32nd Annual INCOSE international symposium

hybrid event

Detroit, MI, USA
June 25 - 30, 2022

James Hummell, MBSE Solutions

Functional Architectures in SysML

Bio

- James Hummell is an expert trainer for SysML, UML, and UPDM/UAF, currently working as chief consultant for MBSE Solutions. He is an expert in software and systems engineering, specializing in modeling and simulation analysis using UML and SysML.
- James has extensive experience in embedded systems for safety critical systems (Do178b Level A), configuration management (CM), the software development life cycle (SDLC), and process engineering development. He has been developing software and systems in model-based design engineering (UML and SysML) for over 20 years.
- He is a member of the RTCA SC-205 subgroup developing Do-178C model-based development and verification supplement, and has worked with the Object Management Group (OMG) and the International Council on Systems Engineering (INCOSE) on many specifications and working groups.

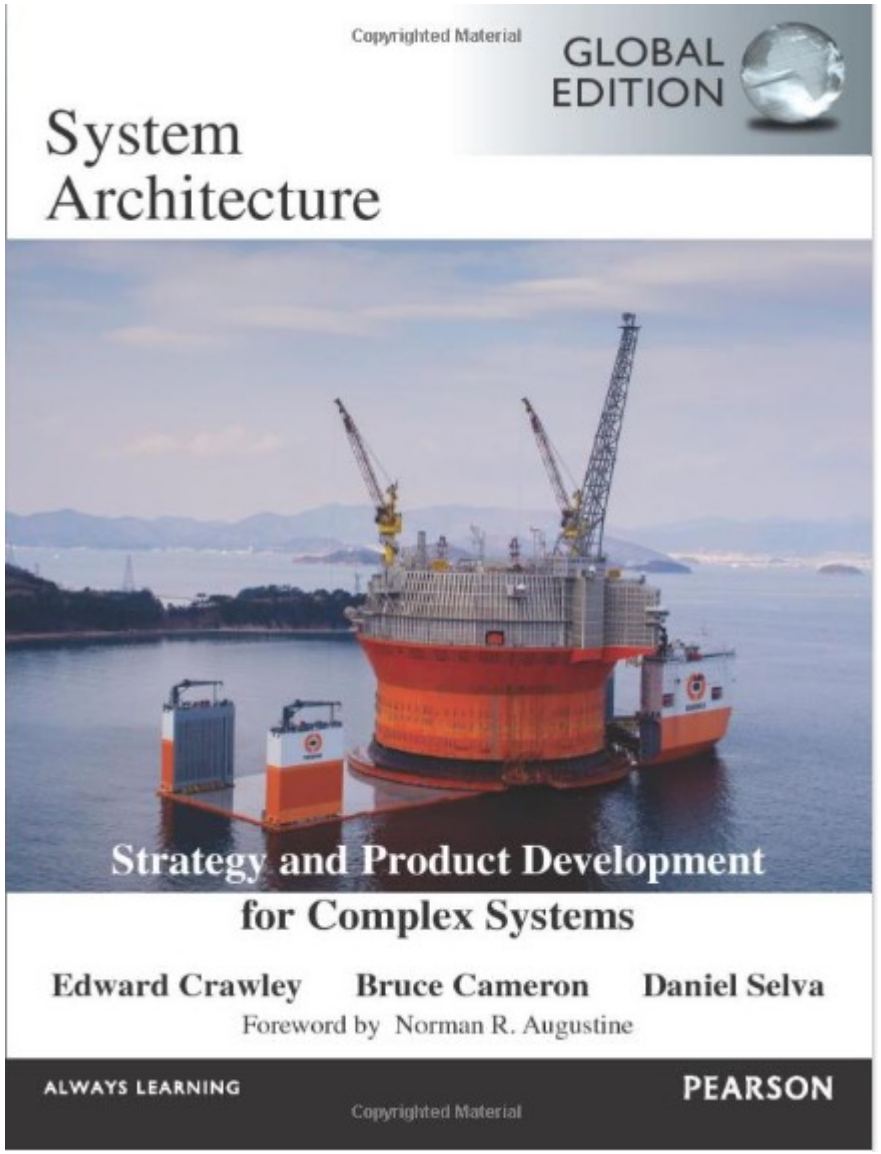
http://MBSE.Solutions
jhummell@MBSE.Solutions
In/jameshummell
T: 480-463-4359
M: 480-521-2125

What you will learn

- Why?
  - Functional Thinking
- What is Functional Architectures
- How to implement in SysML
- How to model Functional Architectures
- What can you get from the model?

Resources

- MIT xPRO
- Carnegie Mellon
- Purdue
- Cal Tech
- …

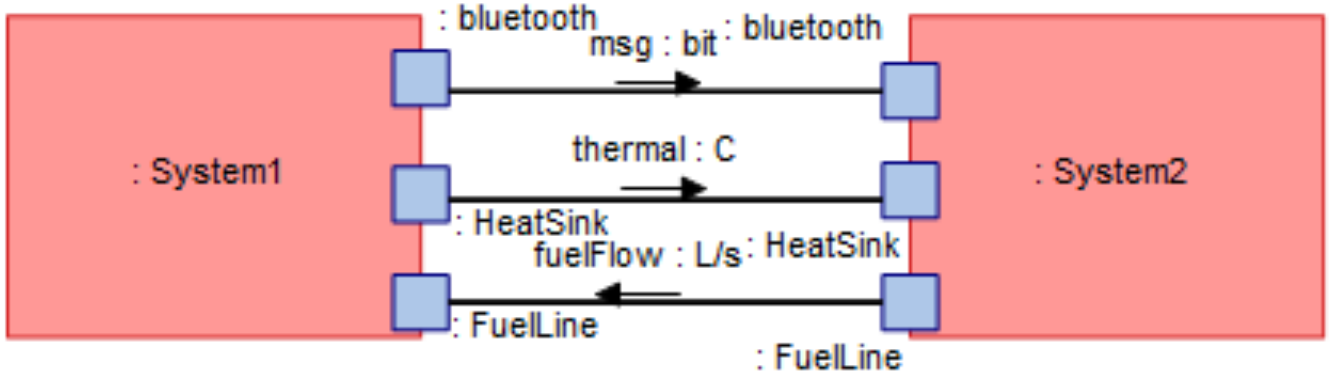


Types of System Functions

- Architecture Systems
  - Physical Systems
- Control Systems
  - Software Controlled System

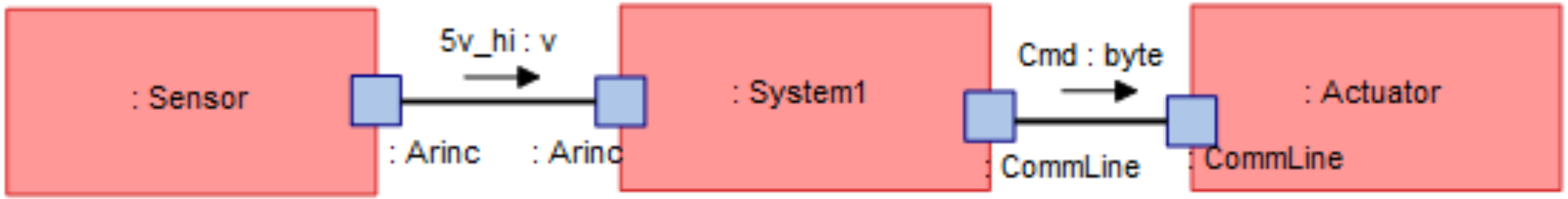
Architecture Systems

- Physical components and interactions
  - Energy, Heat transfer, Voltage …
  - Force (Newton) between components
  - Oil flow, Water flow, Fuel flow



Control Systems

- Sensor inputs/outputs
  - Actuators
  - Signal values
- Messaging (Communication)
- Control logic



Function Rules for Modeling

- ✓ Define Functions Independent of Form
- ✓ See Functional Interactions (Functional Architecture)
- ✓ Functional Hiearchy
  - See how Functions break down to Sub Functionality
- ✓ See how Functions related to Form/Structure

Ask the model:

- ❑ If part of the system breaks what Functionality is not going to be performed?
- ❑ If Function changes, what system do we need to review?
- ❑ Can I get a high-level view of Function inputs and outputs?

