Representation of Functional Relations among Parts and Its Application to Product Failure Reasoning

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Objectives and Approaches of This Study

- Develop a Representation Method of Functional Relation among Components of a Mechanical System
  - Functional Stream
  - Constraints
  - Assembly Relations
- Utilize Functional Relation Model for a Computer Aided Failure Analysis
  - FMEA
    - Covering All the Possible Failure Modes
    - Identification of Failure Mechanism
  - Find failure which occurs at interfaces
- Explore the Possibility and Limitations of the Approach

Background

- Product Quality Management through Product Life Cycle
  - Product – Medium for Providing Service
  - Proper Management of Product Quality
    - Performance
    - Latest Technologies

    → Low Environmental Impacts
- Design phase has strong effects on quality management.
  - Robustness → Failure, Deterioration
  - Quality Management Procedures: Maintenance, Upgrade, …
  - How is function realized?

    → Structure, Module
- Repair and refurbishment are difficult.

  → Design intentions are difficult to derive.
- "Function" should be expressed in some way for quality management.

Goal: Quality Management
Focus: Computer Aided Failure Analysis

- Quality Management
  - Quality: Reliability and Performance
  - Operations for Quality Management;
    Replacement, Upgrade, Adjustment, …
- Preparation for Quality Management in Design Phase
  - Reliability Analysis
    - Reliability Block Diagrams
    - Fault Trees
    - Statistical Analysis
  - Performance Analysis
    - Product Models for Simulating/Evaluating Functional Behavior

  → *Robustness, Modularity*

- Reliability, especially failure analysis, is considered.

  → *Computer Aided FMEA for Mechanical Products*

FMEA and Design Support

- FMEA (Failure Mode and Effect Analysis)
  - Failure at Components → Effects on a system.
- Design Support by FMEA

  For Better Quality Management
  - Sensitivity, Criticality

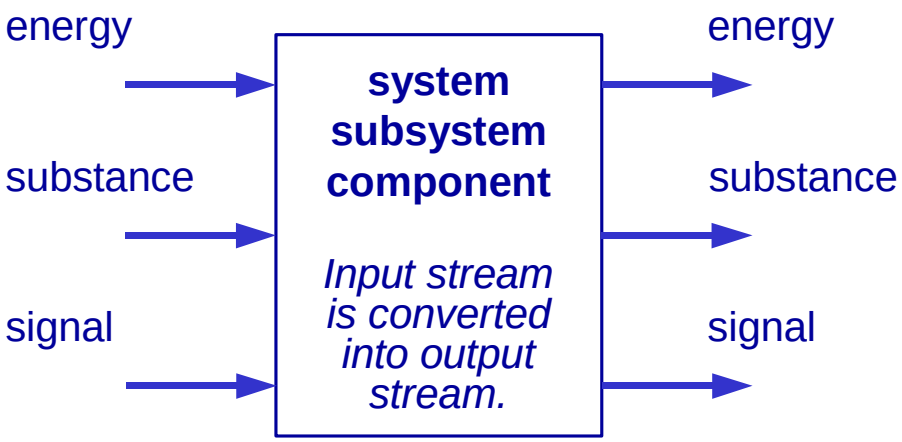
    → Design Modification

    → Fault Tolerant, Robustness
- Defects
  - Failure mechanism must be specified.

    → Difficult for Mechanical Products
  - Side-effects and unexpected behavior are difficult to find, and they have important effects on failure of a system.
  - Top-down approach, such as FTA, should be executed concurrently.
- Functional Relations instead of Reliability Diagrams

Representing Functional Relations in Design — Existing Methods

- Functional Diagram
  - Systems Engineering
  - Energy, Substances, Signal
- <F, B, S>
  - Function, Behavior, State
  - Function, Behavior, Structure
  - Mapping
    - Function
    - Behavior (Structure)
- Features in Product Models
  - Kinematic Pair
  - Tolerance

