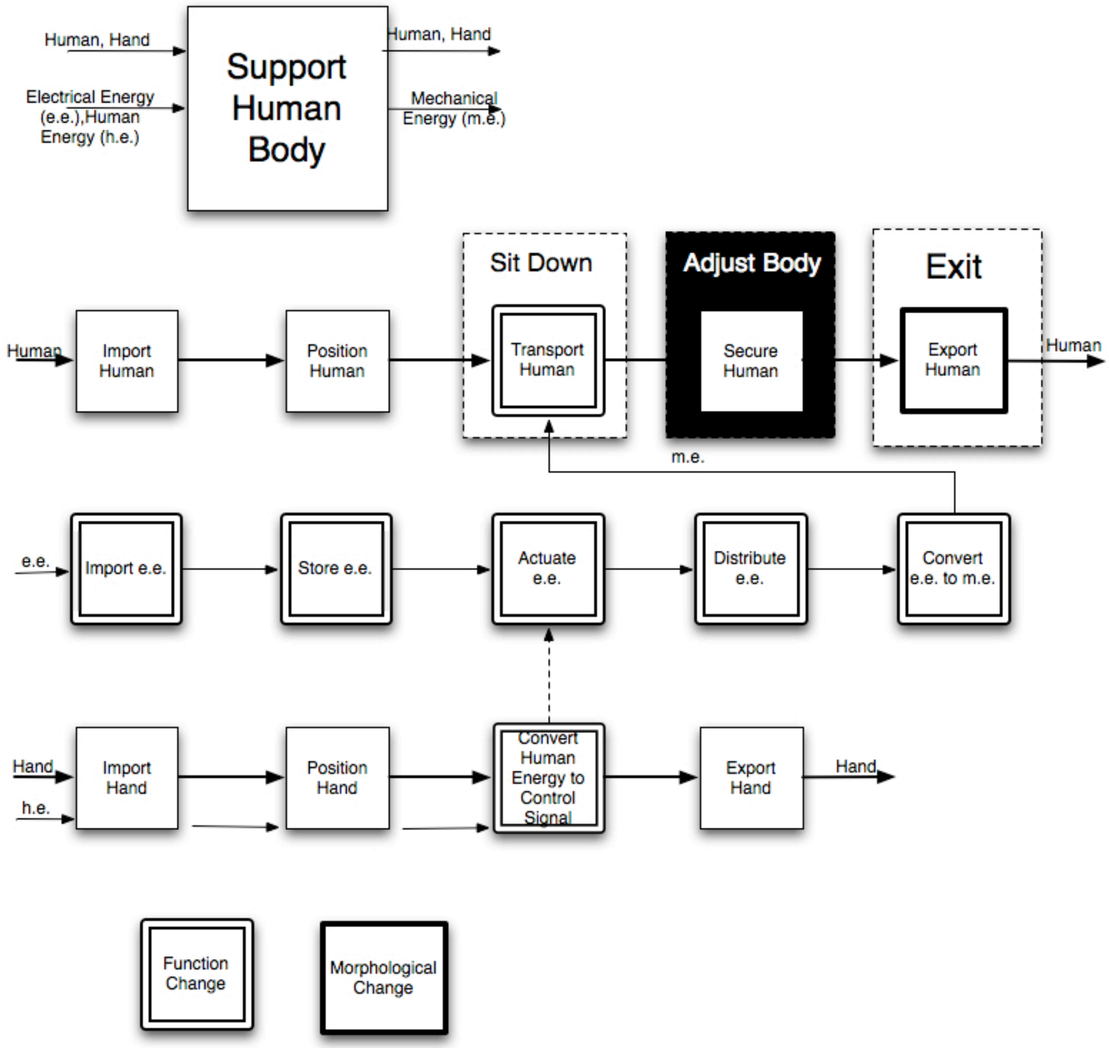

human
Import
Human
Position
Human
Sit Down
Transport
Human
Adjust
hand
Secure
Human
Exit
Export
Human
hand
human
mechanical energy
(m.e.)
hand
Import Hand
human
energy
(h.e.)
Position
Hand
Convert
human
energy to
control signal
control
signal
(c.s.)
mechanical
energy
(m.e.)
electrical
energy (e.e.)
Import
Electrical
Energy
Distribute
Electrical
Energy
Actuate
Electrical
Energy
Regulate
Electrical
Energy
Convert
Electrical
Energy to
Mechanical
Energy
Function
Change
Morphological
Change

Recliner:



Human, Hand
Human Energy (h.e.)
Secure Human
Human, Hand
Human Energy (h.e.),Mechanical Energy (m.e.)
mechanical energy (m.e.)
Sit
Adjust
Exit
Human
Import Human
Position Human
Transport Human
Position Human
Stabilize Human
Export Human
Human
electrical energy (e.e.)
Import Electrical Energy
Store Electrical Energy
Actuate Electrical Energy
Convert Electrical Energy to Mechanical Energy
Hand
human energy (h.e.)
Import Hand
Position Hand
Convert Human Energy to Control Signal
Export Hand
Hand
Function Change
Morphological Change

Chair Lift:

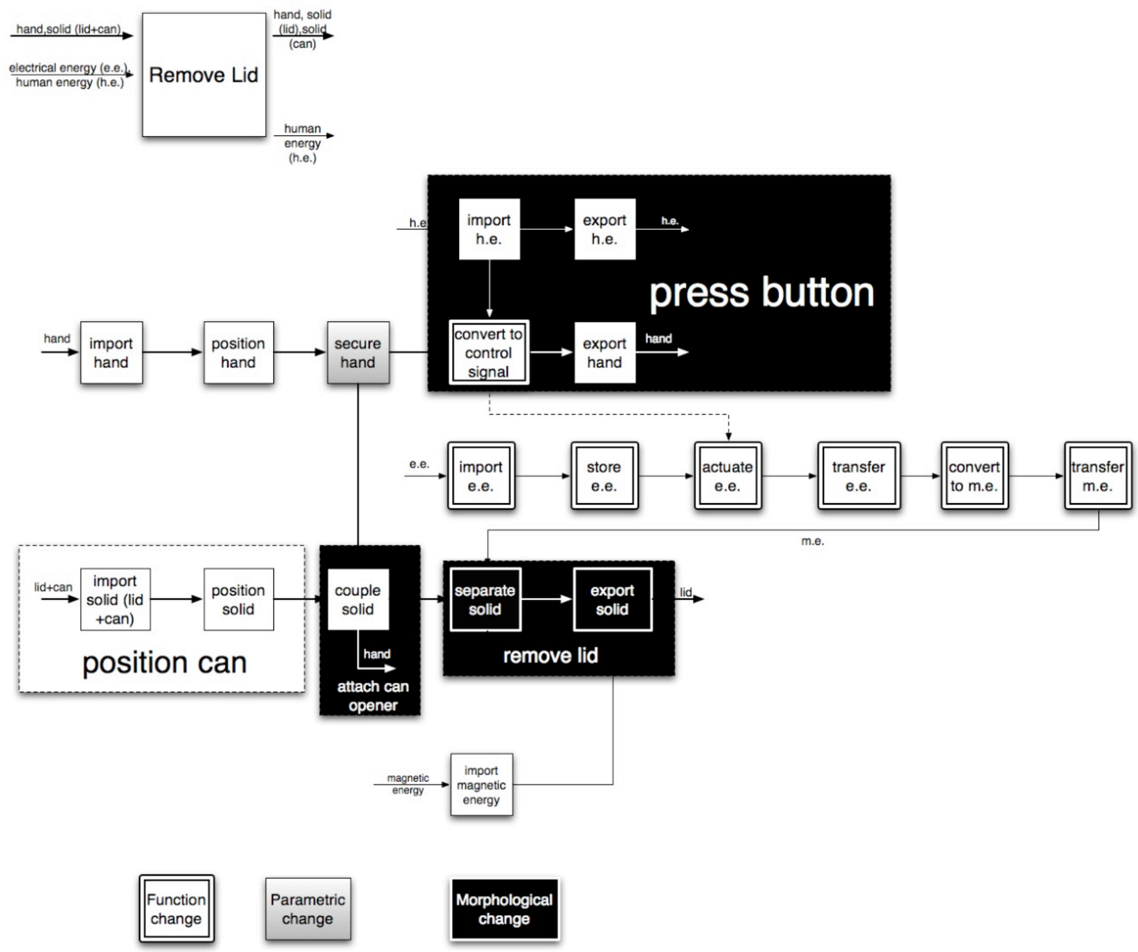

Human, Hand
Electrical Energy (e.e.),Human Energy (h.e.)
Support Human Body
Human, Hand
Mechanical Energy (m.e.)
Sit Down
Adjust Body
Exit
Human
Import Human
Position Human
Transport Human
Secure Human
Export Human
Human
m.e.
e.e.
Import e.e.
Store e.e.
Actuate e.e.
Distribute e.e.
Convert e.e. to m.e.
Hand
h.e.
Import Hand
Position Hand
Convert Human Energy to Control Signal
Export Hand
Hand
Function Change
Morphological Change

D440-Fine Hand Use

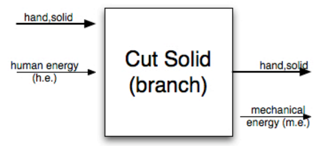
User Activity: *Grab,Rotate,Squeeze,Press,Attach,Remove,Touch,Turn*
ICF Activity: d440-fine hand use
ICF Body Function: B710-mobility of joint functions B715-stability of joint functions B720-mobility of bone functions B730-muscle power functions B735-muscle tone functions B740-muscle endurance functions B760-control of voluntary movement functions B780-sensations related to muscles and movement functions
ICF Body Structure: S7302-structure of the hand

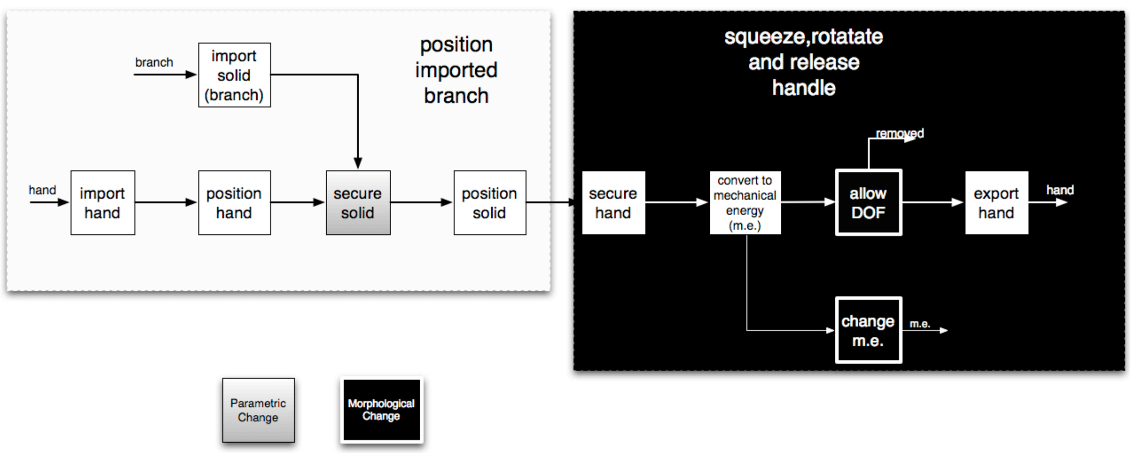
d440	b710,b715,b720,b730,b735, b740,b760,b780	s7302

Electric Can Opener:

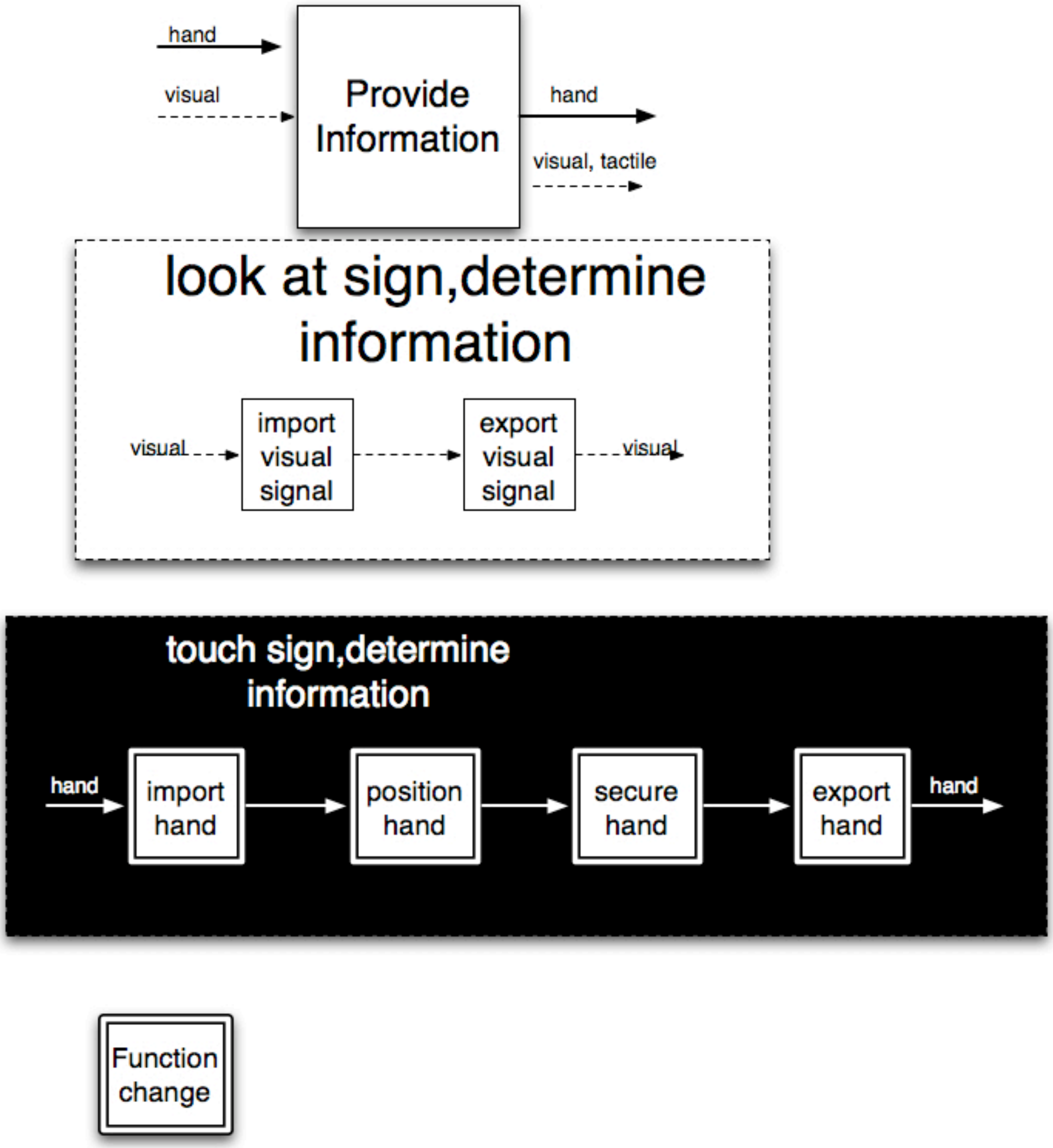


Florian Pruners:

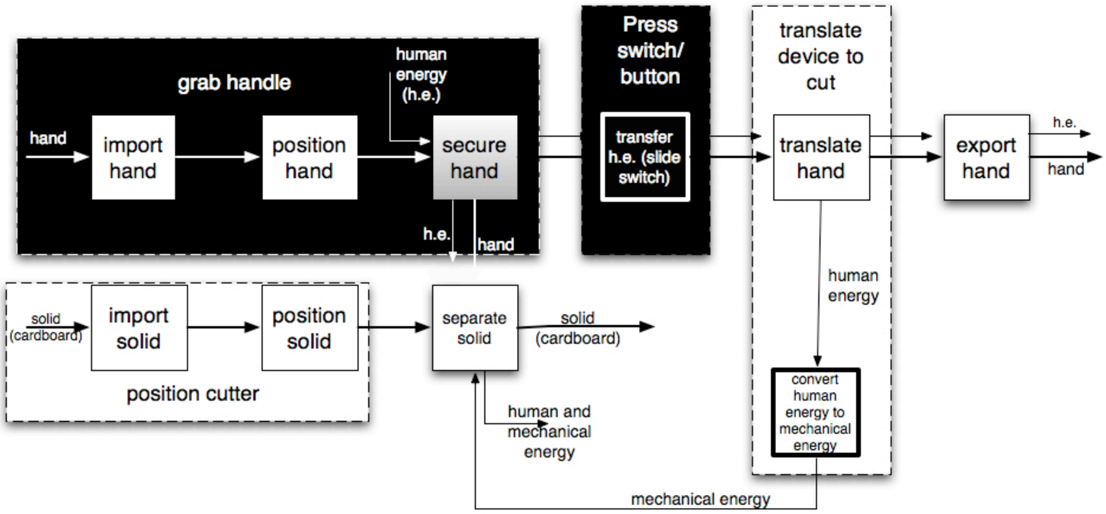


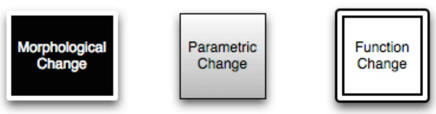


Restroom Sign:

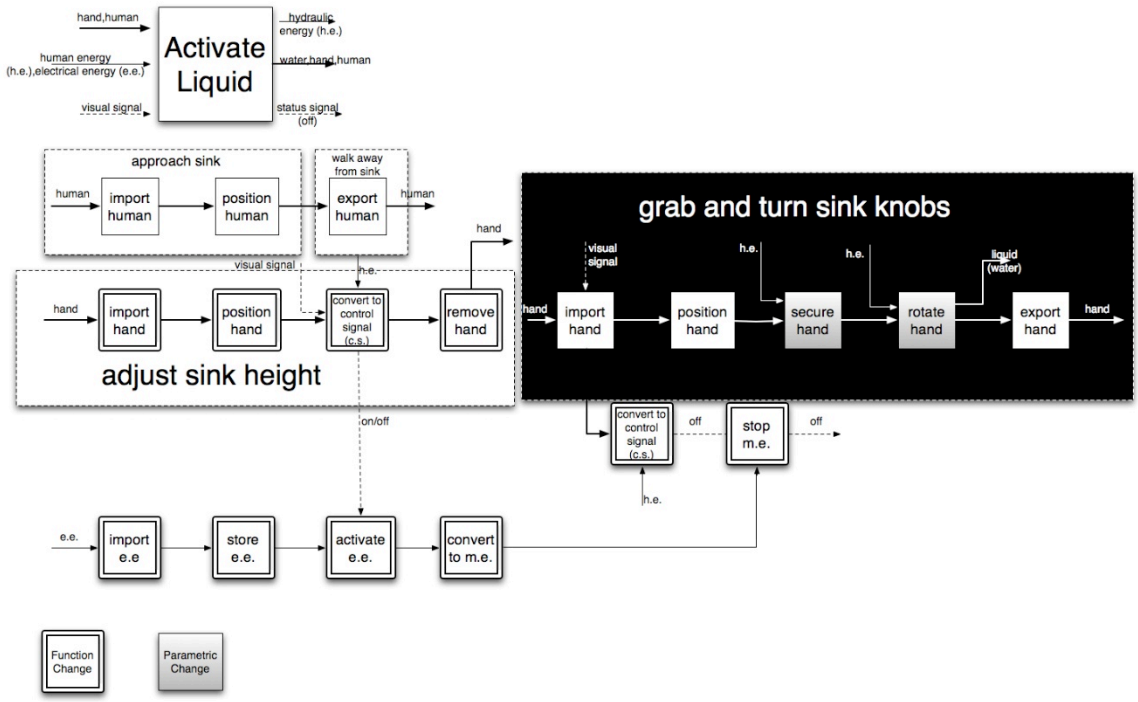


Fiskars Rotary Cutter:

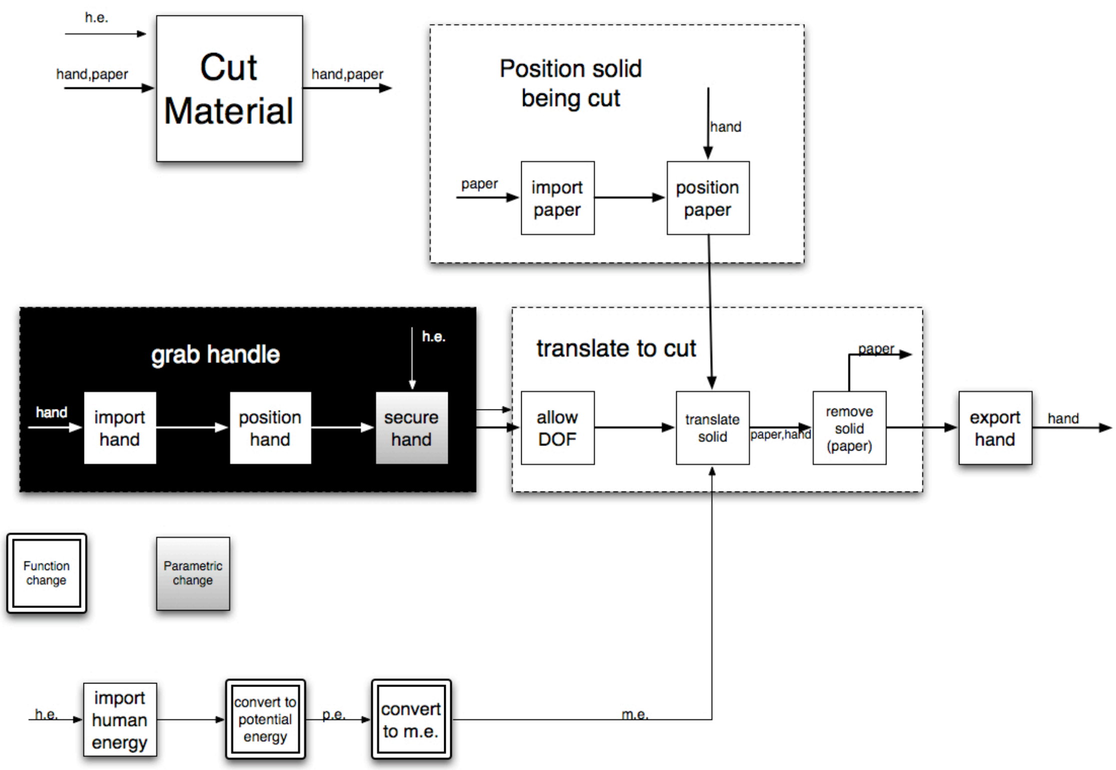




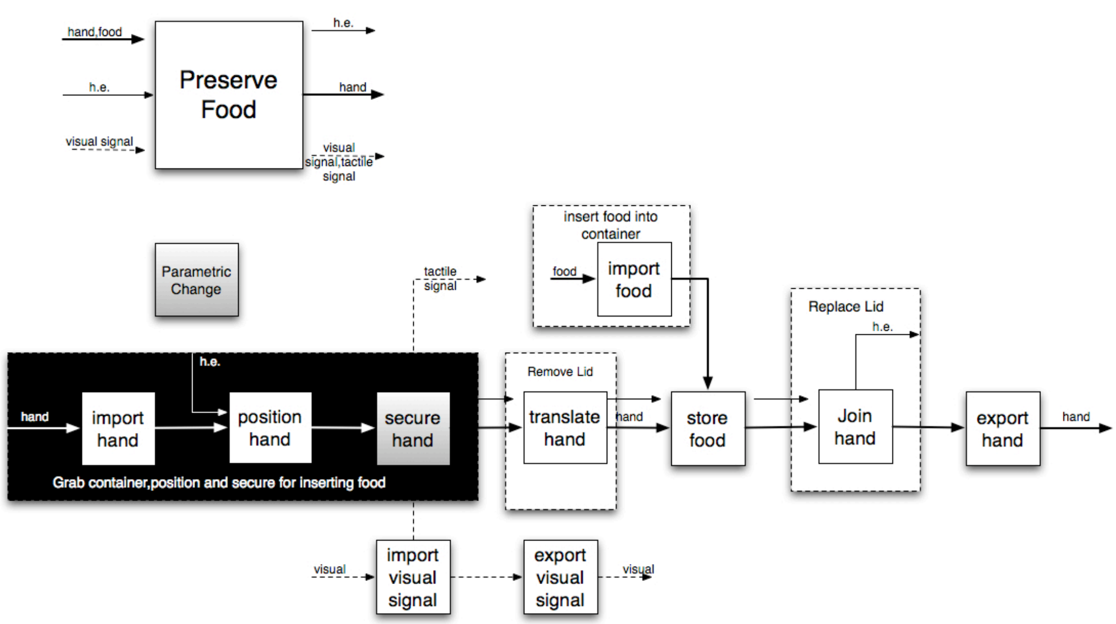
Adjustable Sink:



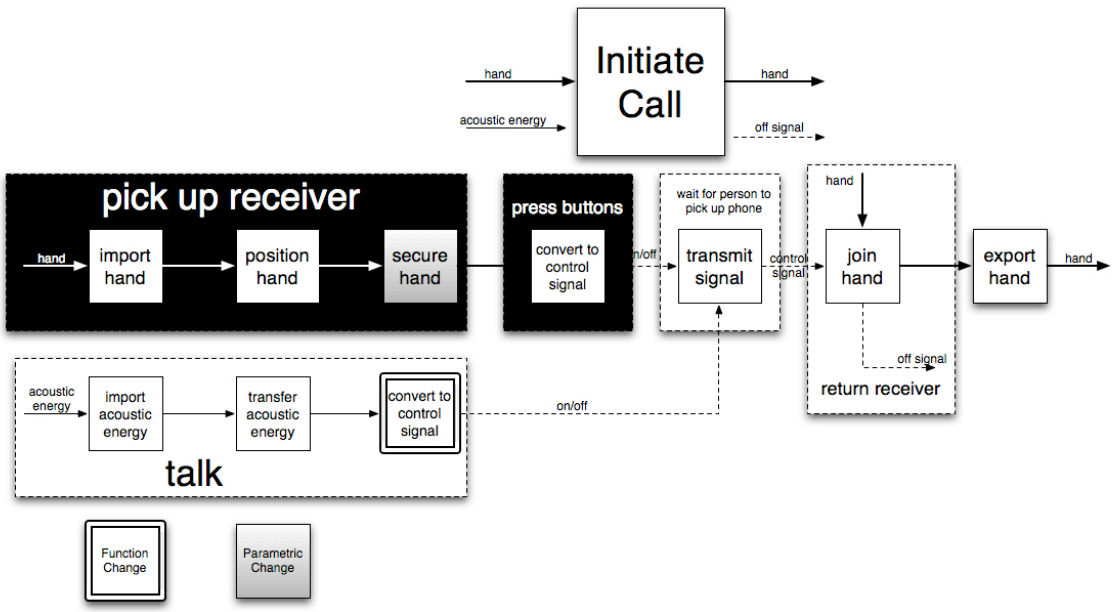
Softouch Scissors:



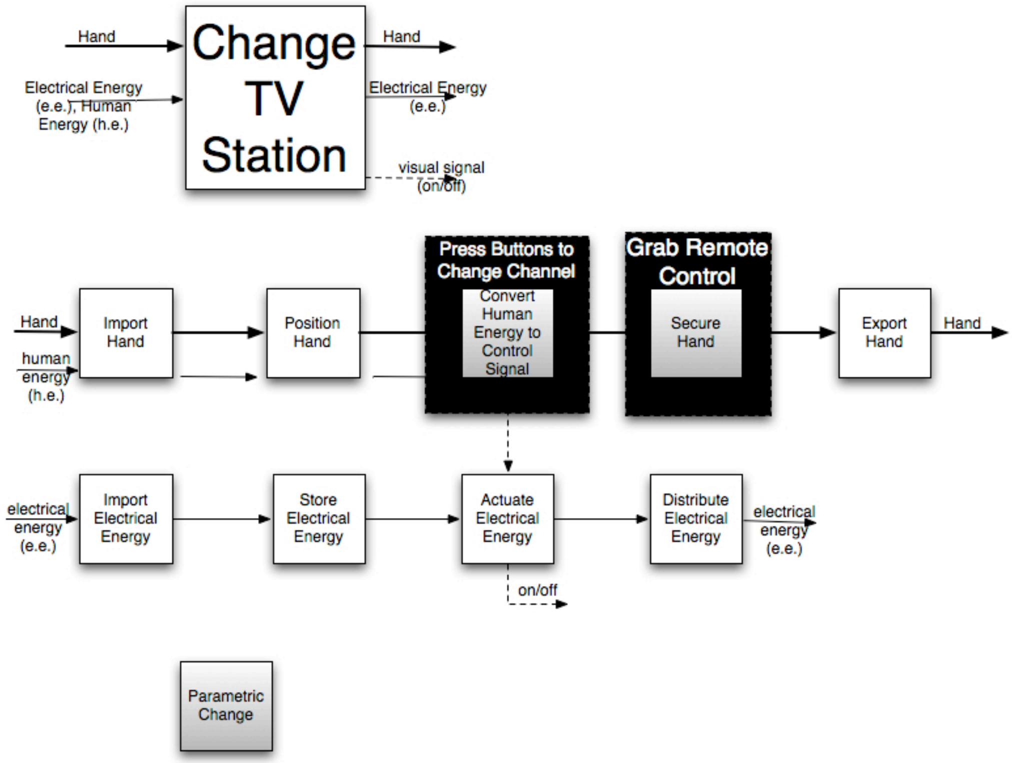
Tupperware:



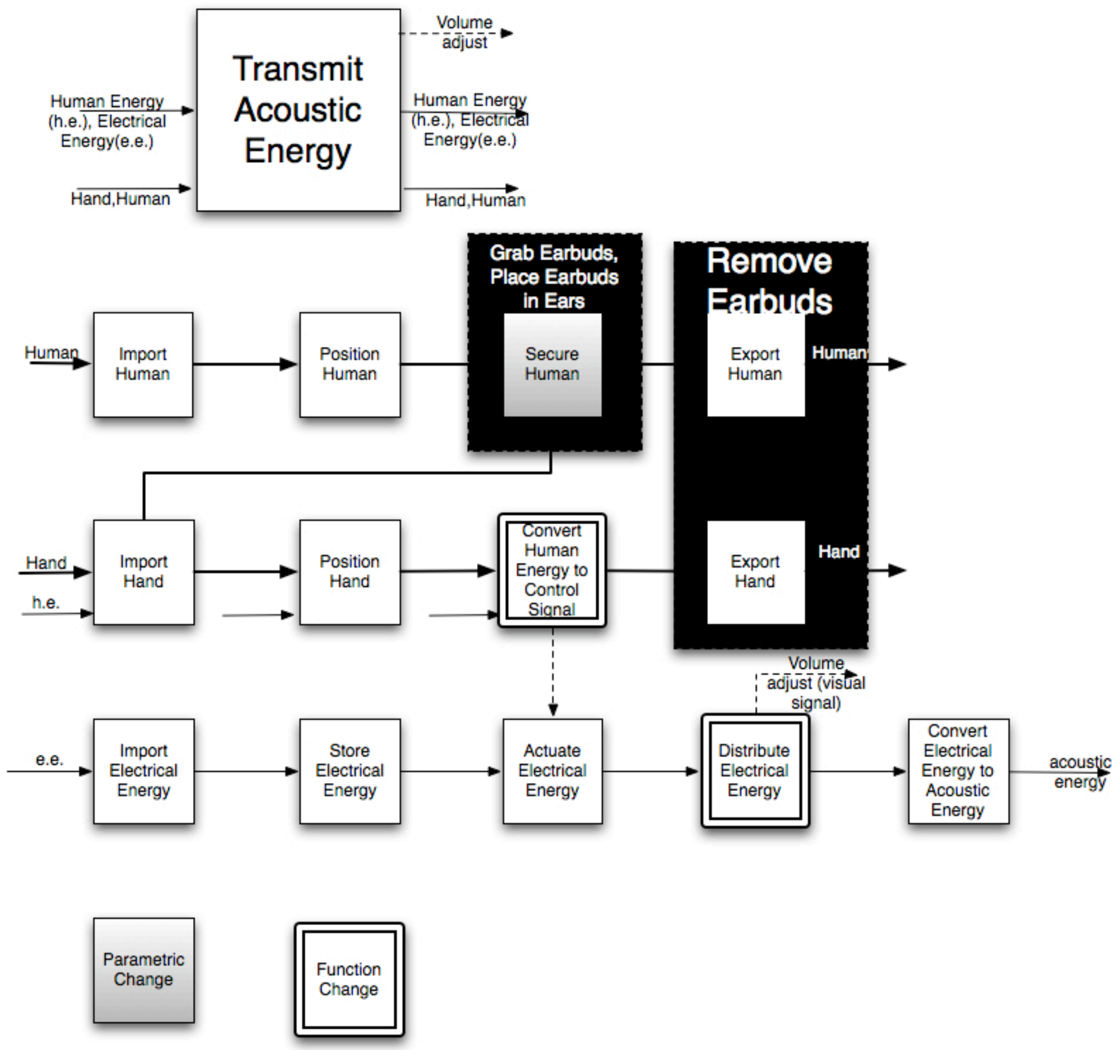
Voice Activated Phone:



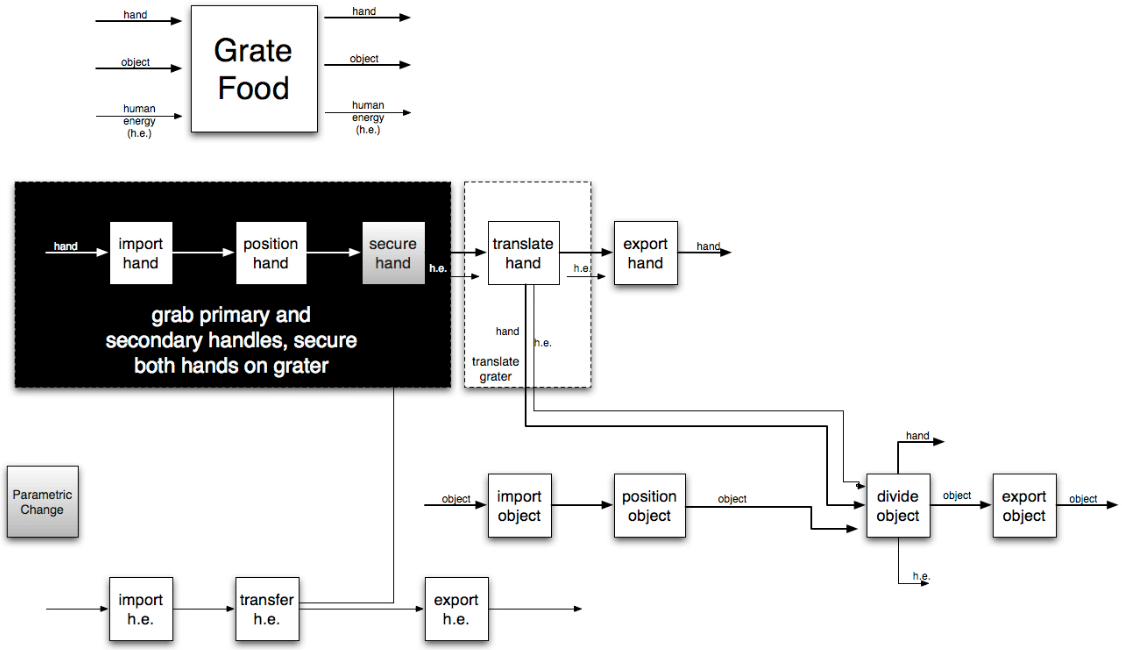
TV Remote Control:



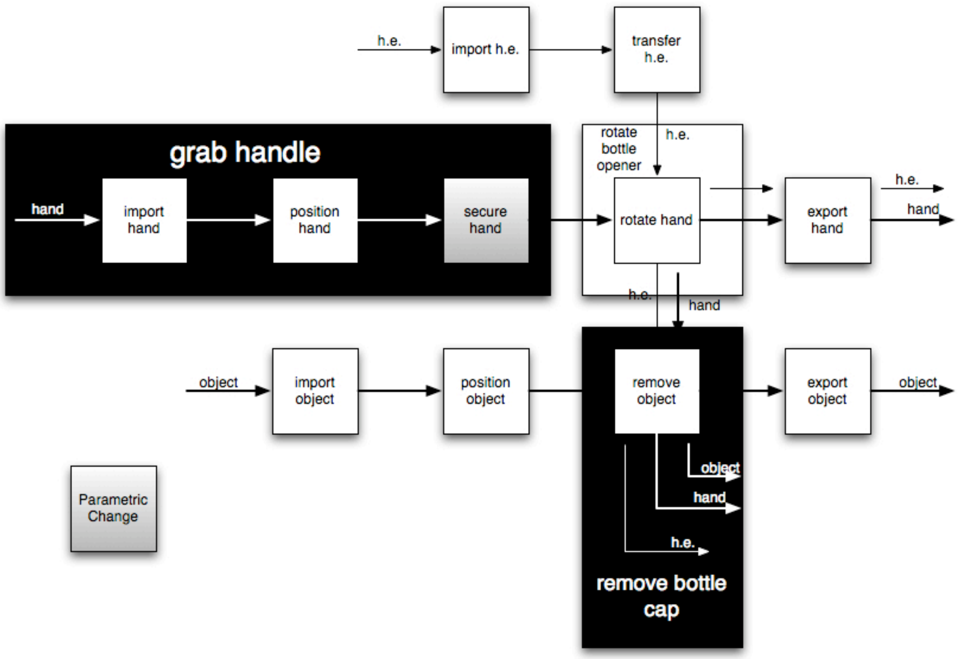
TV Ears:


Transmit Acoustic Energy
Volume adjust
Human Energy (h.e.), Electrical Energy(e.e.)
Hand,Human
Human Energy (h.e.), Electrical Energy(e.e.)
Hand,Human
Grab Earbuds, Place Earbuds in Ears
Remove Earbuds
Human
Import Human
Position Human
Secure Human
Export Human
Human
Hand
h.e.
Import Hand
Position Hand
Convert Human Energy to Control Signal
Export Hand
Hand
Volume adjust (visual signal)
e.e.
Import Electrical Energy
Store Electrical Energy
Actuate Electrical Energy
Distribute Electrical Energy
Convert Electrical Energy to Acoustic Energy
acoustic energy
Parametric Change
Function Change

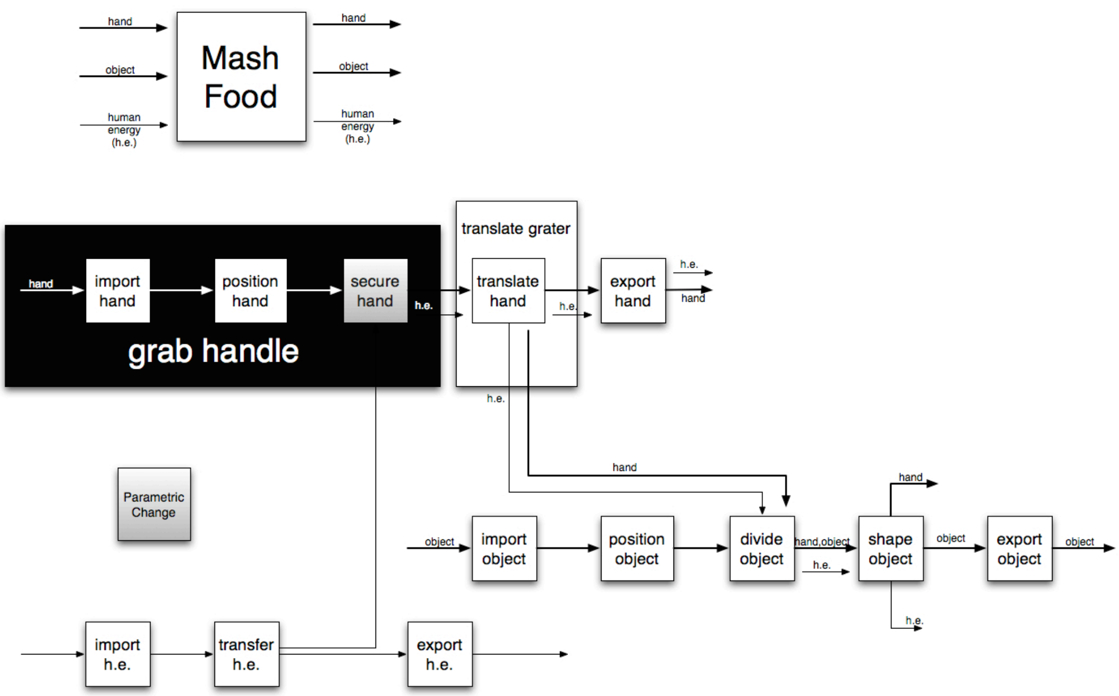
O.X.O Grater:


hand
object
human energy (h.e.)
Grate Food
hand
object
human energy (h.e.)
hand
import hand
position hand
secure hand
h.e.
grab primary and secondary handles, secure both hands on grater
translate hand
h.e.
hand
h.e.
translate grater
export hand
hand
Parametric Change
object
import object
position object
object
hand
divide object
object
h.e.
export object
object
import h.e.
transfer h.e.
export h.e.

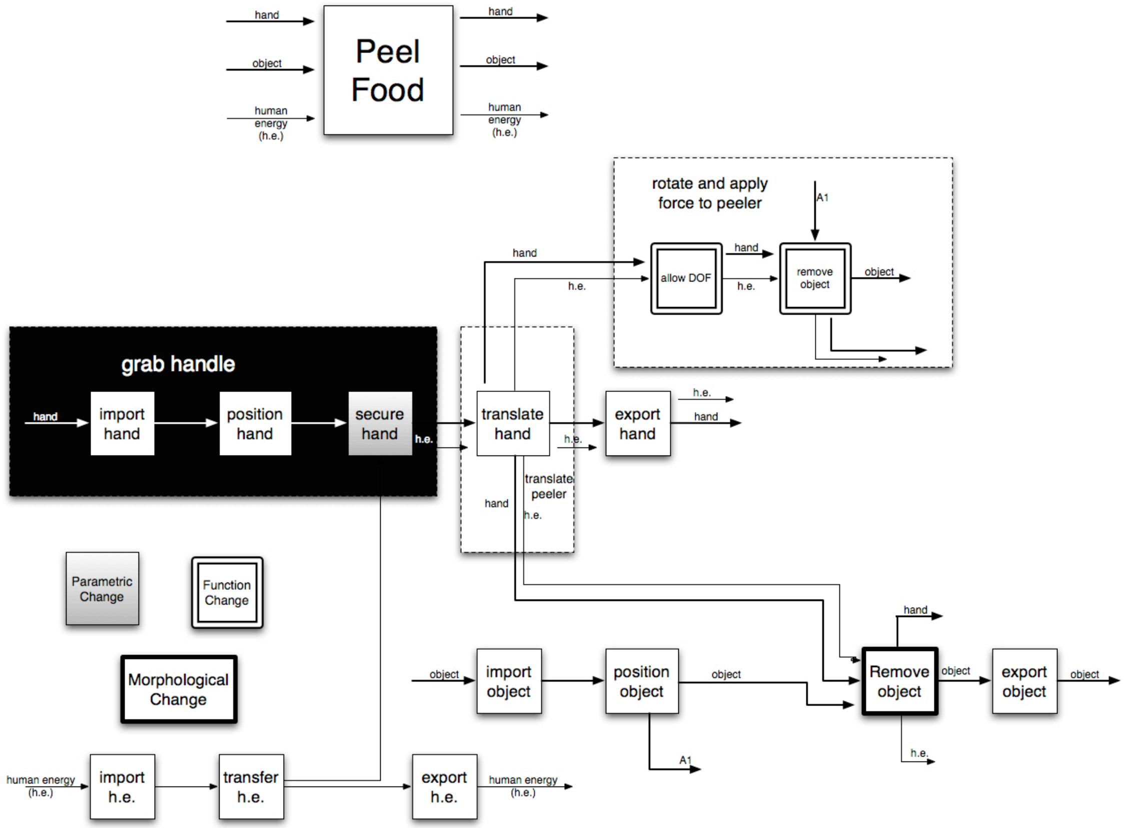
O.X.O Bottle Opener:



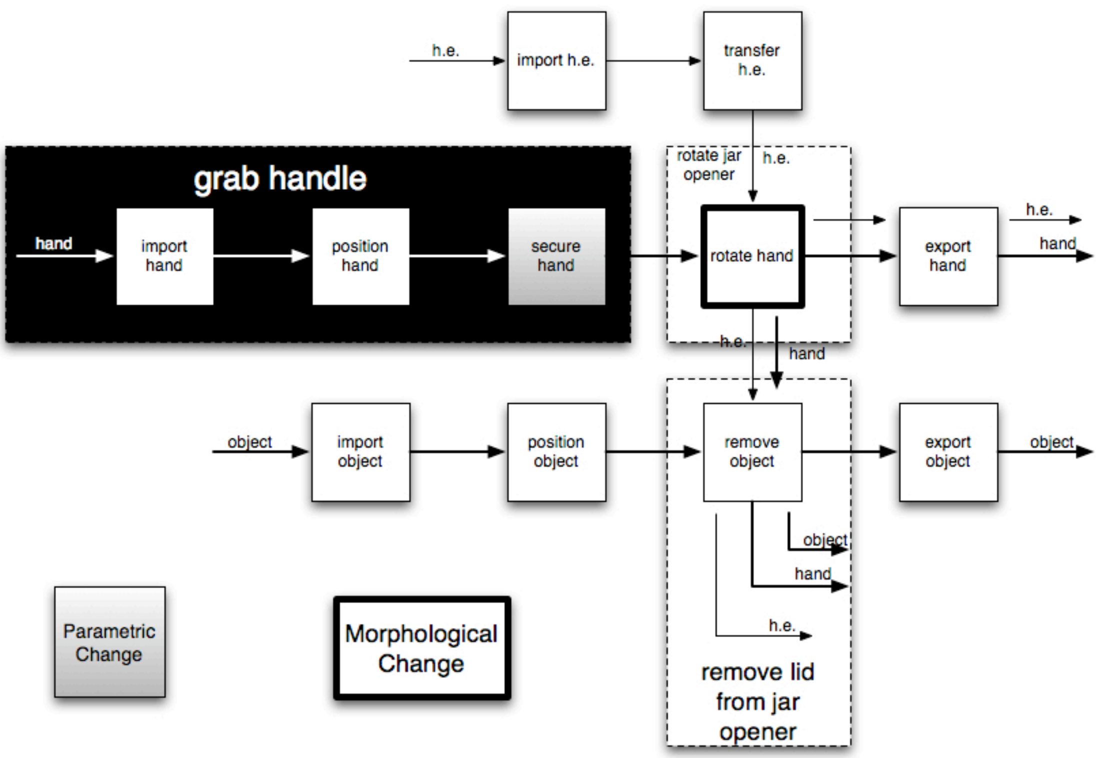
O.X.O Masher:


hand
object
human energy (h.e.)
Mash Food
hand
object
human energy (h.e.)
translate grater
hand
import hand
position hand
secure hand
h.e.
grab handle
translate hand
h.e.
export hand
h.e.
hand
h.e.
hand
Parametric Change
hand
object
import object
position object
divide object
hand,object
h.e.
shape object
object
export object
object
h.e.
import h.e.
transfer h.e.
export h.e.