Functional Modeling in SysML

How to Model in SysML?

SysML is Extensible

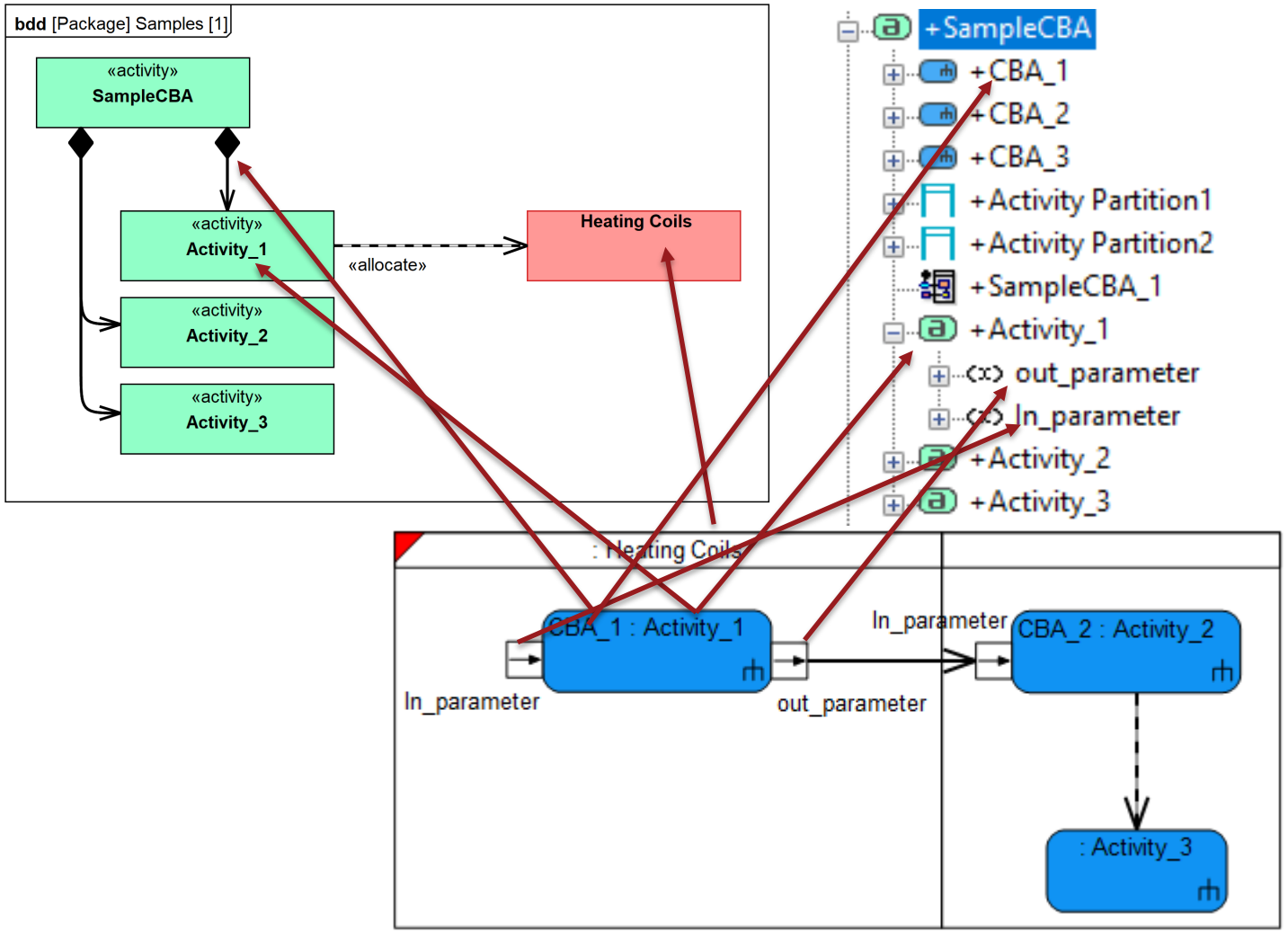
- Extensible means you can extend the language to have your own meaning of a modeling element
  - Stereotype <Function>
- Explicitly make an understanding that you mean something else other than the standard language
- Enabling you to run queries against the model based on the extended …Functionality… you added to your modeling environment.
  - Queries, what queries?
    - Report that all Functions are allocated to a system element, to know that you have achieved all the functionality you set out to do.
    - Report to show allocation matrix between <Function> and <Block>

What are we going to extend?

- Papers on this topic:
  - Activities (Friedenthal, Weilkiens)
    - Activities ⇔ Functions ⇔ FFBD
  - Operations (Friedenthal, Vararcik)
    - UML == Operations Generate to Functions in Coding languages… (Java, etc.)
  - Blocks (Weilkiens, Hummell)
    - Have Input and Output,…