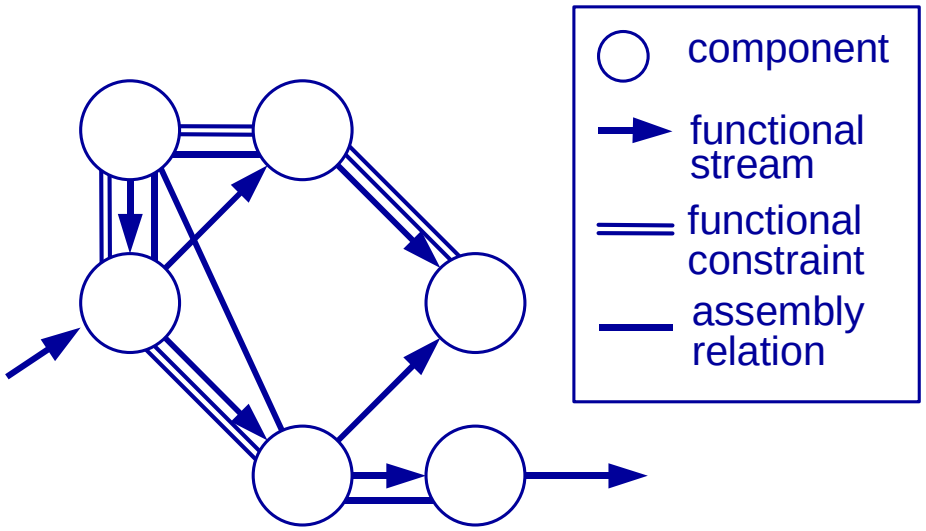


Representation of Functional Relations

- Product
  - → Component
  - → Part
- Graph Representation

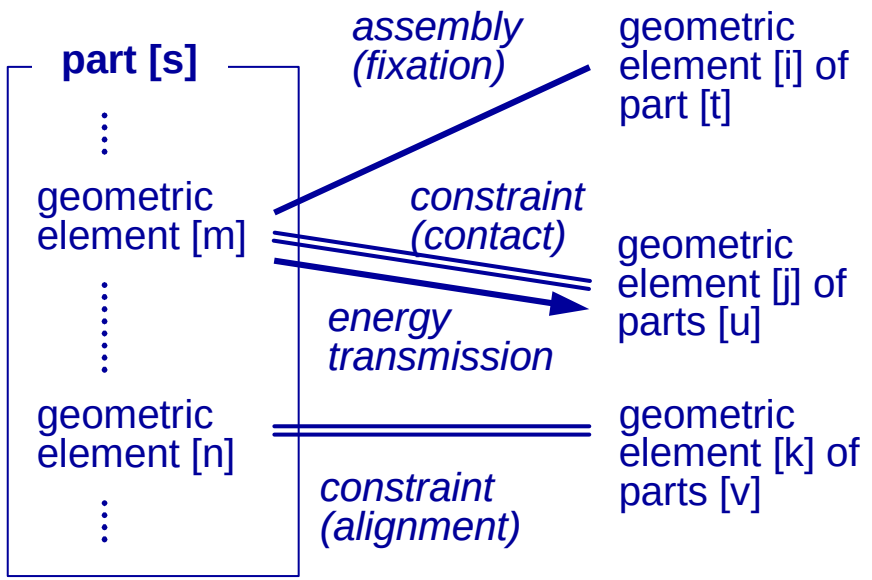
  Node: Component

  Arc: Relation
    - functional stream
    - constraint
    - assembly
  - Arrows show the direction of functional stream.
- Assembly relation can be a part of functional constraint.
  - It could be explicitly expressed in Assembly Models.



Constraints for Realizing Function

- **Functional streams are supported by constraints**;
  - Fixation
  - Guide
  - Relative Position
  - Friction / Smoothness
  - …
- Some of designer's intensions might be expressed in these relations.
- Some of functional constraints remain as;
  - Tolerances Specification
  - Assembly Relation
  - Feature
- Constraints are related to the properties of parts or components.



Assembly Relation

- Assembly Models in Current CAD Systems
  - Component, Subassembly
  - Decide Position and Relation
    - Reference Element and Relative Position
    - Local / World Coordinate
    - Coincidence of Revolving Axis
    - …
  - Check of Interference, Assemble Process
- Do assembly relations reflect functional relation?
  - Yes / No → Depends on Designers
  - Assembly relations are not always the same as functional constraints.
  - They can sometimes reflect functional constraints.