O.X.O Peeler:


Peel Food
hand
object
human energy (h.e.)
rotate and apply force to peeler
A1
allow DOF
remove object
h.e.
grab handle
import hand
position hand
secure hand
translate hand
export hand
translate peeler
Parametric Change
Function Change
Morphological Change
import object
position object
Remove object
export object
import h.e.
transfer h.e.
export h.e.
human energy (h.e.)

O.X.O Jar Opener:

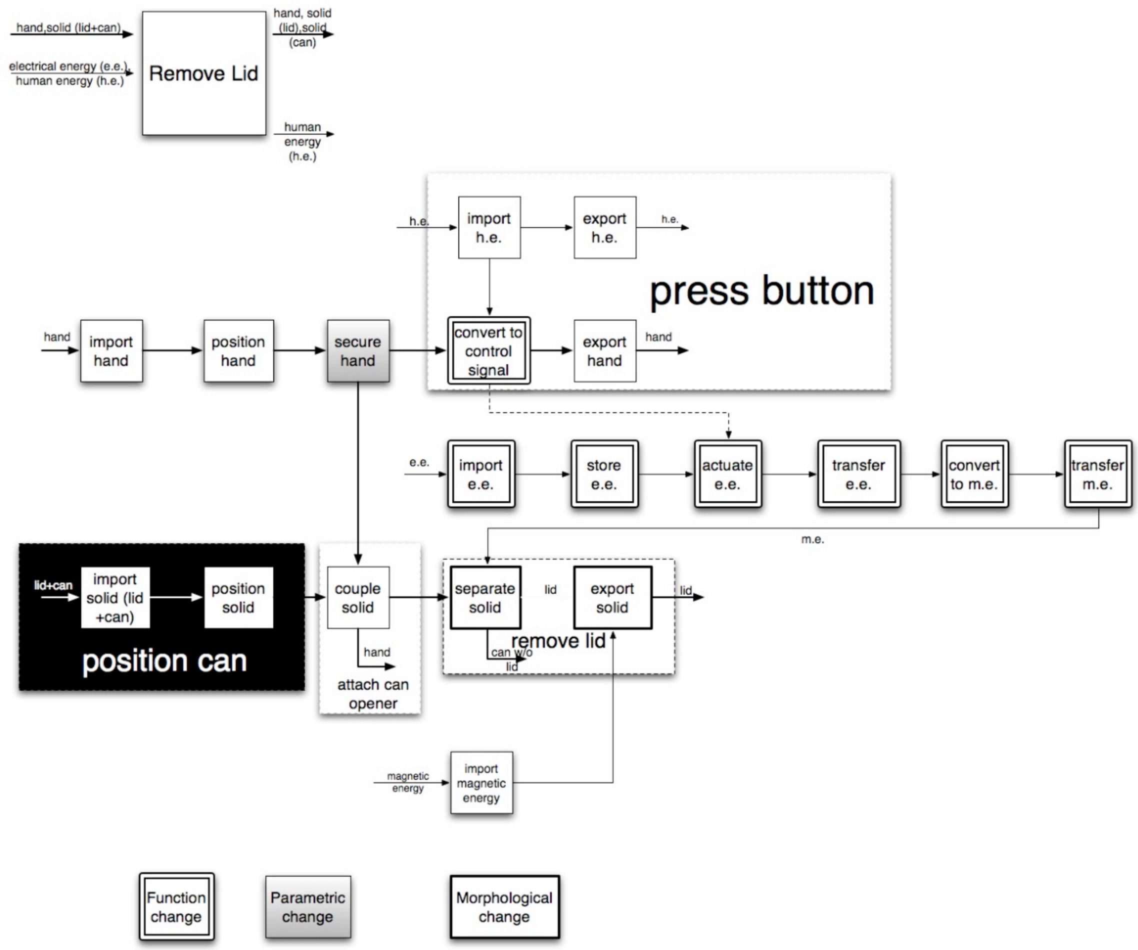


D445-Hand and Arm Use

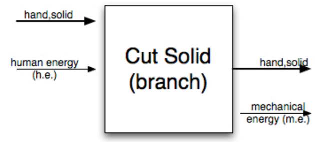
User Activity: *Position,Translate,Adjust,Insert,Replace,Remove,Return, Rotate*
ICF Activity: d445-hand and arm use
ICF Body Function: B710-mobility of joint functions B715-stability of joint functions B720-mobility of bone functions B730-muscle power functions B735-muscle tone functions B740-muscle endurance functions B760-control of voluntary movement functions B780-sensations related to muscles and movement functions
ICF Body Structure: S7302-structure of the hand S7300-structure of the upper arm S7301-structure of the forearm

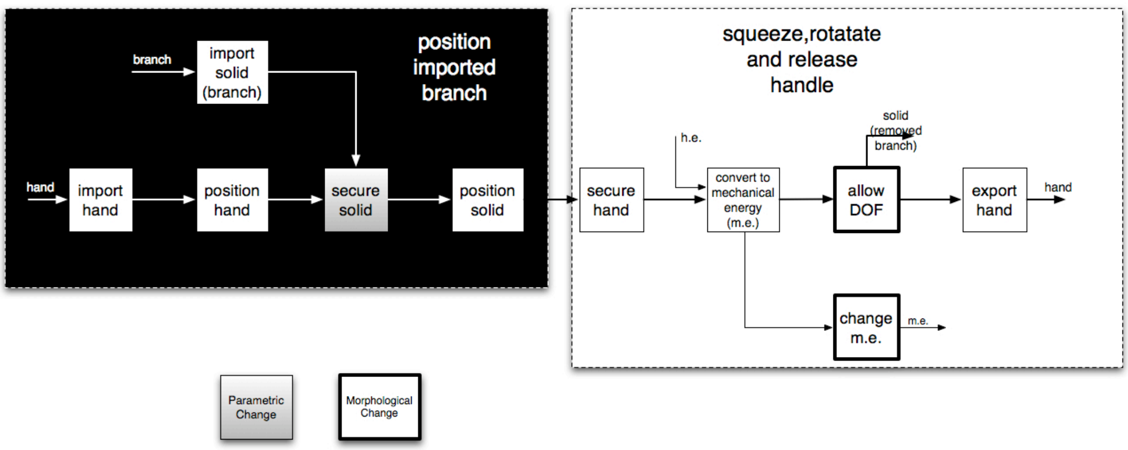
d440,d445	b710,b715,b720,b730,b735, b740,b760,b780	s7302,s7300,s7301

Electric Can Opener:

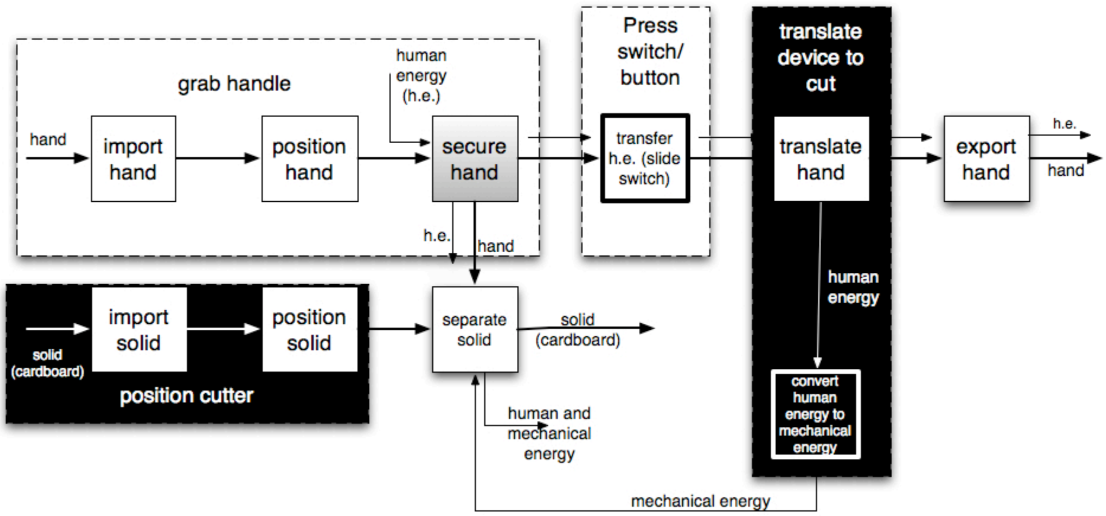


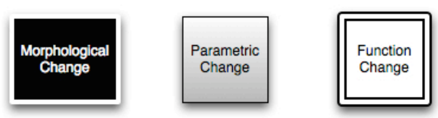
Florian Pruners:



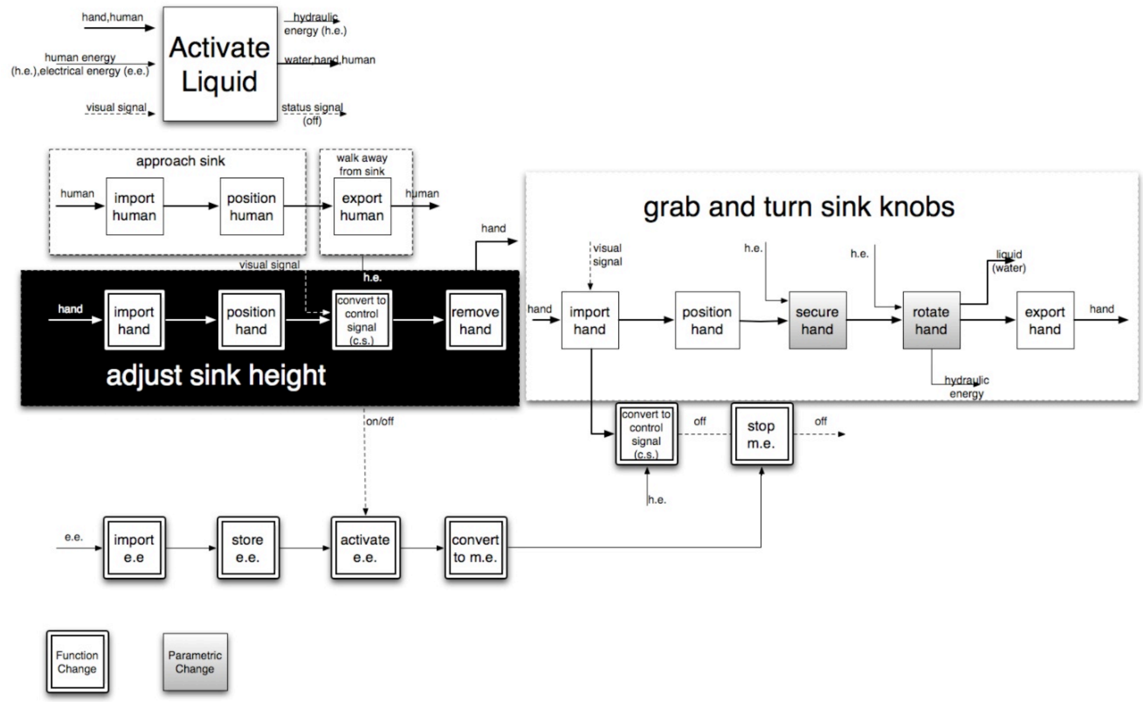


Fiskars Rotary Cutter:

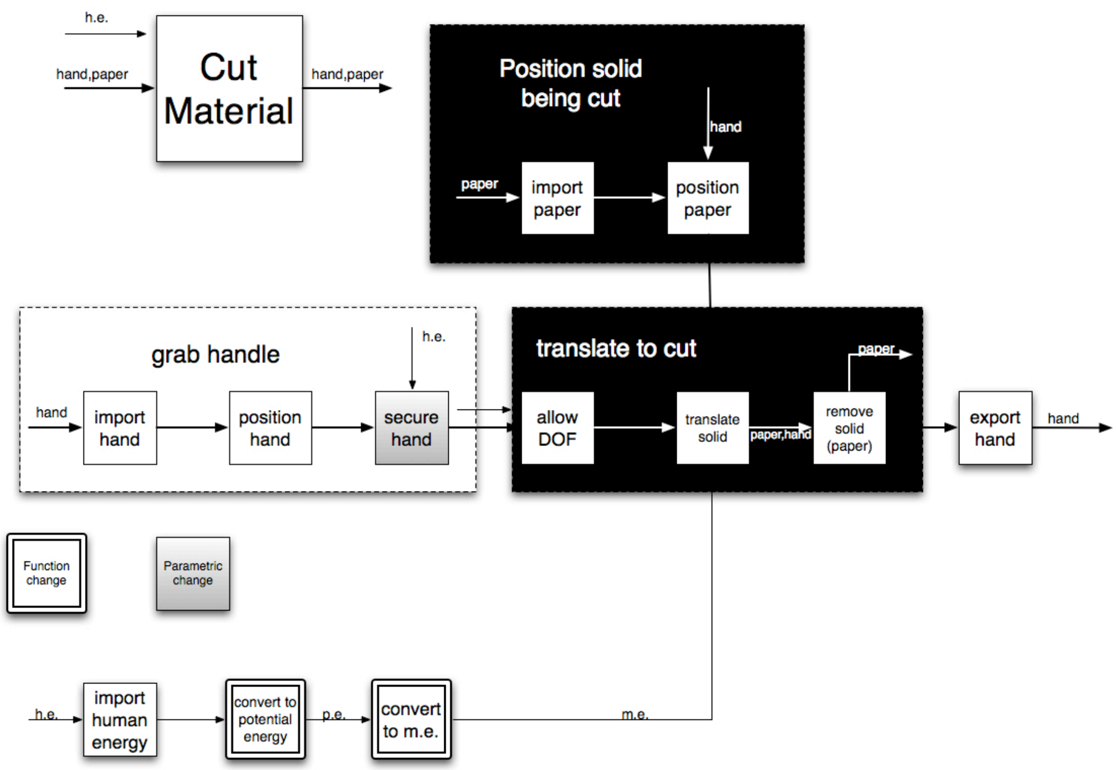




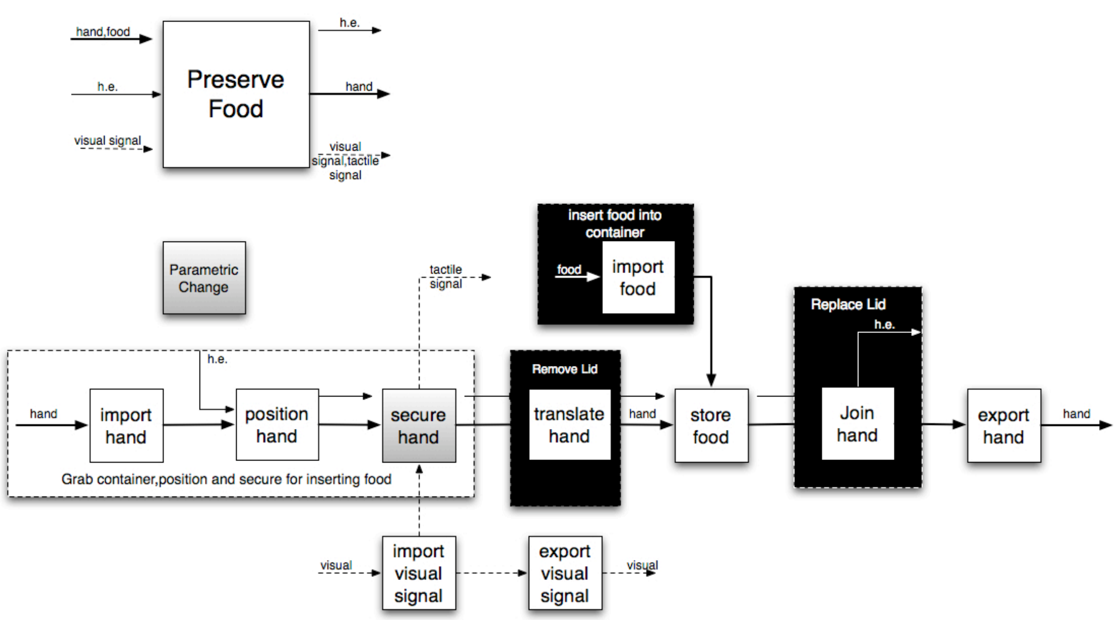
Adjustable Sink:



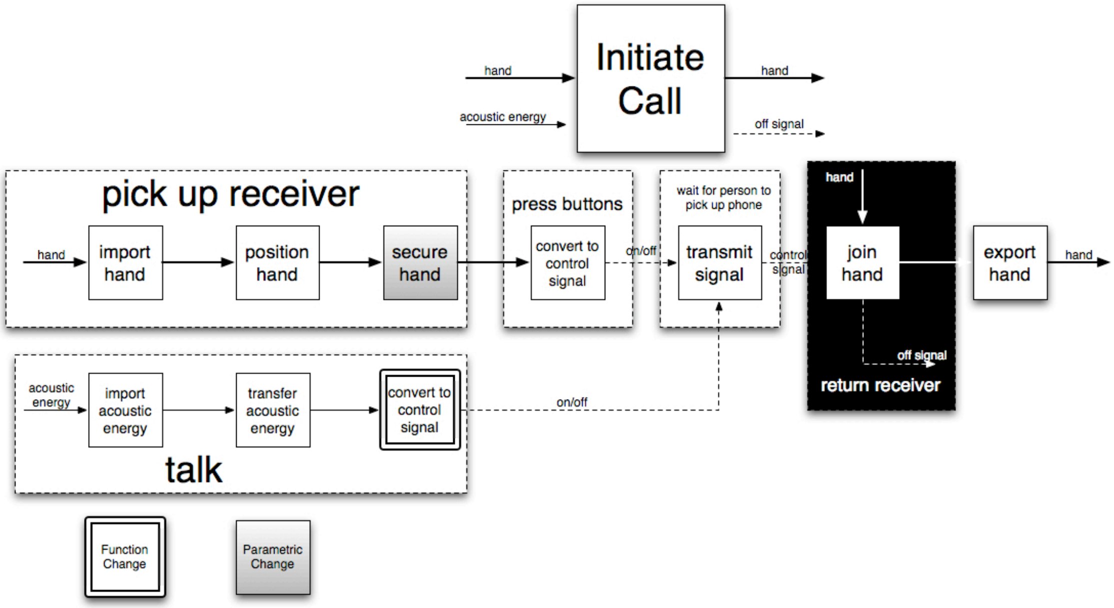
Softouch Scissors:



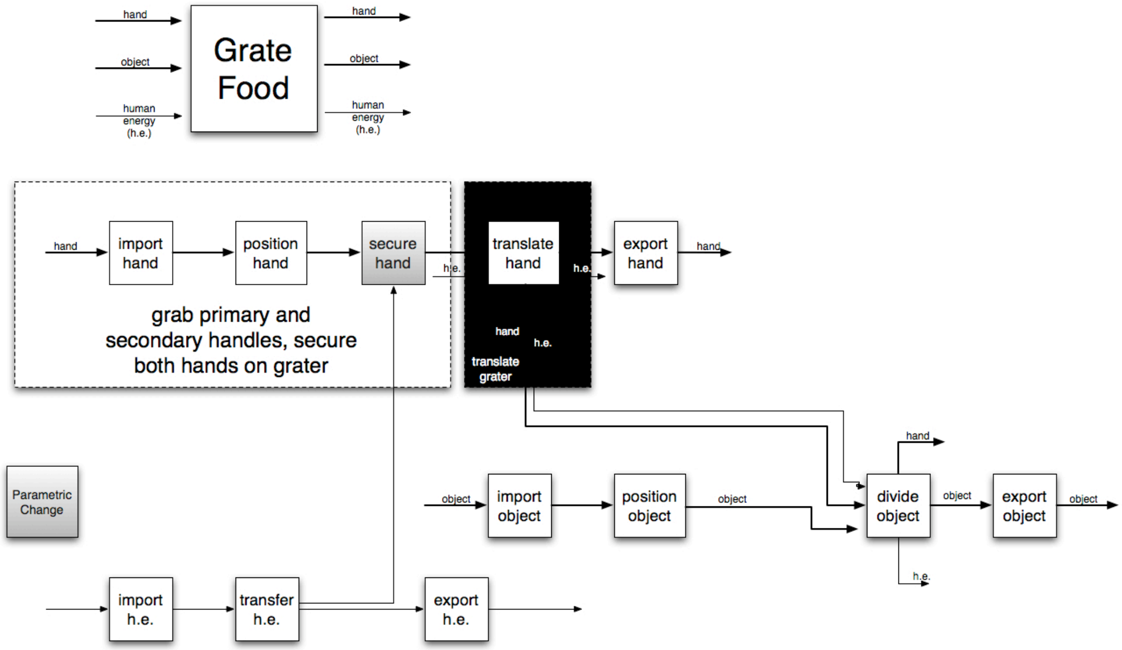
Tupperware:



Voice Activated Phone:

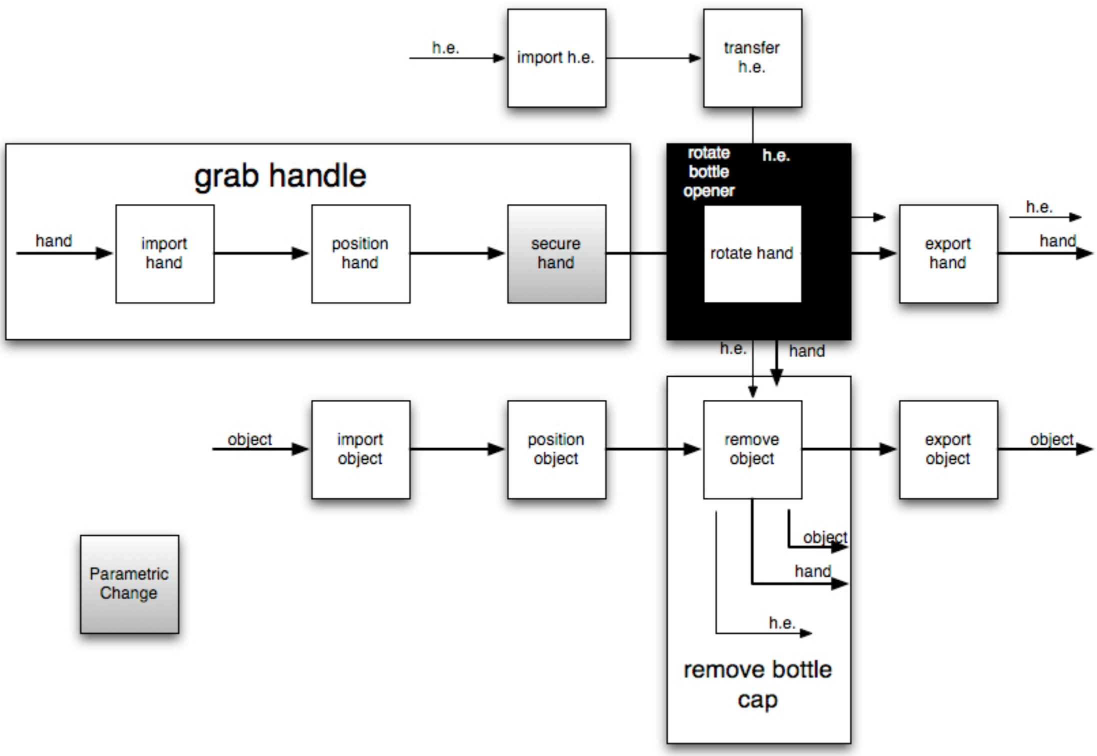


O.X.O Grater:

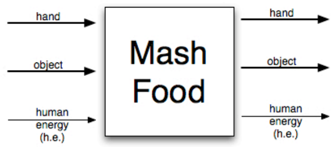


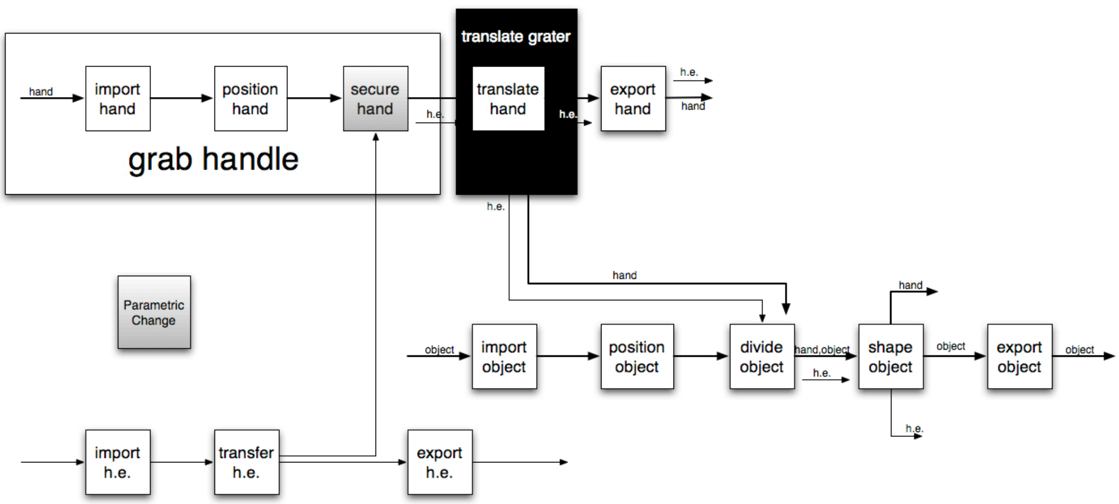
hand
object
human energy (h.e.)
Grate Food
hand
object
human energy (h.e.)
hand
import hand
position hand
secure hand
h.e.
translate hand
h.e.
export hand
hand
grab primary and secondary handles, secure both hands on grater
hand
h.e.
translate grater
hand
Parametric Change
object
import object
position object
object
divide object
object
export object
object
h.e.
import h.e.
transfer h.e.
export h.e.

O.X.O Bottle Opener:

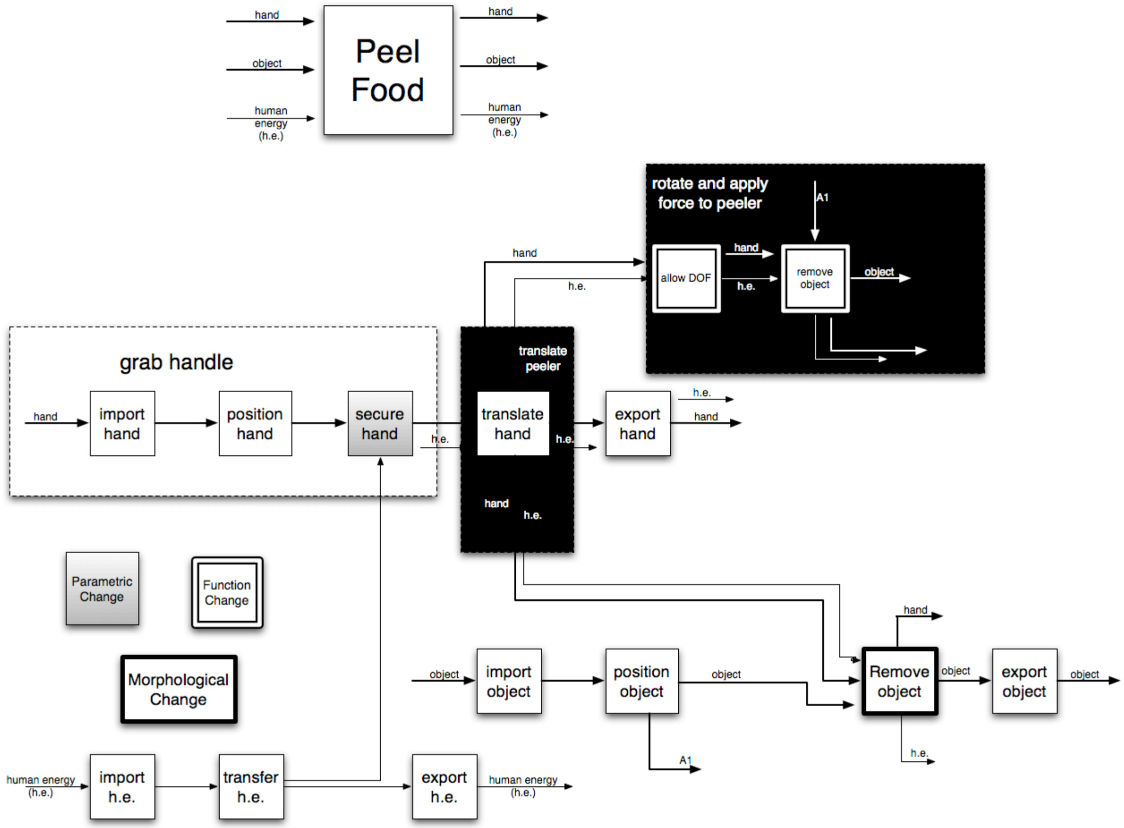


O.X.O Masher:

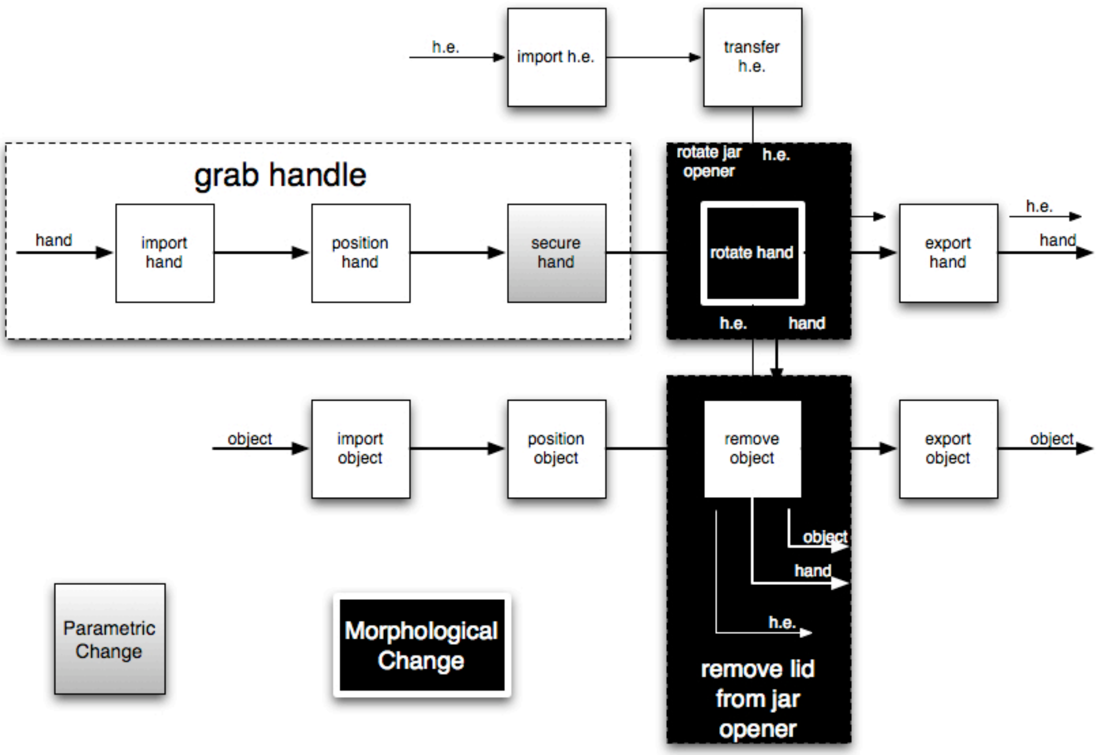

hand
object
human
energy
(h.e.)
Mash
Food
hand
object
human
energy
(h.e.)


hand
import
hand
position
hand
secure
hand
grab handle
h.e.
translate grater
translate
hand
h.e.
export
hand
h.e.
hand
h.e.
hand
Parametric
Change
object
import
object
position
object
divide
object
hand,object
h.e.
hand
shape
object
object
export
object
object
h.e.
import
h.e.
transfer
h.e.
export
h.e.

O.X.O Peeler:


hand
object
human energy (h.e.)
Peel Food
hand
object
human energy (h.e.)
rotate and apply force to peeler
A1
hand
h.e.
allow DOF
hand
h.e.
remove object
object
grab handle
hand
import hand
position hand
secure hand
h.e.
translate peeler
translate hand
h.e.
hand
h.e.
export hand
h.e.
hand
Parametric Change
Function Change
Morphological Change
hand
object
import object
position object
object
Remove object
object
export object
object
A1
h.e.
human energy (h.e.)
import h.e.
transfer h.e.
export h.e.
human energy (h.e.)

O.X.O Jar Opener:

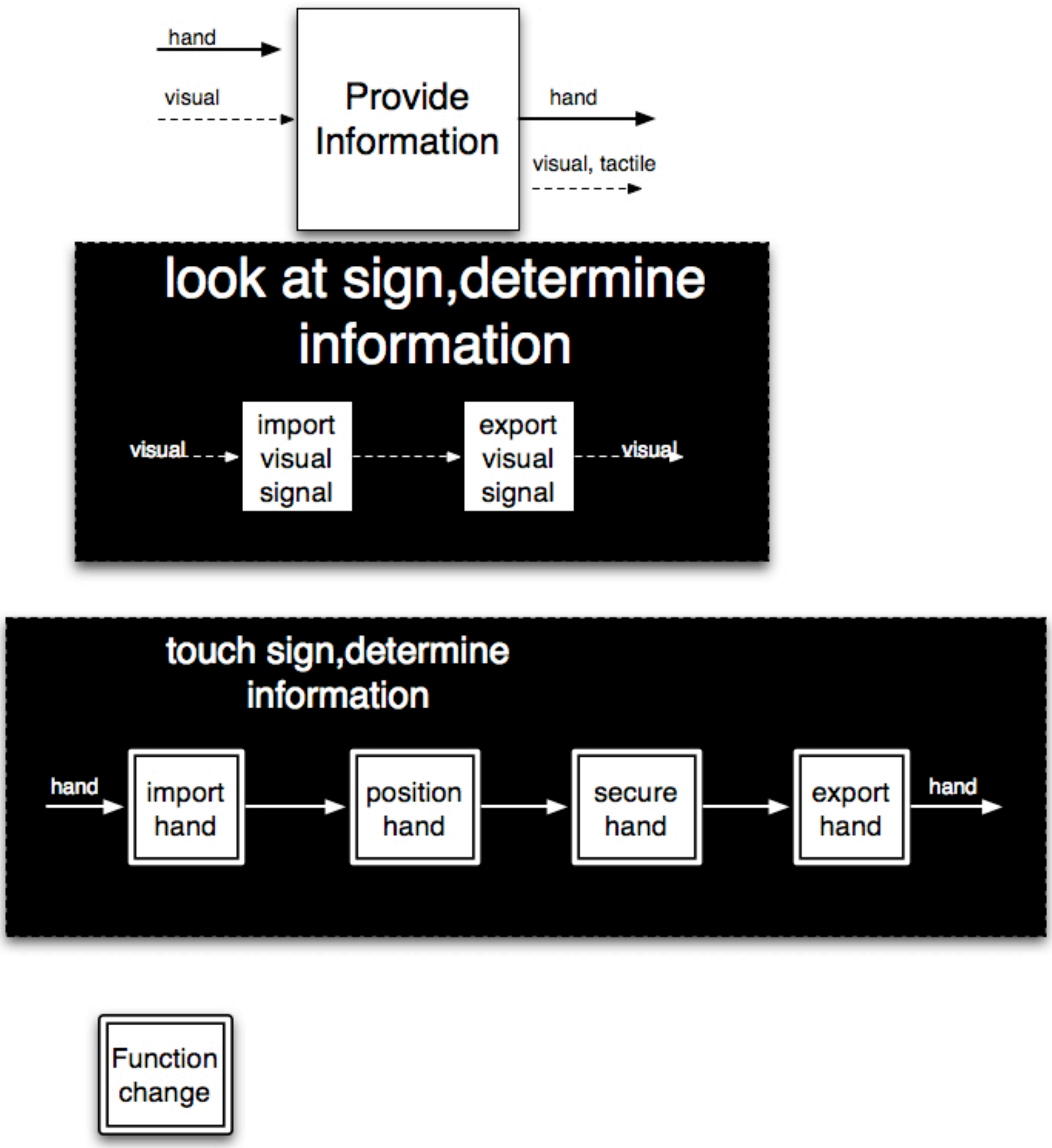


D160-Focusing attention

User Activity: Determine Information
ICF Activity: D160-focusing attention
ICF Body Function: B140-attention functions B156-perceptual functions B160-thought functions B210-seeing functions B215-functions of structure adjoining the eye B220-sensations associated with the eye and adjoining structures B710-B729-functions of the joints and bones B730-B749-muscle functions B750-motor reflex functions B755-involuntary movement reaction functions B760-control of voluntary movement functions B765-involuntary movement functions
ICF Body Structure: S110-structure of brain S210-structure of eye socket S220-structure of eyeball S230-structures around the eye S730-structure of upper extremity

D160	b140,b156,b160,b210, b215,b220,b710-b729,b730-b749,b750,b755,b760,b765	s110,s210,s220,s230,s730

Restroom Sign:

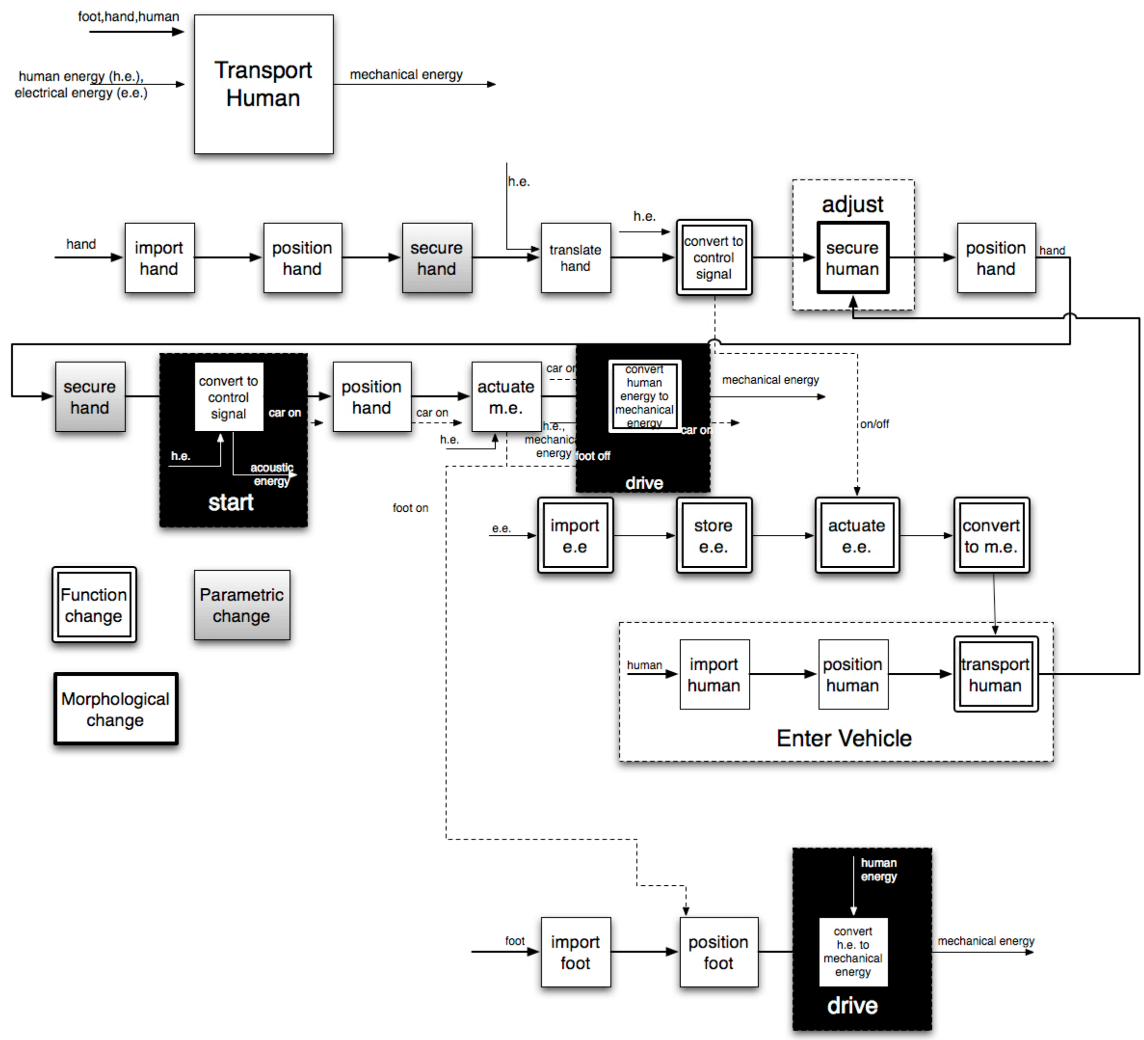


D4751-Driving motorized vehicles

User Activity: *Drive,Start*
ICF Activity: D4751-driving motorized vehicles
ICF Body Function: B140-attention functions B156-perceptual functions B160-thought functions B210-seeing functions B215-functions of structure adjoining the eye B220-sensations associated with the eye and adjoining structures B230-hearing functions B235-vestibular functions B710-B729-functions of the joints and bones B730-B749-muscle functions B750-motor reflex functions B755-involuntary movement reaction functions B760-control of voluntary movement functions B765-involuntary movement functions
ICF Body Structure: S110-structure of brain S210-structure of eye socket S220-structure of eyeball S230-structures around the eye S730-structure of upper extremity S750-structure of lower extremity

d4751	b140,b156,b160,b210, b215,b220,b230,b235,b710-b729,b730-b749,b750,b755,b760,b765	s110,s210,s220,s230,s730,s750

Ford Focus:

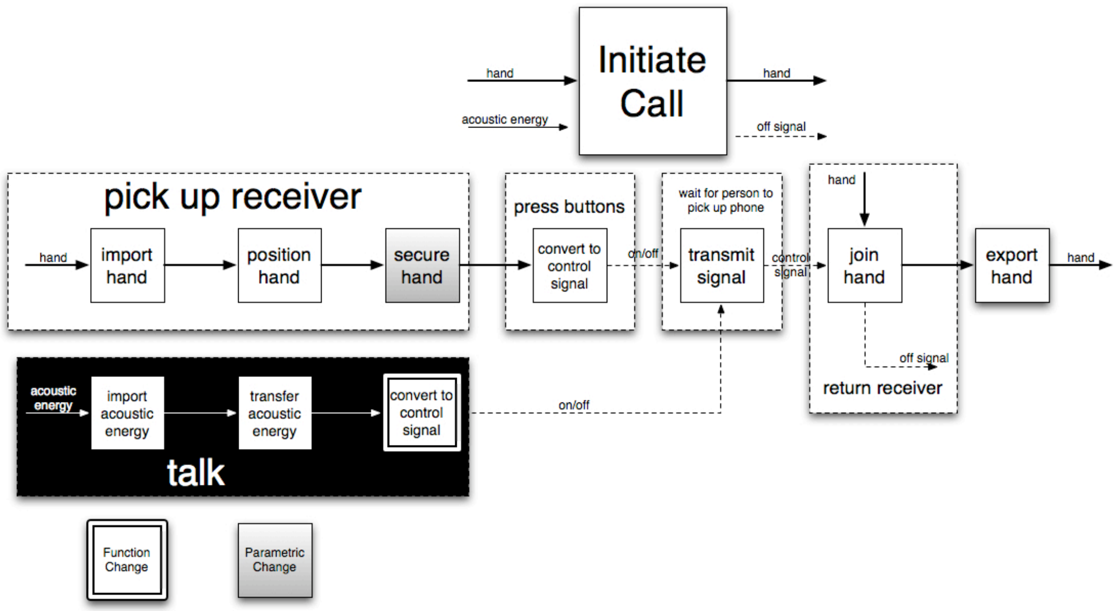


D330-Speaking

User Activity: *Talk*
ICF Activity: D330-speaking
ICF Body Function: B310-voice functions B320-articulation functions B330-fluency and rhythm of speech functions B340-alternative vocalization functions
ICF Body Structure: S310-structure of nose S320-structure of mouth S330-structure of pharynx S340-structure of larynx

d330	b310,b320,b330,b340	s310,s320,s330,s340

Voice Activated Phone:

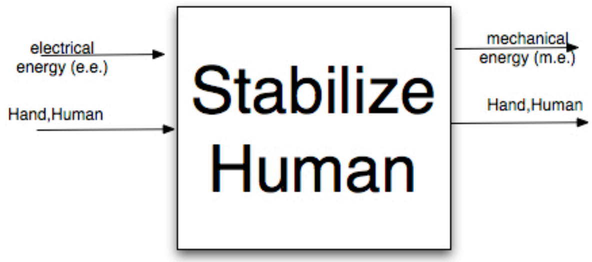


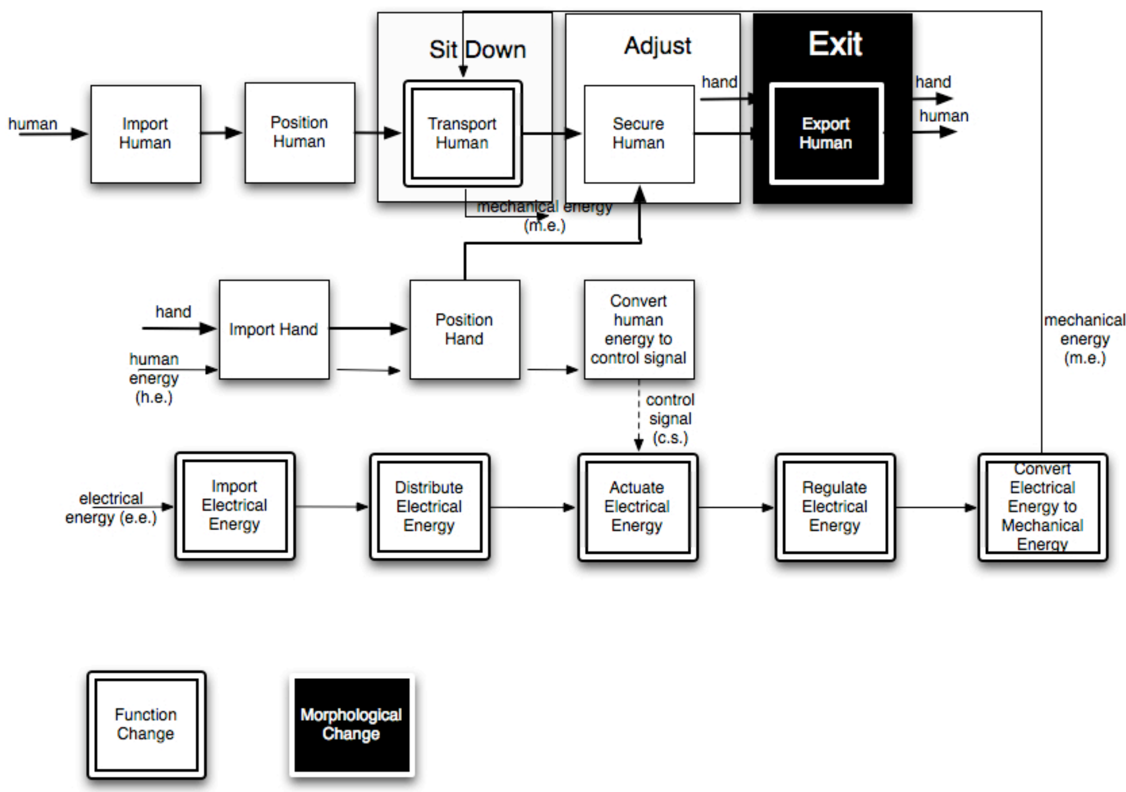
D4200-Transferring oneself while sitting

User Activity: *Exit*
ICF Activity: D4200-transferring oneself while sitting
ICF Body Function: B710-mobility of joint functions B715-stability of joint functions B720-mobility of bone functions   B730-muscle power functions B735-muscle tone functions B740-muscle endurance functions B760-control of voluntary movement functions B780-sensations related to muscles and movement functions
ICF Body Structure: S710-structure of head and neck region S720-structure of shoulder region S730-structure of upper extremity S740-structure of pelvic region S750-structure of lower extremity S760-structure of trunk

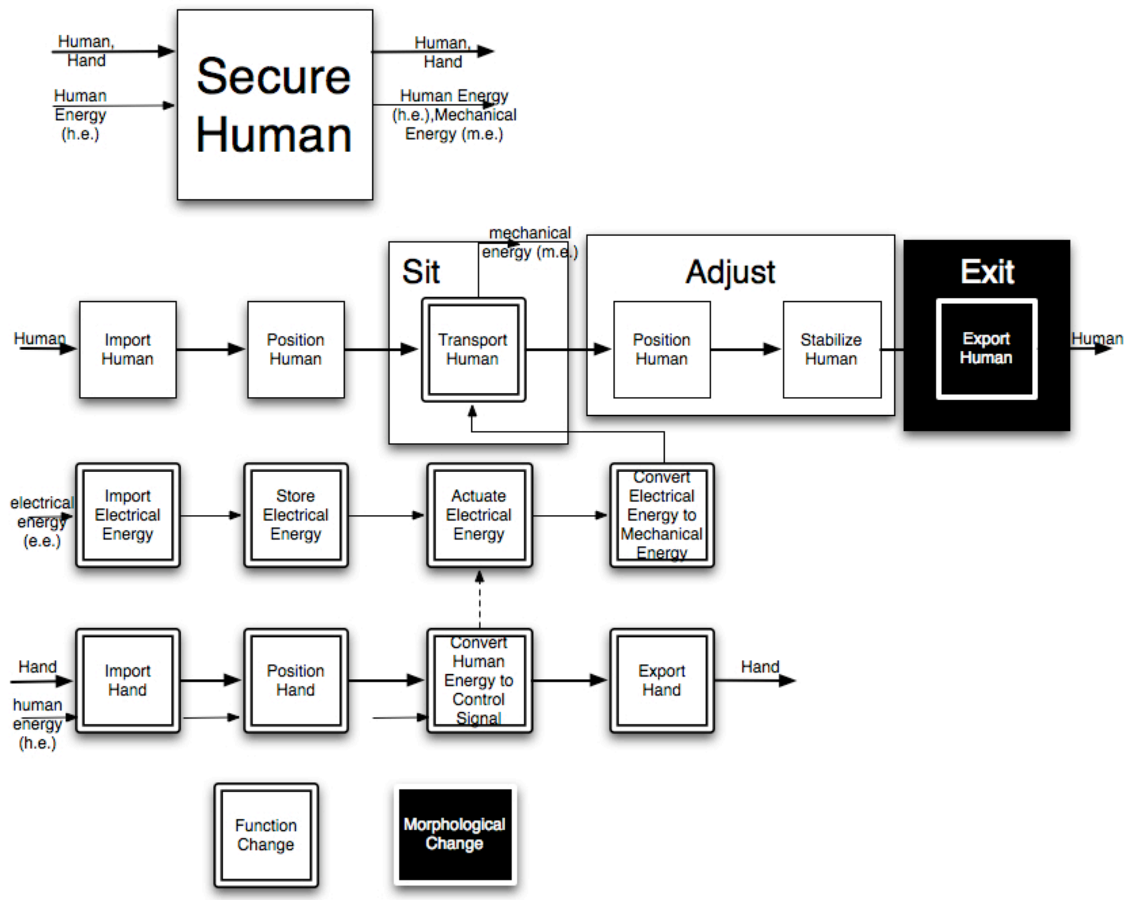
d4208	b710,b715,b720,b730,b735, b740,b760,b780	s710,s220,s730,s740,s750,s760

Toilet Seat:

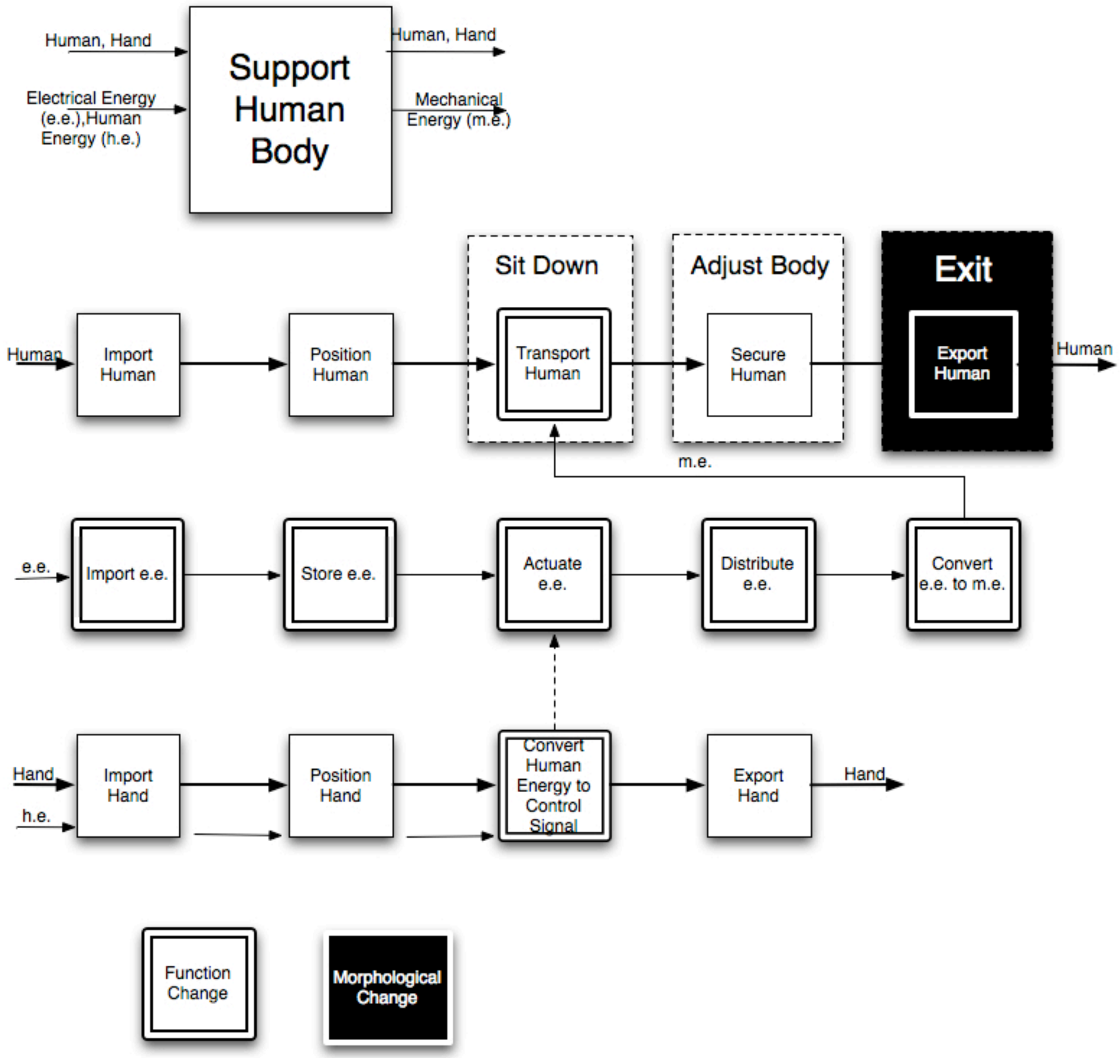

electrical
energy (e.e.)
Hand,Human
Stabilize
Human
mechanical
energy (m.e.)
Hand,Human


Sit Down
Adjust
Exit
human
Import
Human
Position
Human
Transport
Human
Secure
Human
hand
Export
Human
hand
human
mechanical energy
(m.e.)
hand
Import Hand
Position
Hand
Convert
human
energy to
control signal
human
energy
(h.e.)
control
signal
(c.s.)
mechanical
energy
(m.e.)
electrical
energy (e.e.)
Import
Electrical
Energy
Distribute
Electrical
Energy
Actuate
Electrical
Energy
Regulate
Electrical
Energy
Convert
Electrical
Energy to
Mechanical
Energy
Function
Change
Morphological
Change

Recliner:

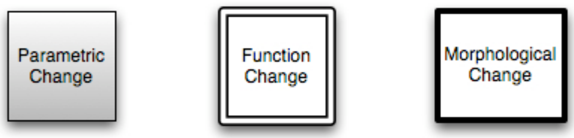

Human,
Hand
Human
Energy
(h.e.)
Secure
Human
Human,
Hand
Human Energy
(h.e.),Mechanical
Energy (m.e.)
mechanical
energy (m.e.)
Sit
Adjust
Exit
Human
Import
Human
Position
Human
Transport
Human
Position
Human
Stabilize
Human
Export
Human
Human
electrical
energy
(e.e.)
Import
Electrical
Energy
Store
Electrical
Energy
Actuate
Electrical
Energy
Convert
Electrical
Energy to
Mechanical
Energy
Hand
human
energy
(h.e.)
Import
Hand
Position
Hand
Convert
Human
Energy to
Control
Signal
Export
Hand
Hand
Function
Change
Morphological
Change

Chair Lift:

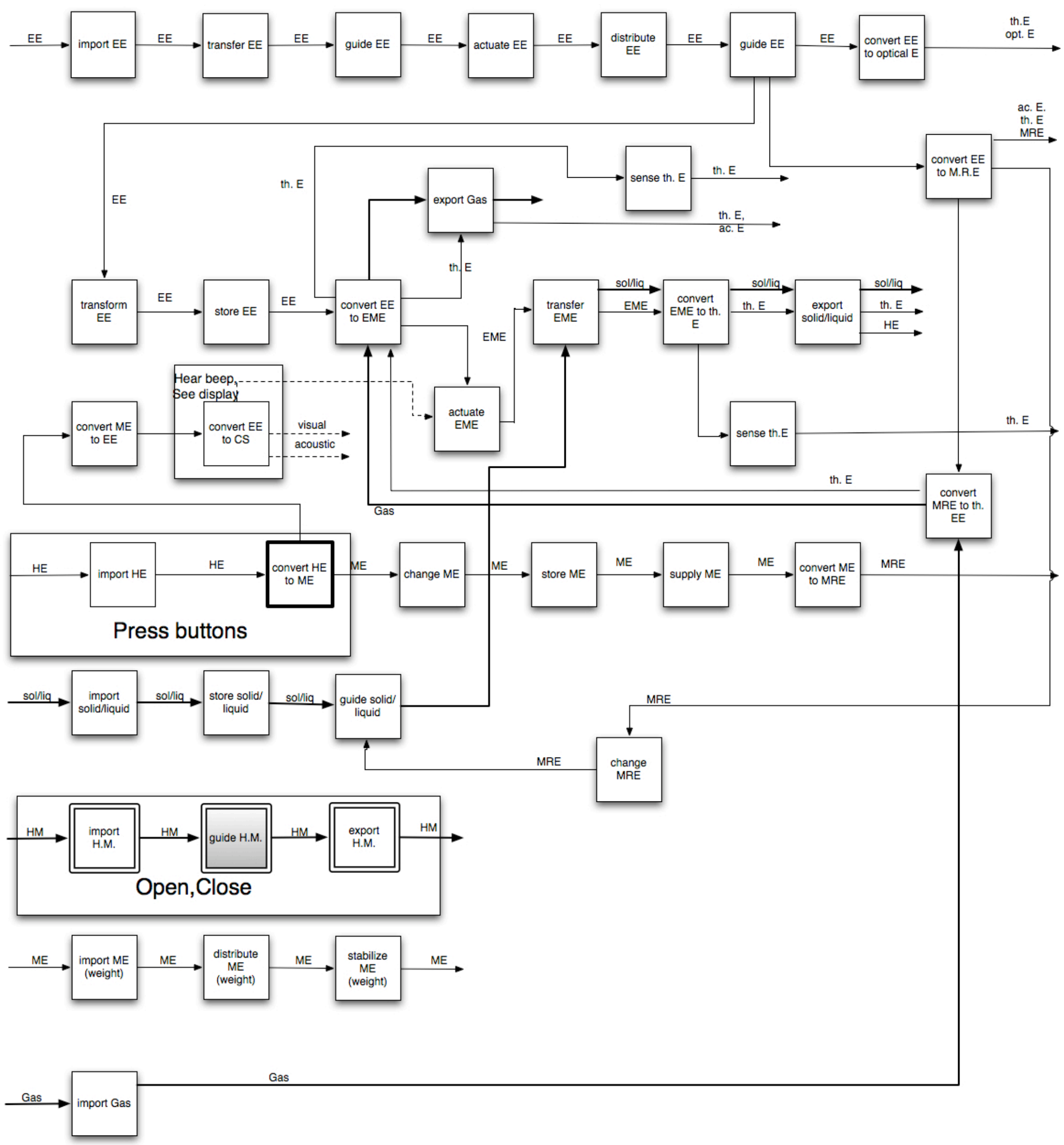

Human, Hand
Electrical Energy (e.e.),Human Energy (h.e.)
Support Human Body
Human, Hand
Mechanical Energy (m.e.)
Sit Down
Adjust Body
Exit
Human
Import Human
Position Human
Transport Human
Secure Human
Export Human
Human
m.e.
e.e.
Import e.e.
Store e.e.
Actuate e.e.
Distribute e.e.
Convert e.e. to m.e.
Hand
h.e.
Import Hand
Position Hand
Convert Human Energy to Control Signal
Export Hand
Hand
Function Change
Morphological Change

APPENDIX E

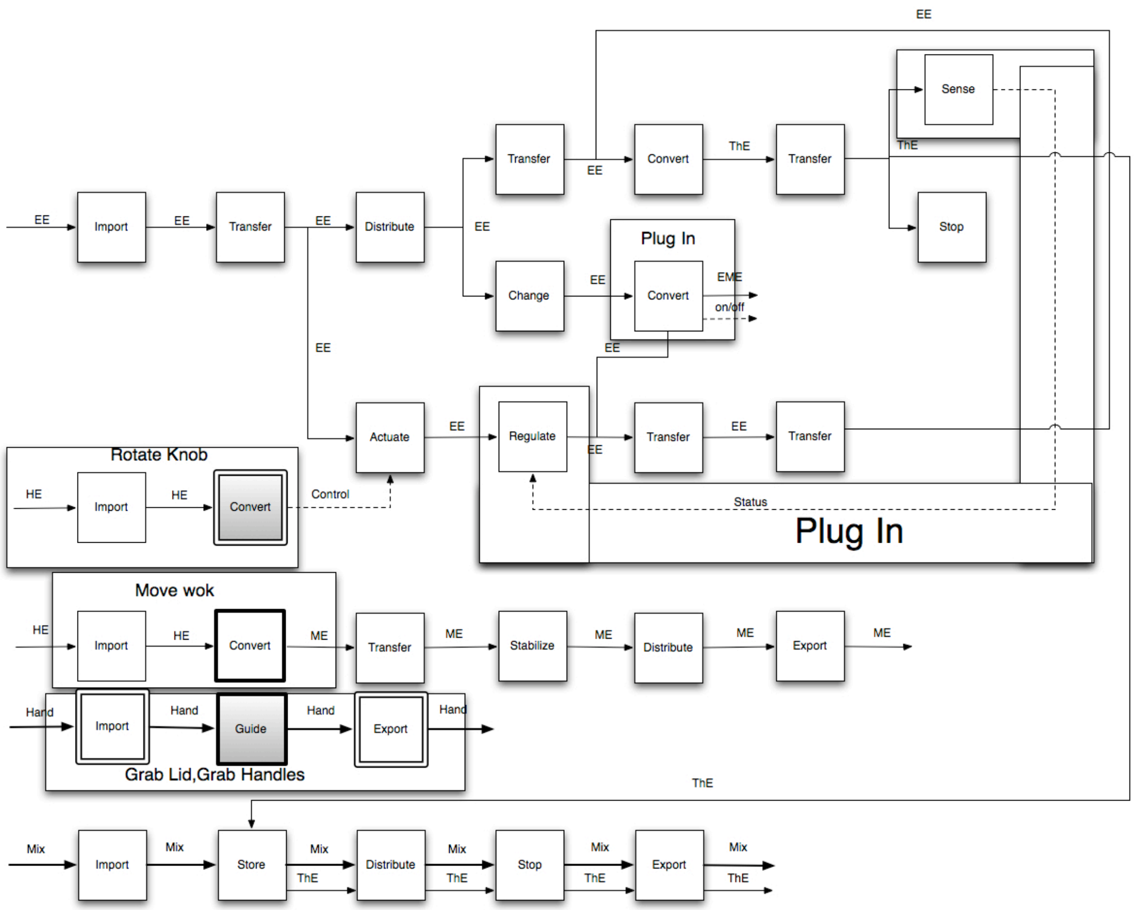
KITCHEN APPLIANCE PRODUCT FAMILY



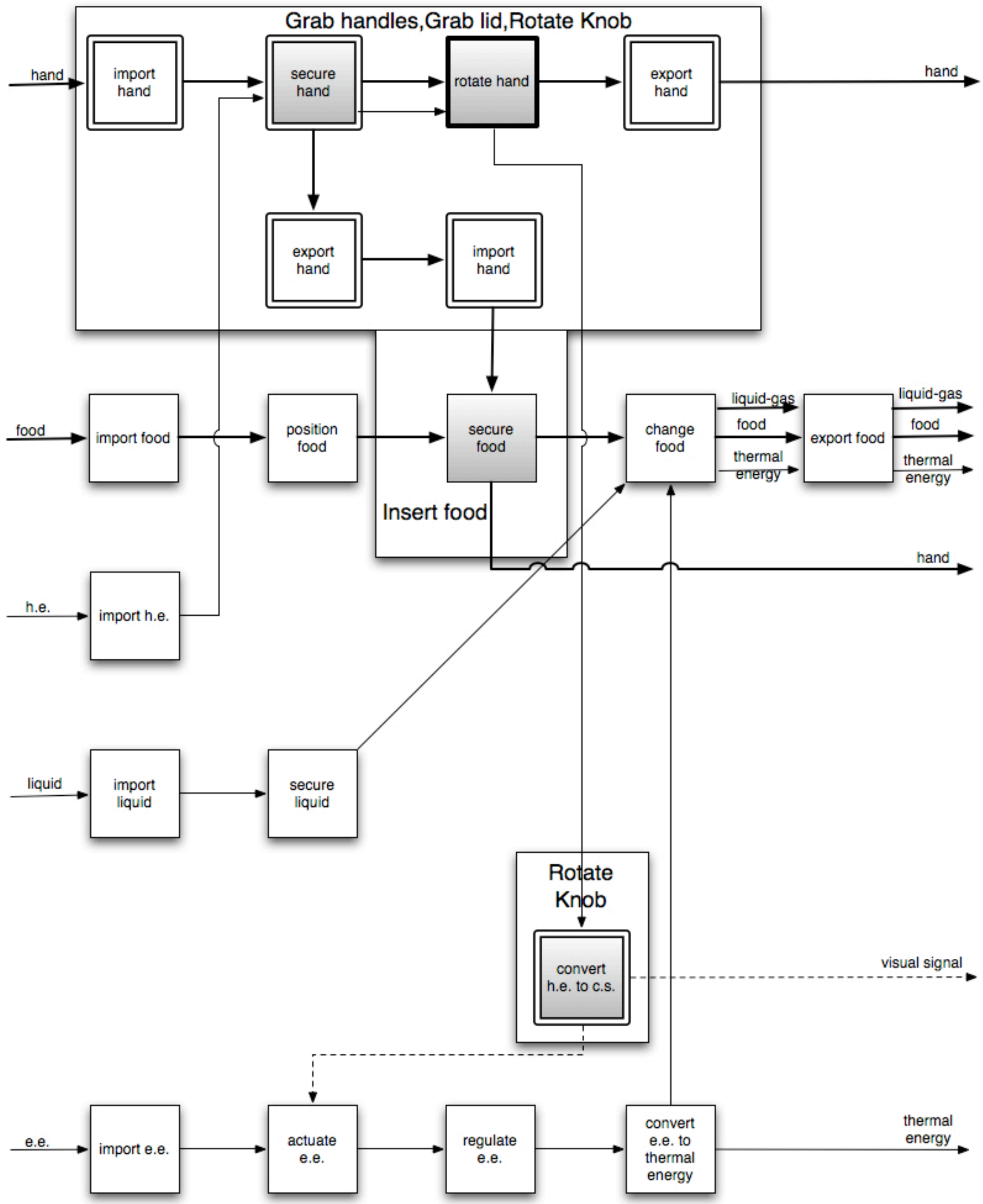
GE Microwave [56]



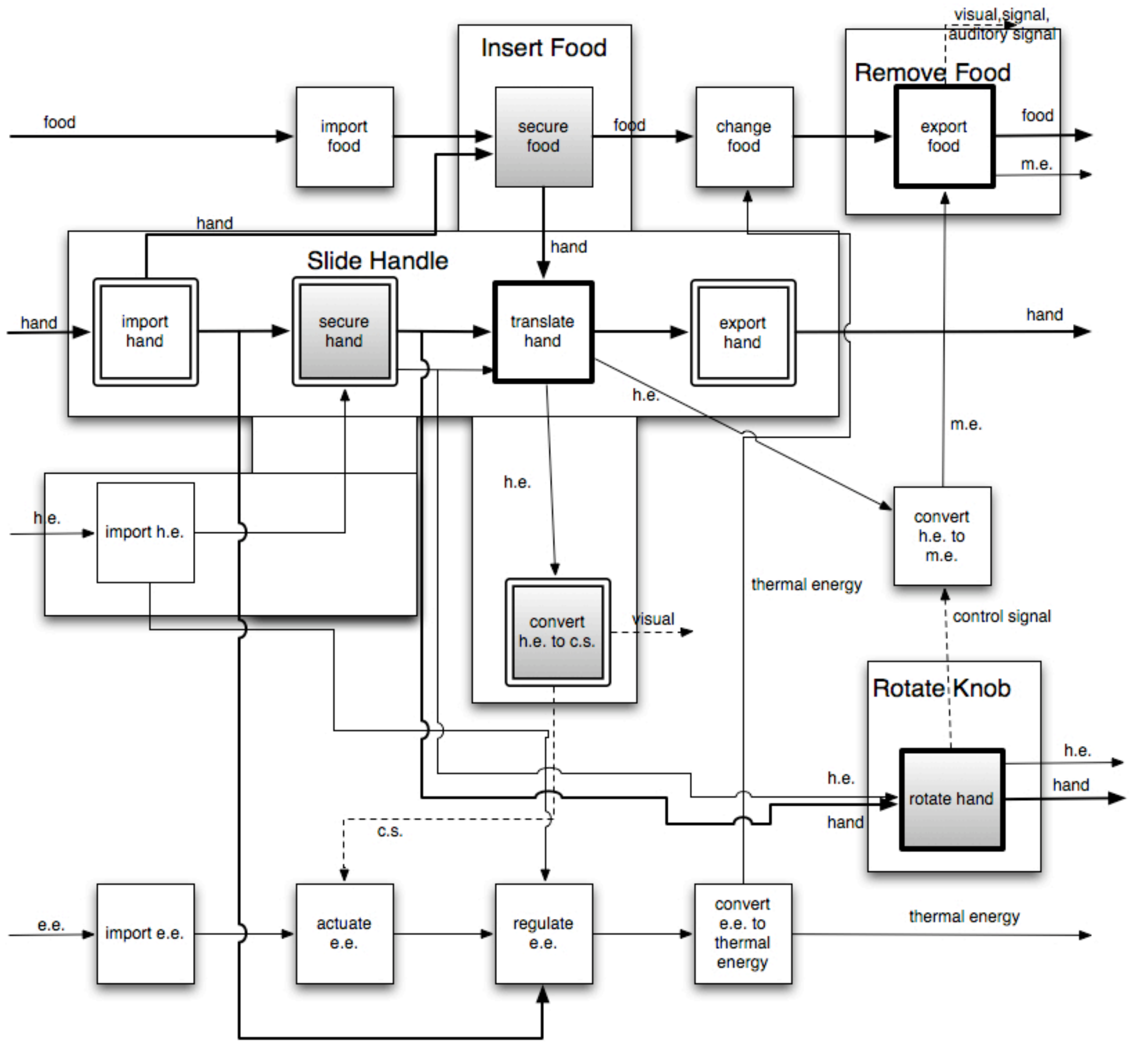
Electric Wok [57]



Slow Cooker


Grab handles,Grab lid,Rotate Knob
hand
import hand
secure hand
rotate hand
export hand
hand
export hand
import hand
food
import food
position food
secure food
Insert food
change food
liquid-gas
food
thermal energy
export food
liquid-gas
food
thermal energy
hand
h.e.
import h.e.
liquid
import liquid
secure liquid
Rotate Knob
convert h.e. to c.s.
visual signal
e.e.
import e.e.
actuate e.e.
regulate e.e.
convert e.e. to thermal energy
thermal energy

Toaster


Insert Food
Remove Food
Slide Handle
Rotate Knob
food
import food
secure food
food
change food
export food
food
m.e.
visual signal,
auditory signal
hand
hand
import hand
secure hand
translate hand
export hand
hand
h.e.
h.e.
m.e.
import h.e.
convert h.e. to m.e.
convert h.e. to c.s.
visual
thermal energy
control signal
h.e.
hand
rotate hand
h.e.
hand
c.s.
e.e.
import e.e.
actuate e.e.
regulate e.e.
convert e.e. to thermal energy
thermal energy

VITA

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