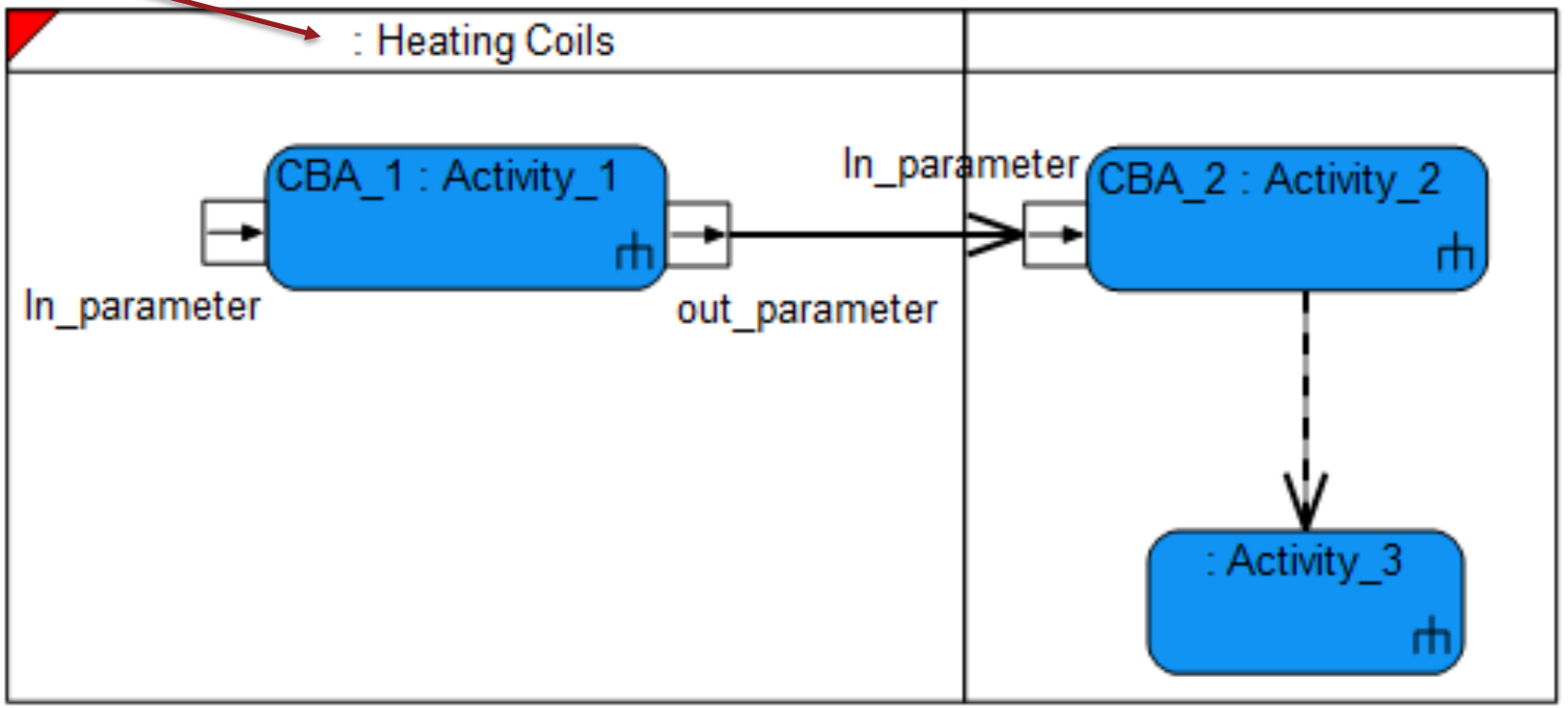
How do Activities behave in Modeling

- Block Definition Diagrams (BDD)
  - Hiearchy
  - Allocation to <Block>
- Activity Diagram to show
  - Inputs/Outputs
  - Interactions between Functions
  - Allocation using swim lanes
    - **Issues with Language!!!**



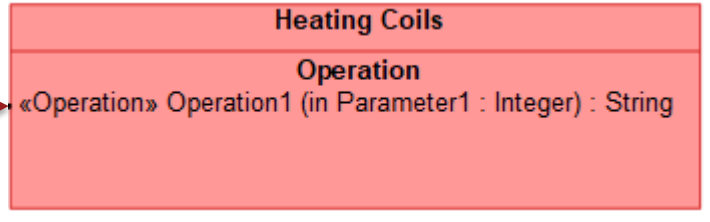
Activity Diagram Swim Lanes typed by

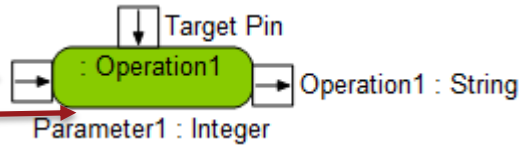
- Block
- Part
- Port
- Actor
- ItemFlow

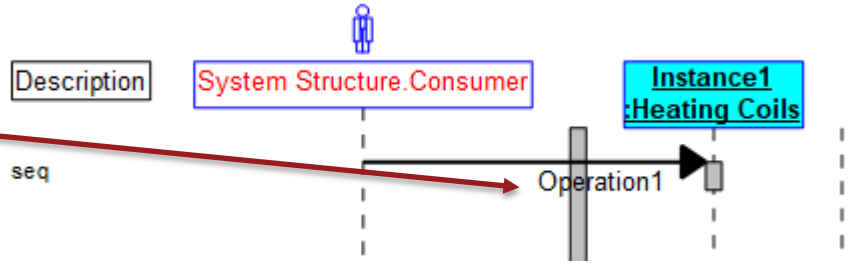


How do Operations behave in modeling

- Operations belong to <Block>
  - Allocation is implicit
  - Can show inputs and outputs through parameters
  - Can show interactions on an Activity Diagram using Call Operation Actions
  - Can show Order of interaction on a Sequence Diagram
  - Can have Activity Diagrams and Sequence Diagrams
  - Can not show hiearchy