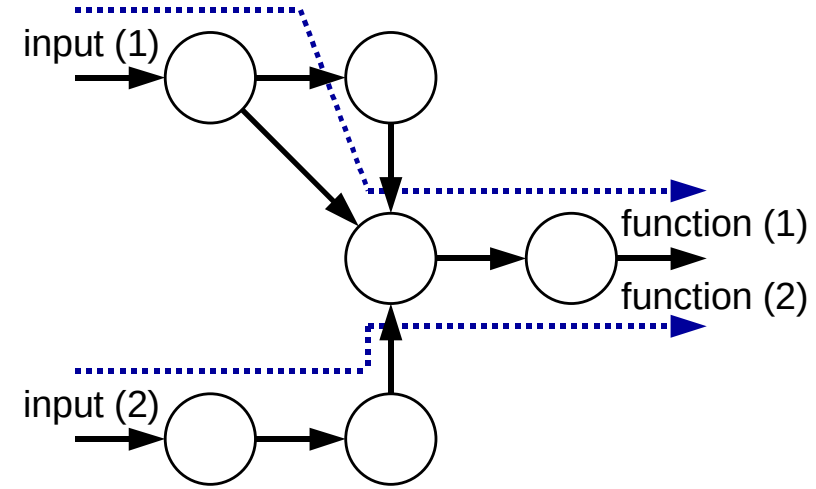
Functional Stream

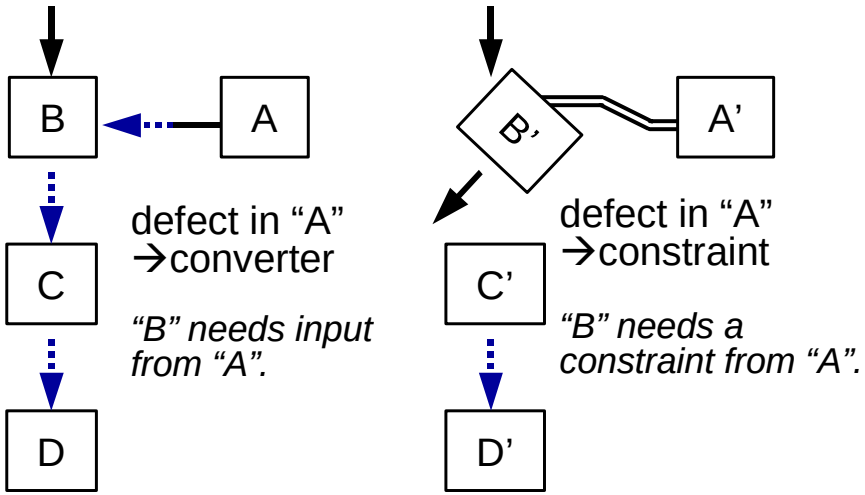
- Functional Stream
  - Signal
  - Energy
    - Kinetic Energy
    - Electrical Power
  - Substances
- Failure Mode