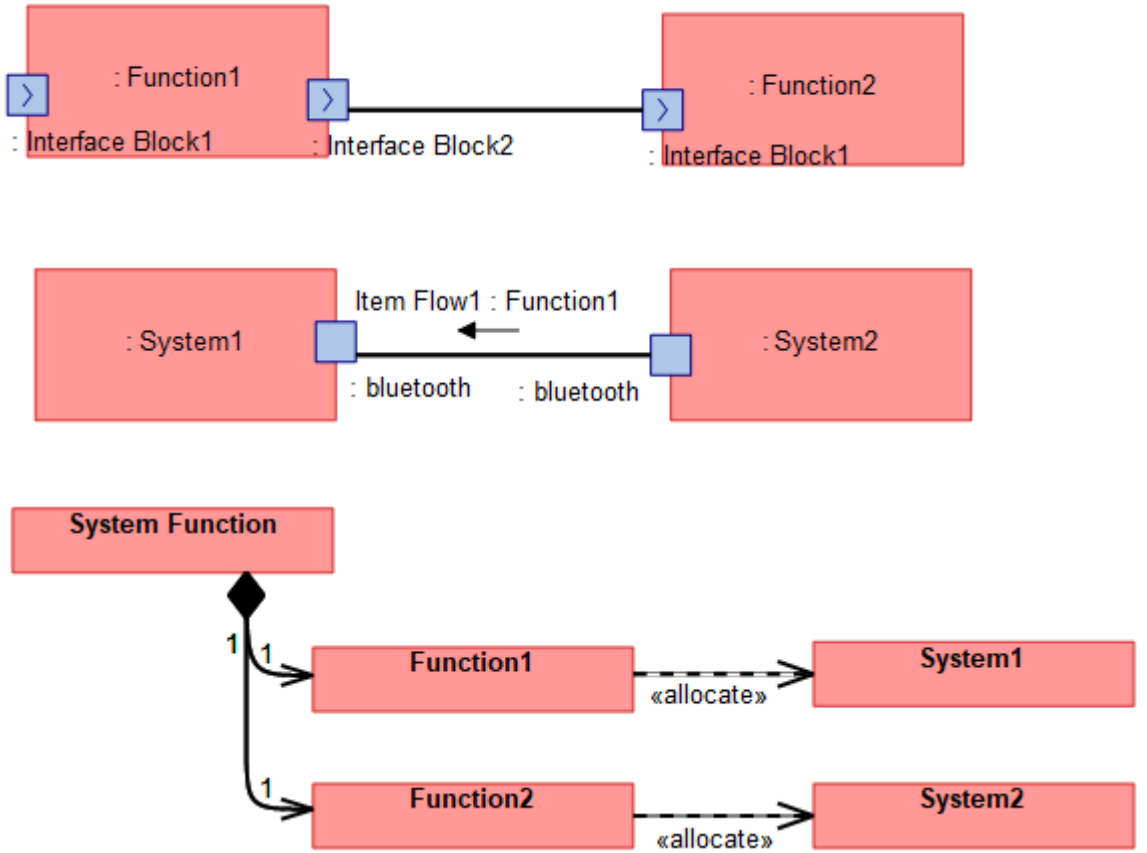






How do Blocks behave in modeling

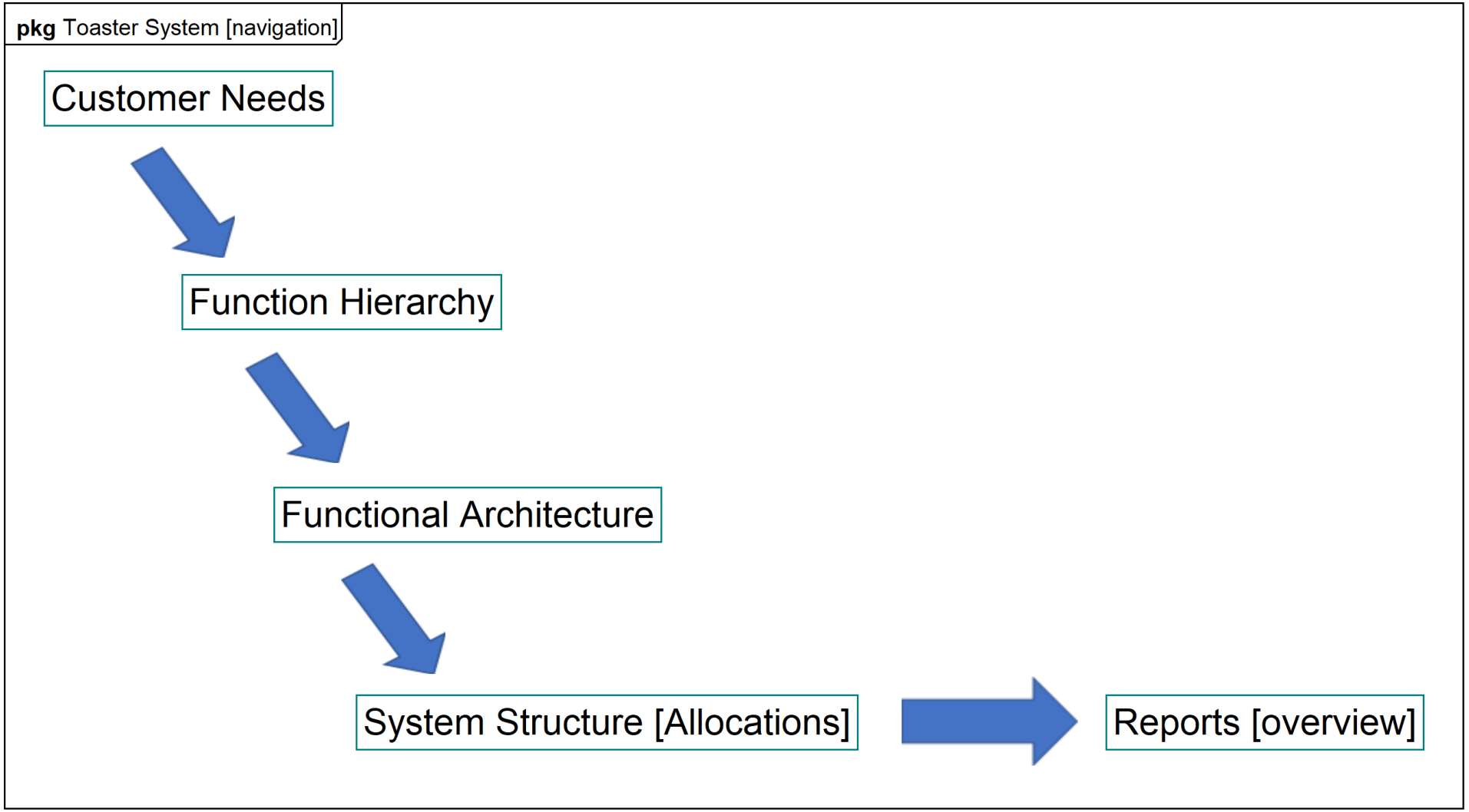
- Blocks have ports to show inputs and outputs
- Blocks can type other modeling elements
  - <itemFlows>
- BDD shows hiearchy
- BDD shows Allocation
- Can have Parametric Sequence or State Behavior Diagrams to define details of the function?!?!



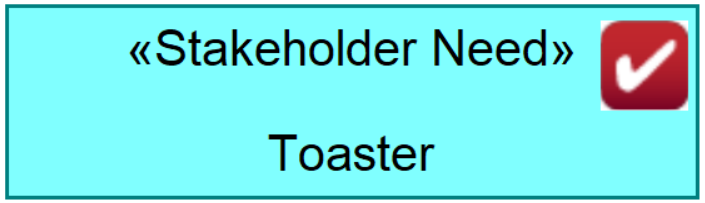
How to Model Functional Architectures in SysML

Functional Architectures in SysmL

Function Process

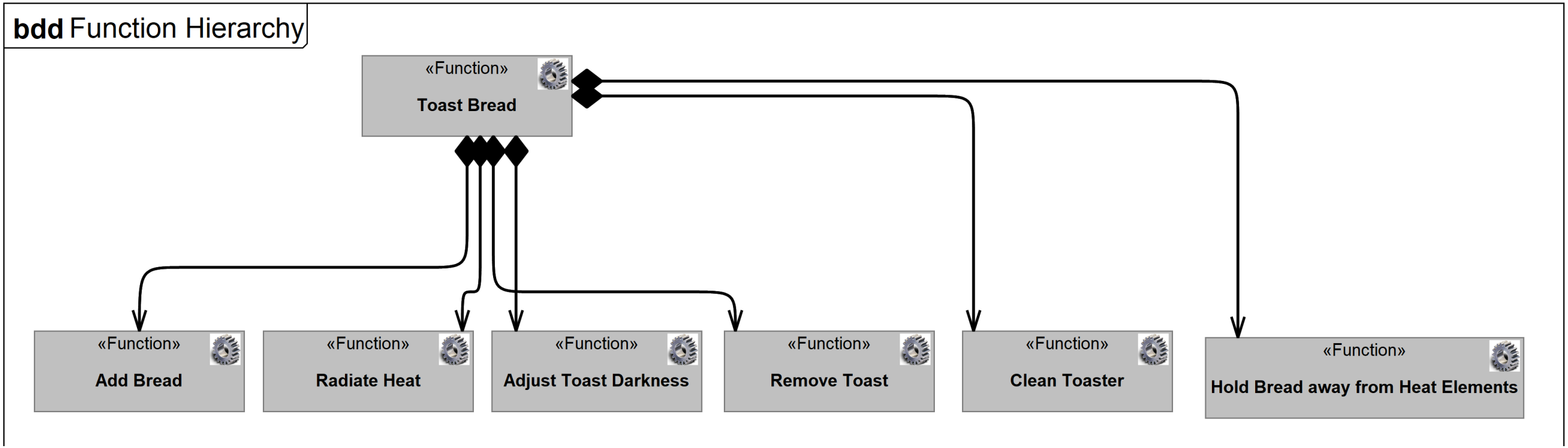


req Customer Needs

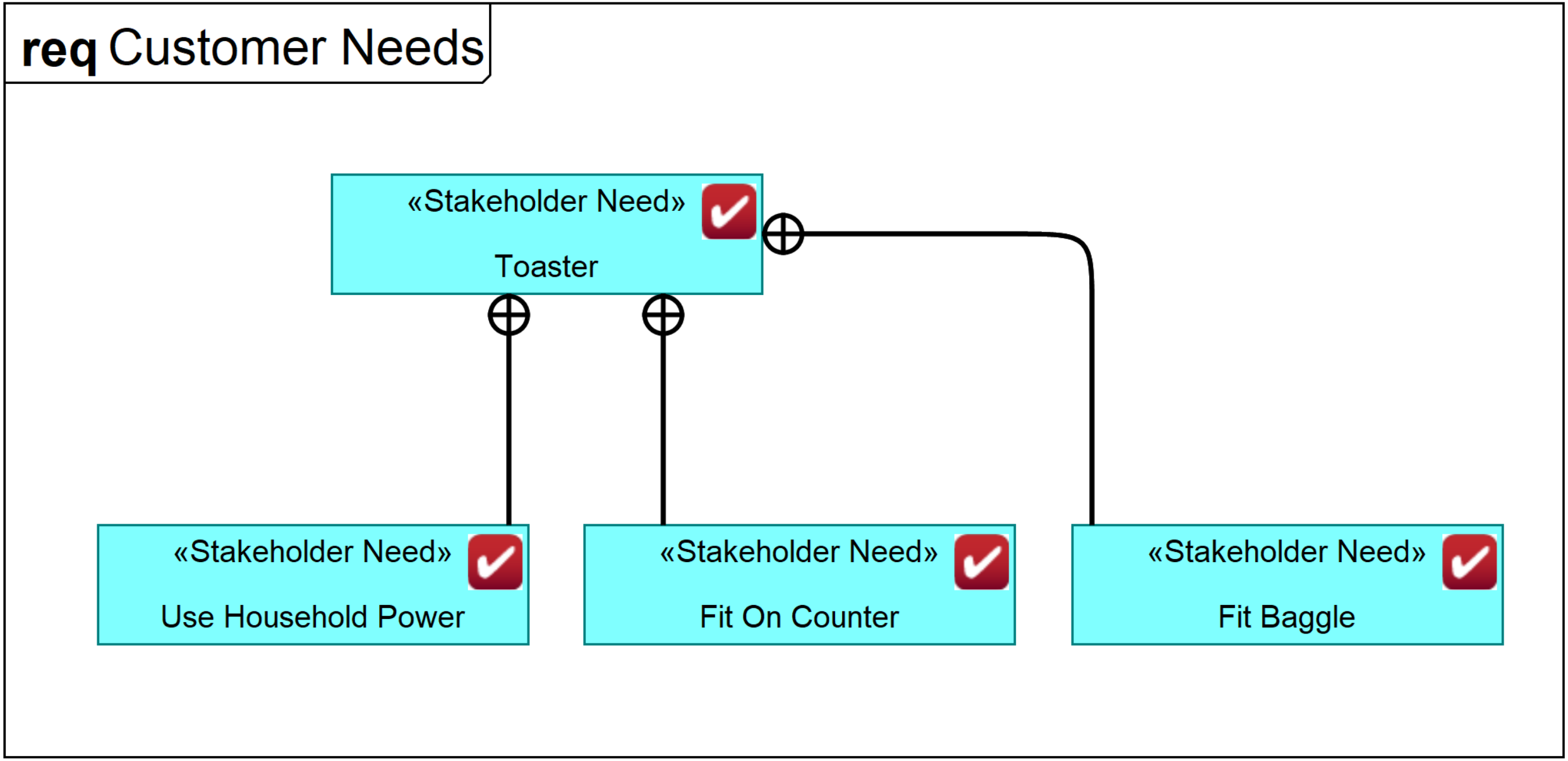


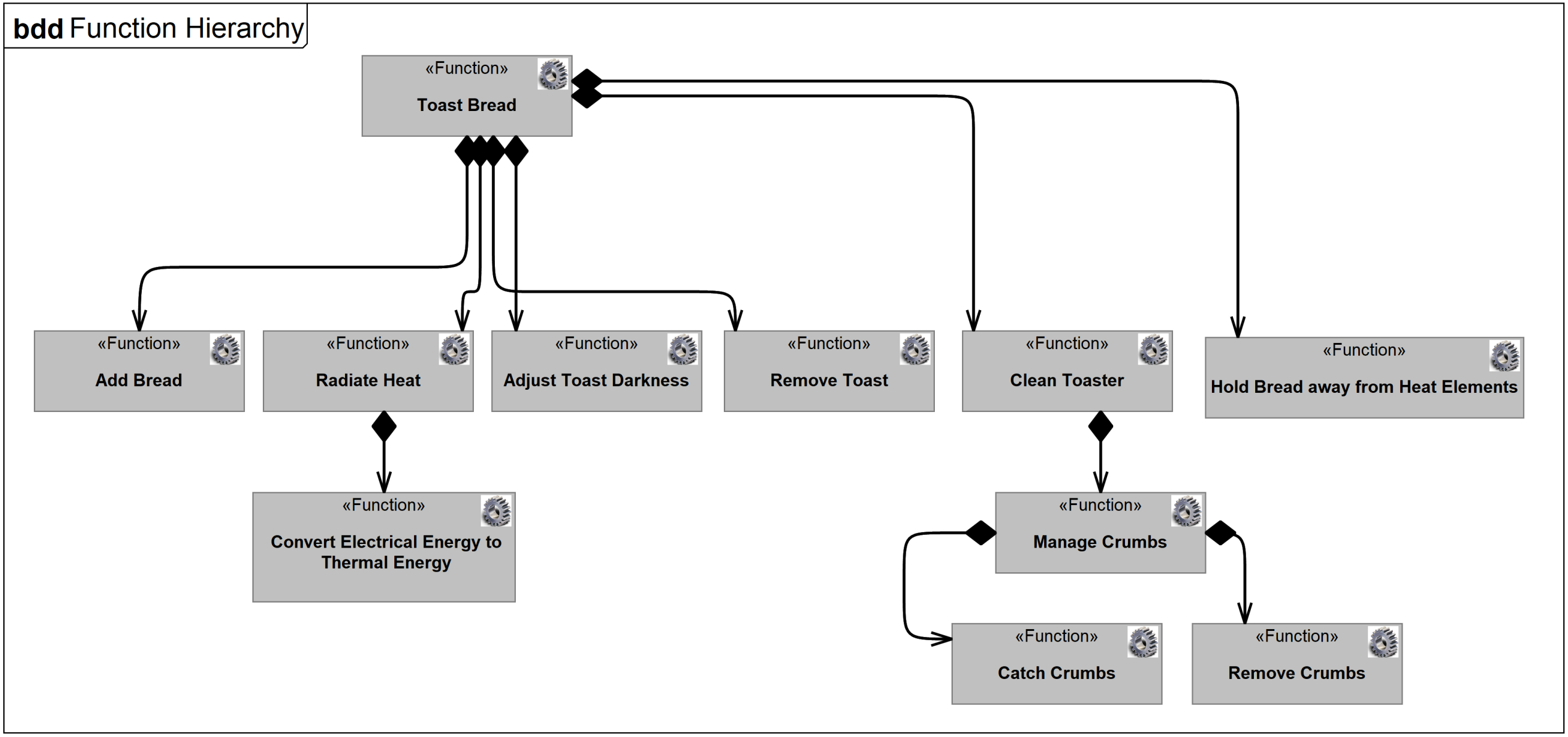
Functional Hiearchy (BDD)