  ← Loss of Stream
  - Malfunction in Component

    ← *Direct Effect*
  - Change in Relation, Interface
    - Changes in Components

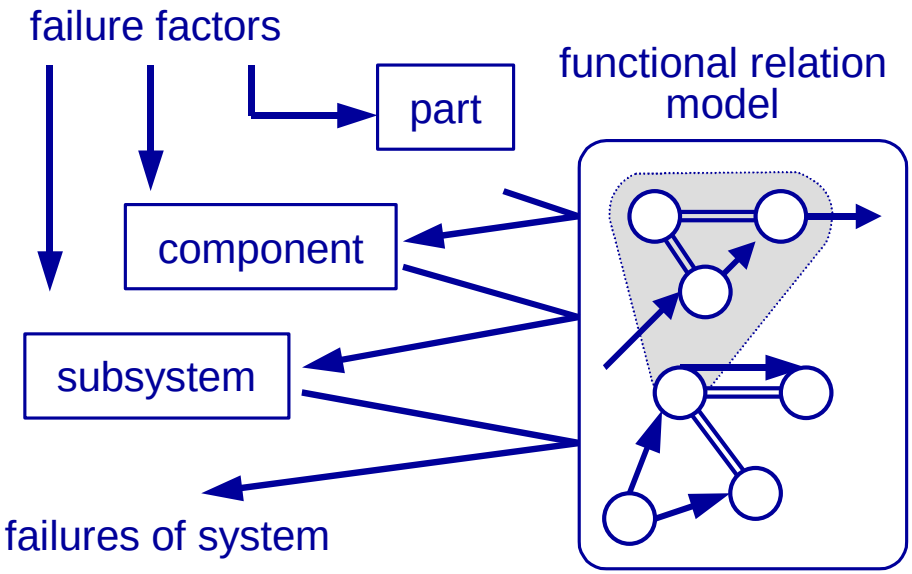
    ← *Indirect Effect*





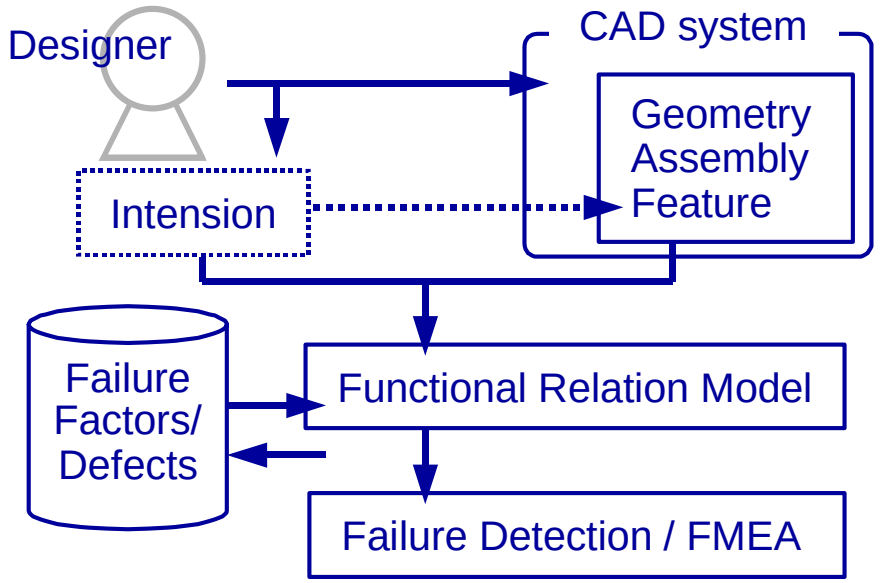
Reasoning Failure Mechanism with Functional Relation Model

- Factors of Failure
  - Wear
  - Fatigue
  - Deformation
  - Stochastic
- Failure Propagation
  = Reasoning Failure
  - Check components and constraints.
  - Trace functional stream.
- Hierarchical Structures
  - Failure analysis can be started from a systems level description.
- For reasoning;
  - Typical Patterns



Generation of Functional Relation Model

- Geometric Model
  + Assembly Relation
    → Assembly Model
- Assembly Model
  + Feature
    → Skeleton
- Skeleton
  + Designer Intension
    → Functional Relation Model



Failure Reasoning: Prototype Program

- Check All The Modes

  Generative Approach
- Qualitative Description
  - Criticality, Possibility

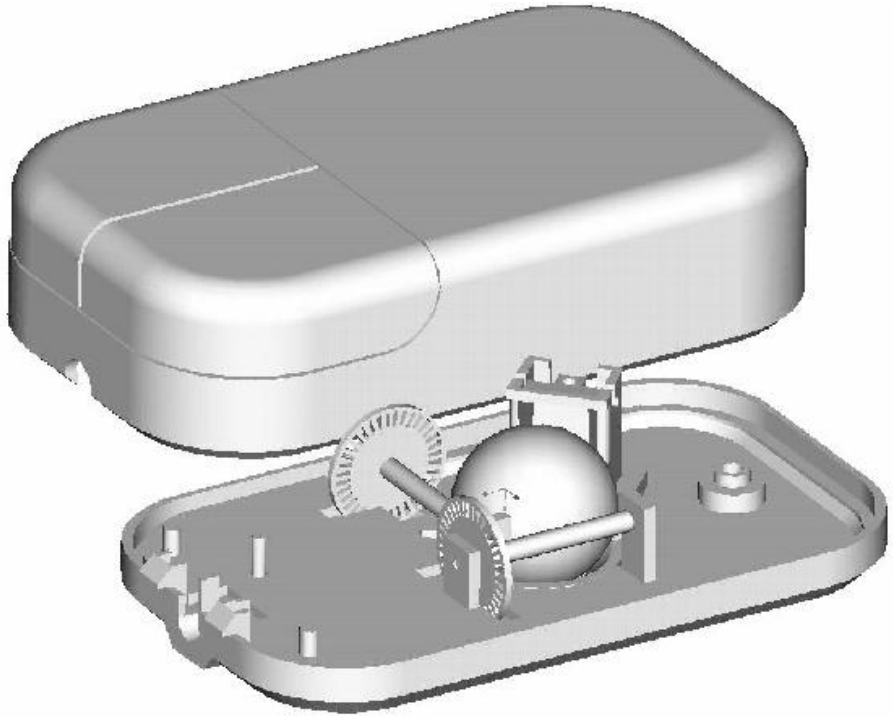
    → Not Specified

For Each Component

1. Assign Failure Factor
2. Expand Failure Modes of a Component
3. Identify Effects on Constraints
4. Trace All Functional Streams and Check whether functions are completed.
5. Generate Failure Mode

Example: A Pointing Device for Computers

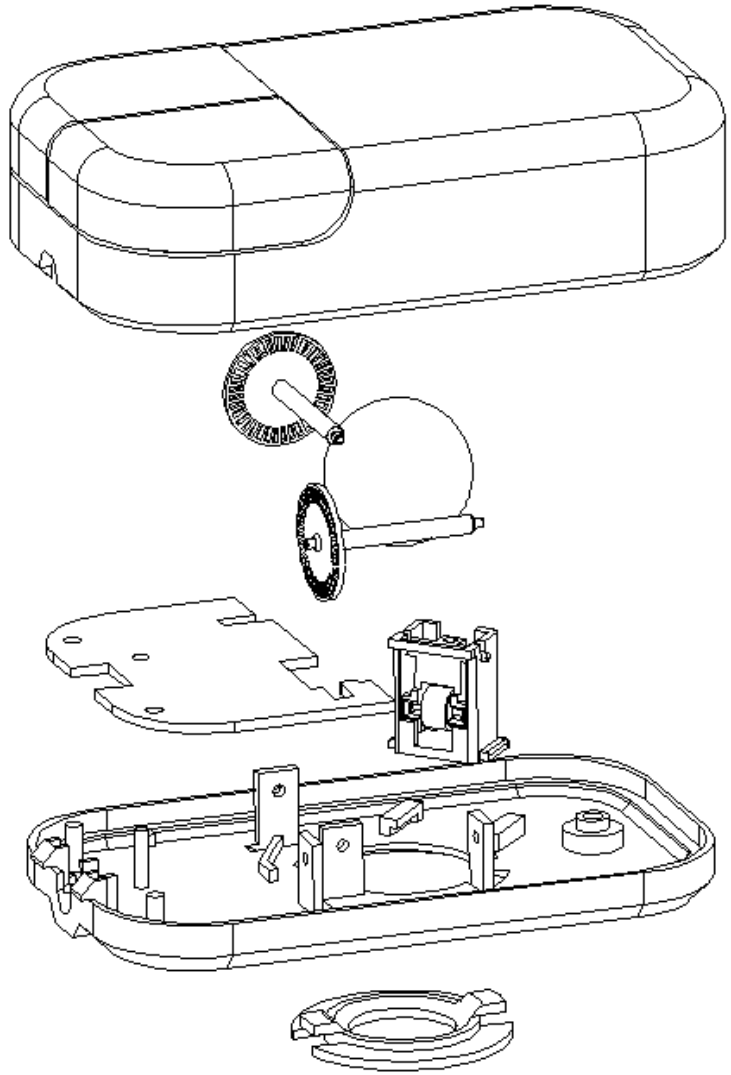
- Function
  - Translation → Signal
    - Ball
    - Roller
    - Encoder
  - "Click" → Signal
- Detection & Transmission