- Block Definition Diagrams (BDD) are used to show Functional Hiearchy



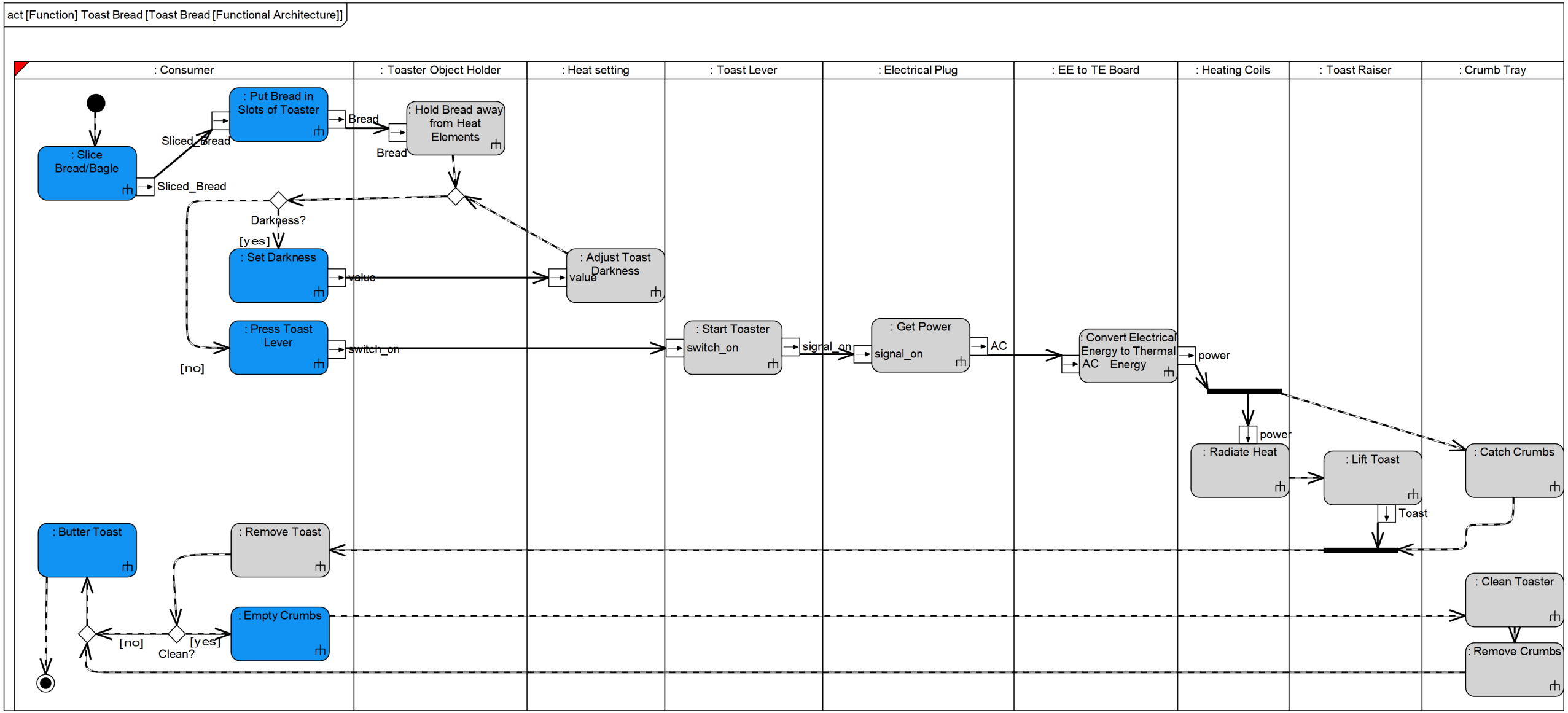
Form Follows Function


req Customer Needs
«Stakeholder Need»
Toaster
«Stakeholder Need»
Use Household Power
«Stakeholder Need»
Fit On Counter
«Stakeholder Need»
Fit Baggle


bdd Function Hierarchy
«Function»
Toast Bread
«Function»
Add Bread
«Function»
Radiate Heat
«Function»
Adjust Toast Darkness
«Function»
Remove Toast
«Function»
Clean Toaster
«Function»
Hold Bread away from Heat Elements
«Function»
Convert Electrical Energy to Thermal Energy
«Function»
Manage Crumbs
«Function»
Catch Crumbs
«Function»
Remove Crumbs

Functional Architecture (AD)

- Activity Diagrams are used to show the Architecture between Functions

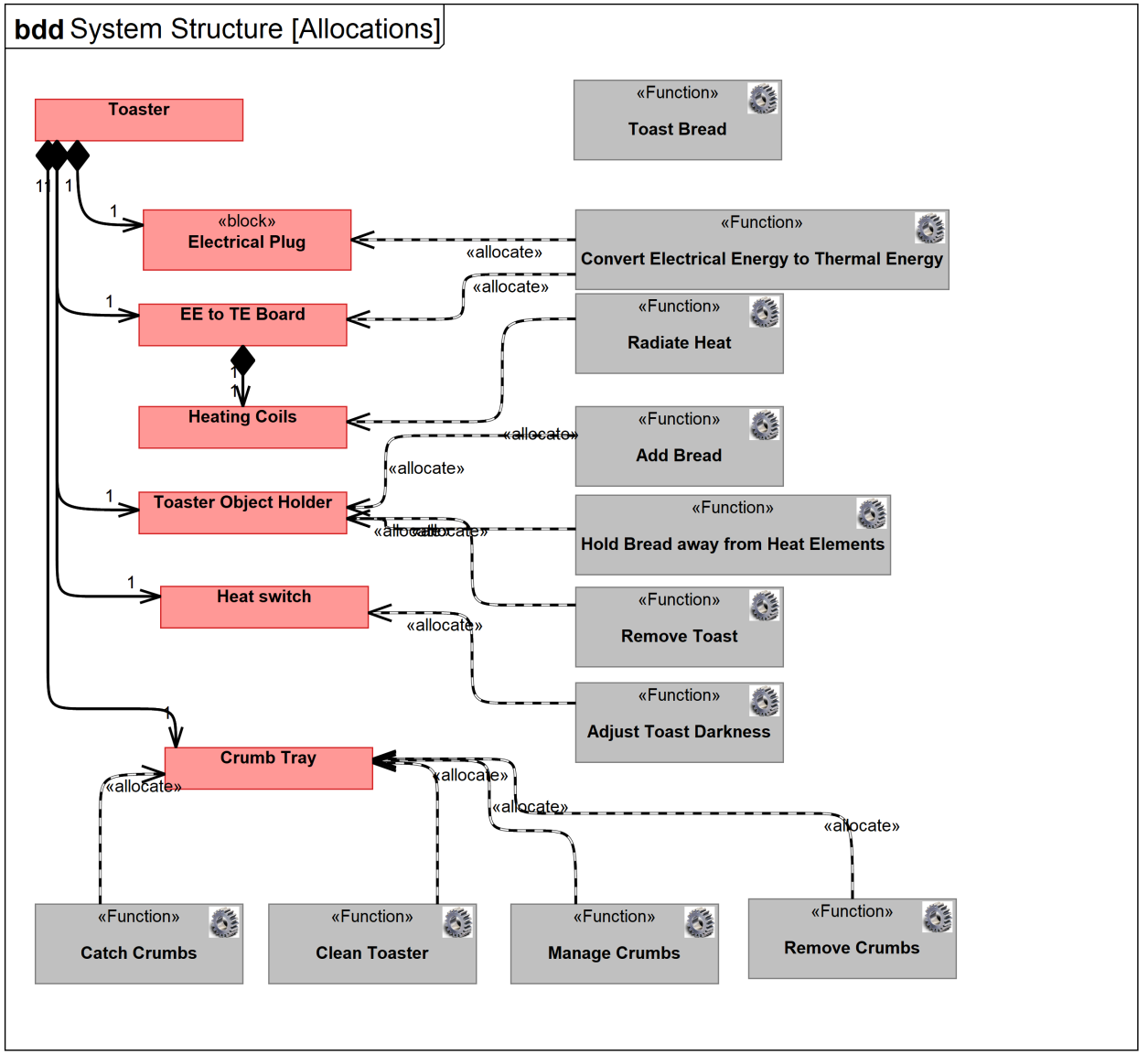


Allocation from Function to Form

- BDD
- Allocation Matrix
- Activity Diagrams

Allocation (BDD)