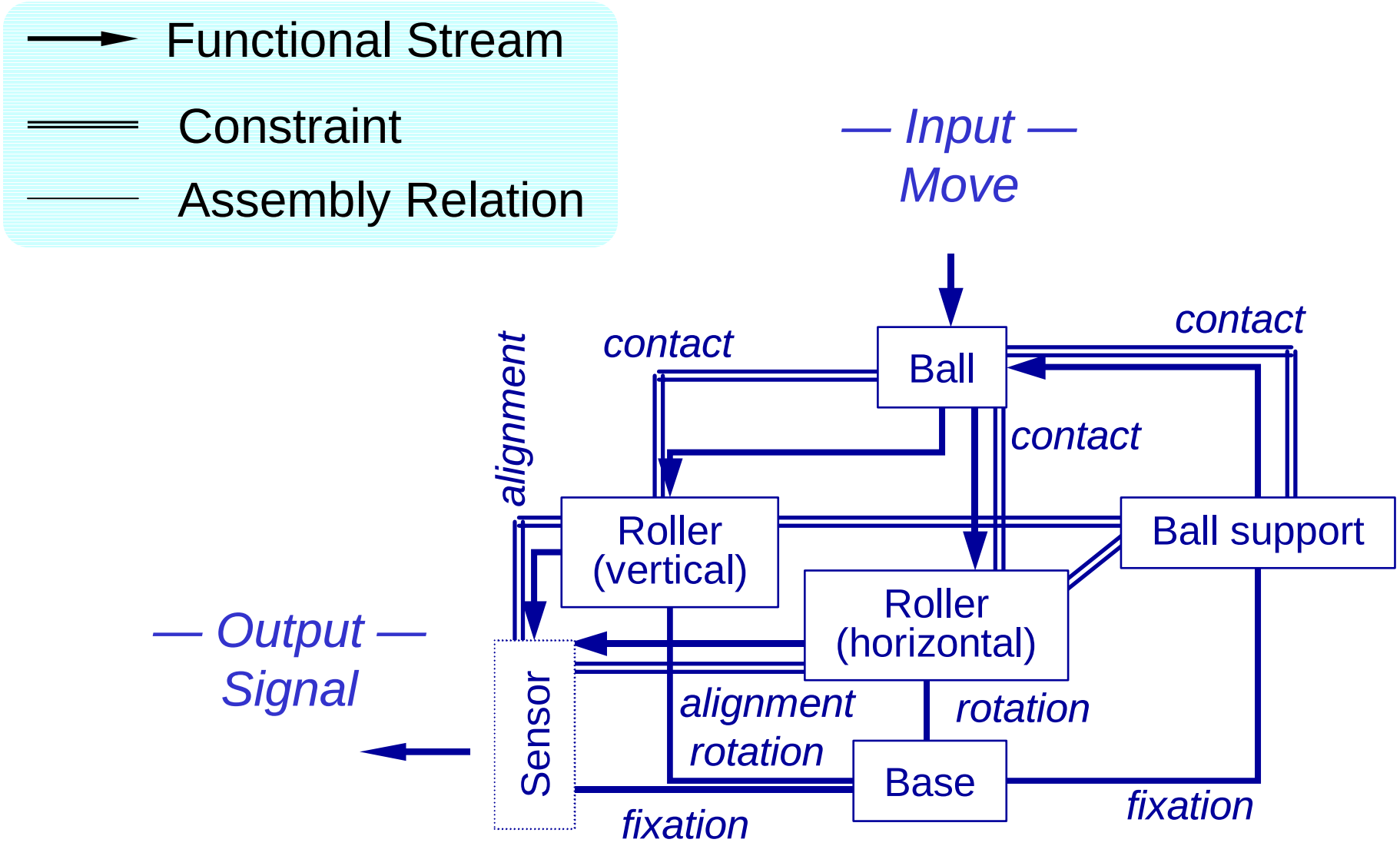
Example: Pointing Device Assembly Relation