- Allocation is shown using link



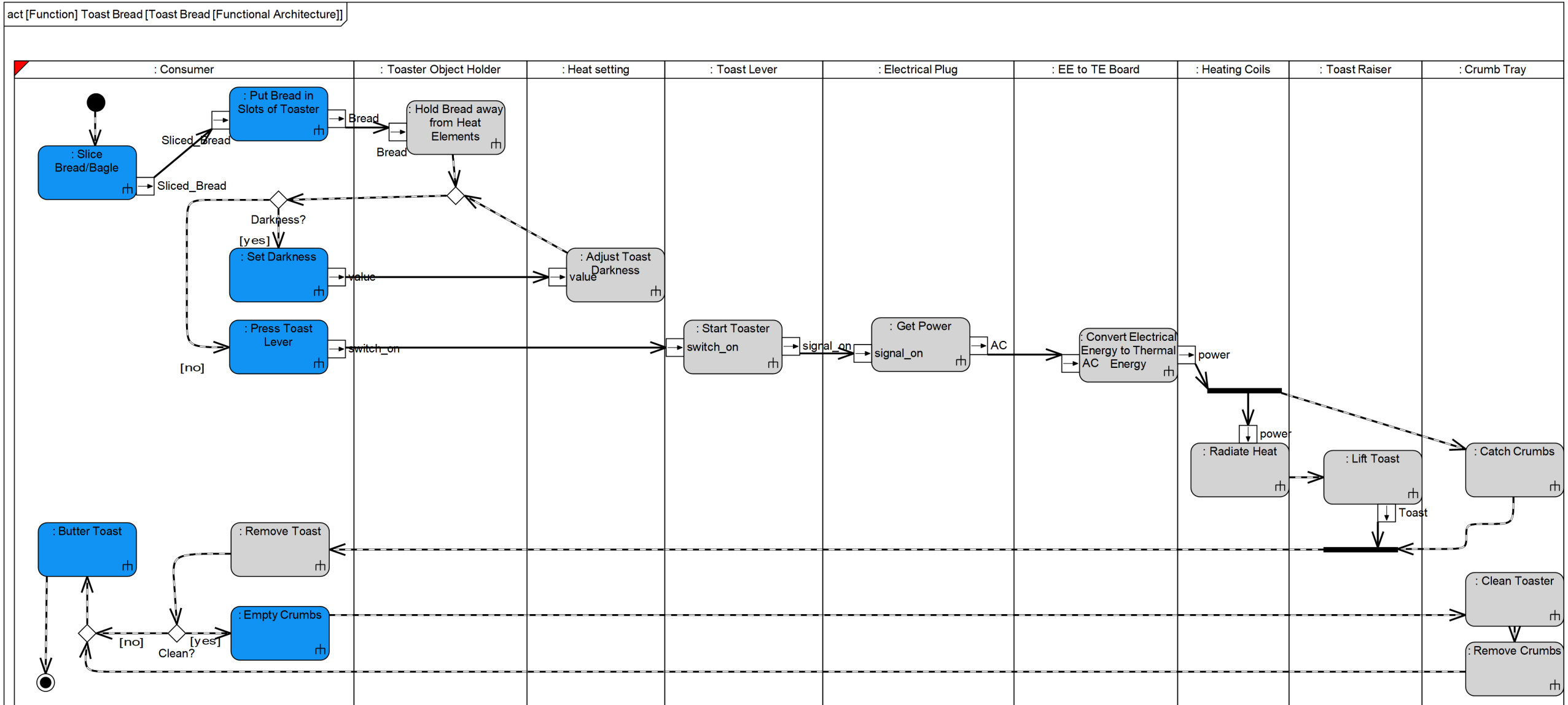
Allocation Matrix

- Can be used to set and view allocations

	«Activity» Add Bread ::Functions	«Activity» Adjust Toast Darkness ::Functions	«Activity» Catch Crumbs ::Functions	«Activity» Clean Toaster ::Functions	«Activity» Convert Electrical Energy to Thermal Energy ::Functions	«Activity» Hold Bread away from Heat Elements ::Functions	«Activity» Manage Crumbs ::Functions	«Activity» Radiate Heat ::Functions	«Activity» Remove Crumbs ::Functions	«Activity» Remove Toast ::Functions
«Actor» Consumer ::System Structure										●
«Block» Crumb Tray ::System Structure			●	●			●		●	
«Block» EE to TE Board ::System Structure					●					
«Block» Electrical Plug ::System Structure					●					
«Block» Heat switch ::System Structure		●								
«Block» Heating Coils ::System Structure								●		
«Block» Toaster Object Holder ::System Structure	●					●				●

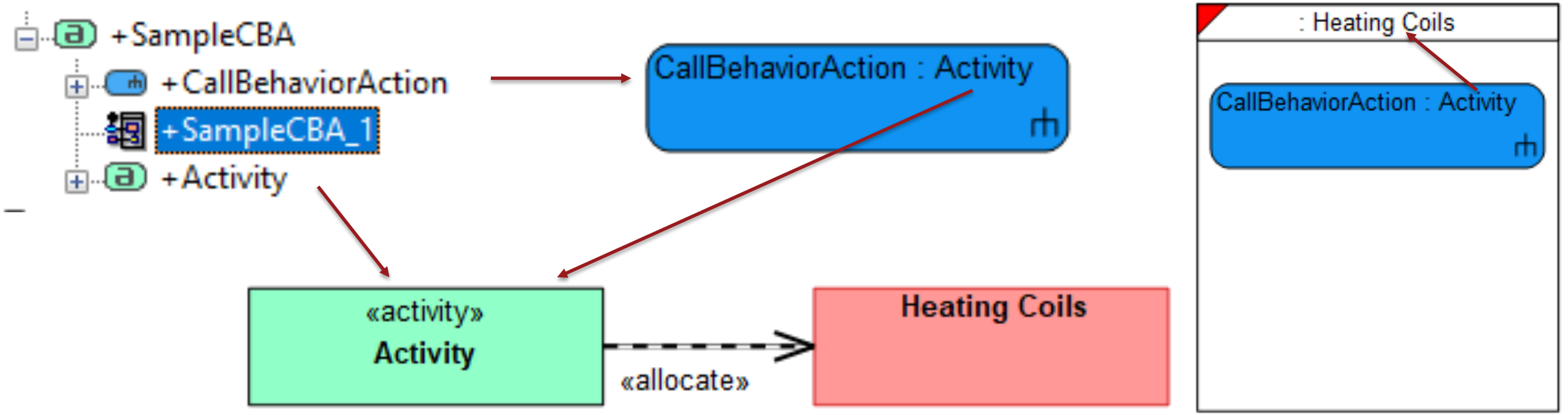
Allocation Activity Diagram

- Swim Lane used to do Allocation Function to Form
  - Modification needs to happen



Issues with Activities & Call Behavior Actions

- Call Behavior Action
  - Call to the Behavior of the Activity



Viewpoint Generation from models

Outcomes

pkg Reports [overview]

Function Hierarchy

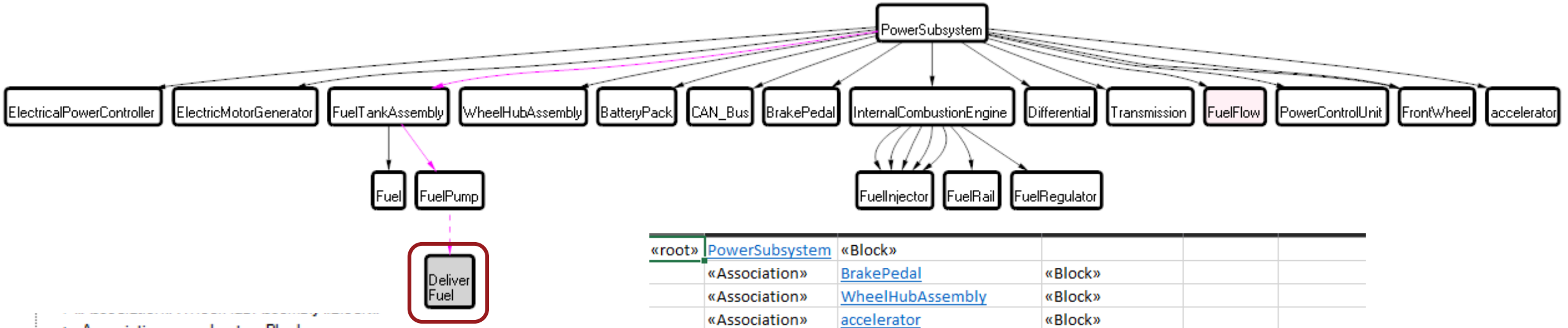
Functional Architecture

- n-square
- Toaster [Allocation Matrix]

System Structure [Allocations]

- Impact Analysis
- What Function isn't performed when Interface breaks

Impact Analysis

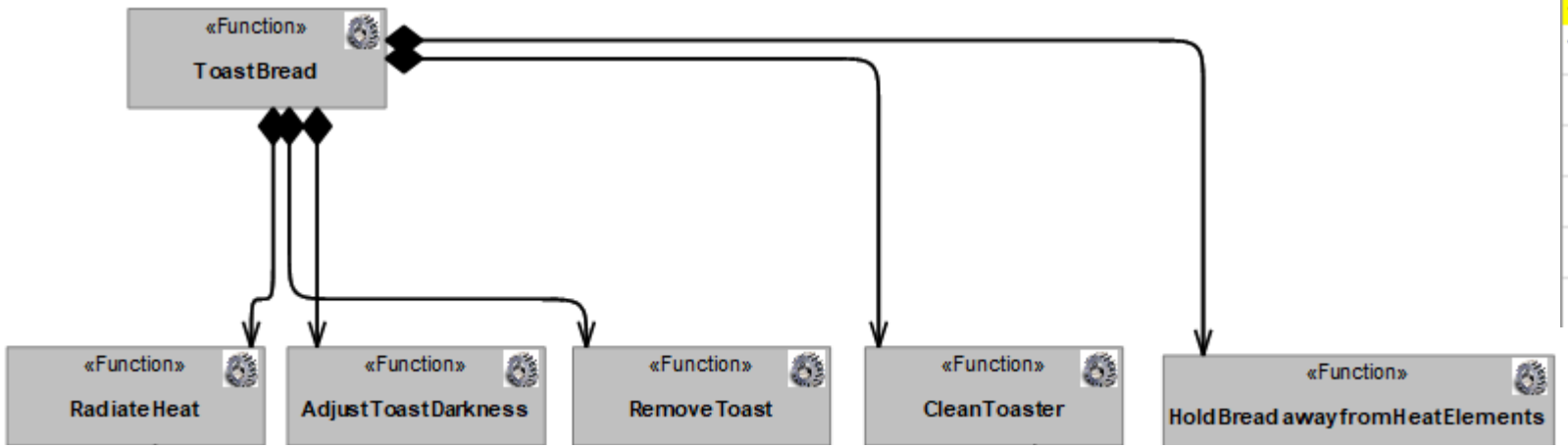


- -><Association>accelerator<Block>
- -><Association>BatteryPack<Block>
- -><Association>FuelTankAssembly<Block>
  - -><Association>Fuel<Block>
  - -><Association>FuelPump<Block>
    - -><Allocate>Deliver Fuel<Function>
- -><Association>PowerControlUnit<Block>
- -><Association>ElectricalPowerController<Block>
- -><Association>Differential<Block>
- -><Association>Transmission<Block>
- -><Association>InternalCombustionEngine<Block>
  - -><Association>FuelRail<Block>
  - -><Association>FuelInjector<Block>

«root»	PowerSubsystem	«Block»			
	«Association»	BrakePedal	«Block»		
	«Association»	WheelHubAssembly	«Block»		
	«Association»	accelerator	«Block»		
	«Association»	BatteryPack	«Block»		
	«Association»	FuelTankAssembly	«Block»		
		«Association»	Fuel	«Block»	
		«Association»	FuelPump	«Block»	
			«Allocate»	Deliver Fuel	«Function»
	«Association»	PowerControlUnit	«Block»		
	«Association»	ElectricalPowerController	«Block»		
	«Association»	Differential	«Block»		
	«Association»	Transmission	«Block»		
	«Association»	InternalCombustionEngine	«Block»		
		«Association»	FuelRail	«Block»	
		«Association»	FuelInjector	«Block»	
		«Association»	FuelInjector	«Block»	
		«Association»	FuelInjector	«Block»	

Functional Summary

- What dose the systems do?
  - Start from top level function and ask how deep?



System Functionality	
Toast Bread	
	Radiate Heat
	Adjust Toaster Darkness
	Remove Toast
	Clean Toaster
	Hold Bread away from Heat Elements

Impact of System Issues

- Ask what function isn't performed if system/sub system/interface breaks
- Heating Coils break
  - Generates Radiate Heat Functionality not performed

N-Squared chart to show functional connectivity

- Shows Function interfaces and data

System	Toaster Object Holder	Heat Setting	Toast Lever	Electrical Plug	EE to TE Board	Heating Coil	Crumb Tray	Toast raiser	Customer	Crumb Tray	Crumb Tray
Customer	Bread	value	switch_on								
	Hold Bread away from Heat Elements										
		Adjust Toast Darkness									
			Start Toaster	signal_on							
				Get Power	AC						
					Convert Electrical Energy to Thermal Energy	pwer					
						Radiate Heat					
							Catch Crumbs				
								Lift Toast	Toast		
									Remove Toast		
										Clean Toaster	
											Remove Crumbs

Contact Info

MBSE Solutions, LLC
James Hummell, Consultant

http://MBSE.Solutions
jhummell@MBSE.Solutions
480-463-4359

32nd Annual INCOSE international symposium

hybrid event

Detroit, MI, USA

June 25 - 30, 2022

www.incose.org/symp2022