- Roller — Base
- Roller — Encoder
- Ball

- In prototype Approach
  - Derive skeleton for functional relation model from assembly model
  - Adding functional relations to Skeleton
    - Functional Stream
    - Types of Interfaces (pairs)

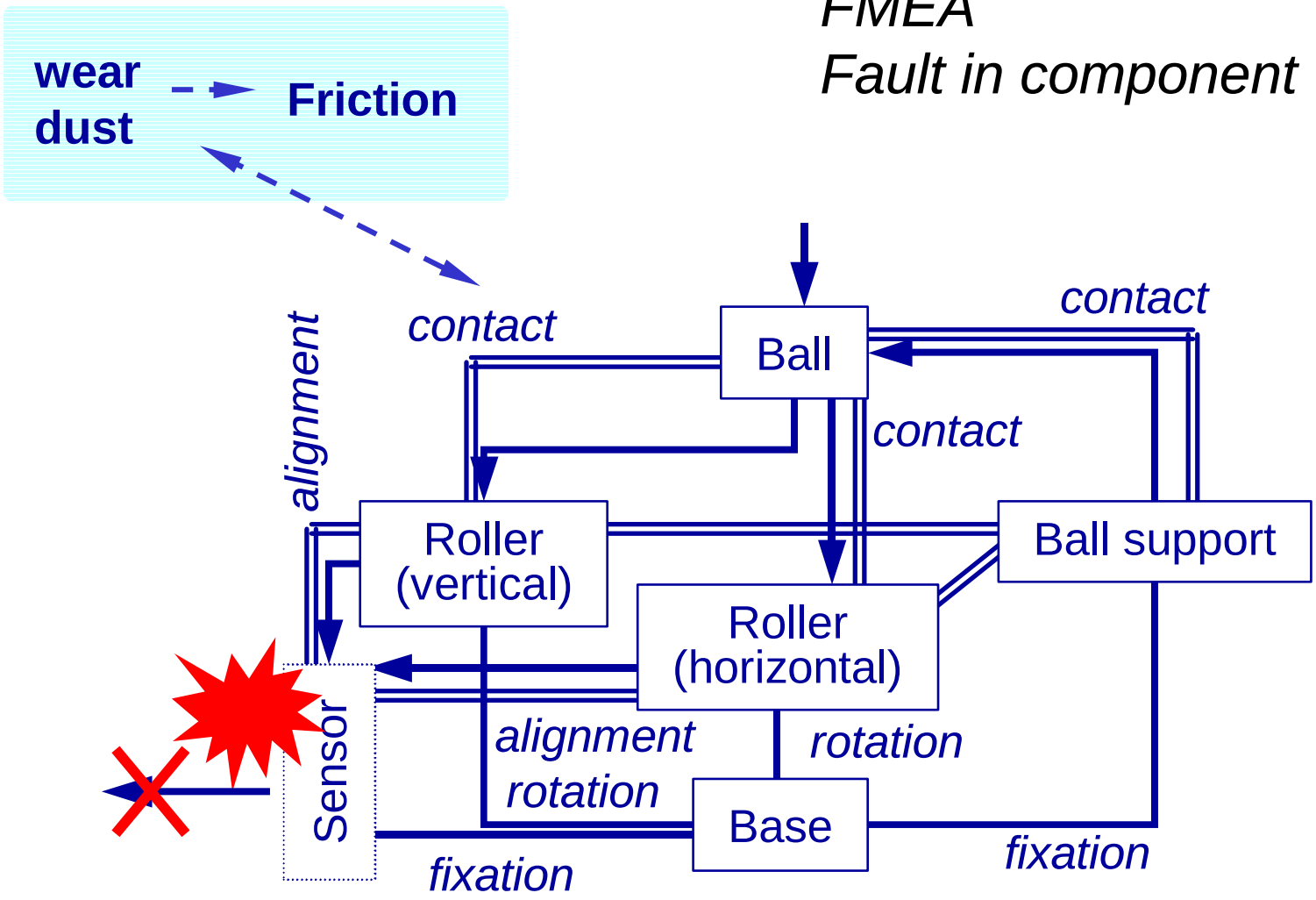


Example: Pointing Device
Functional Relation



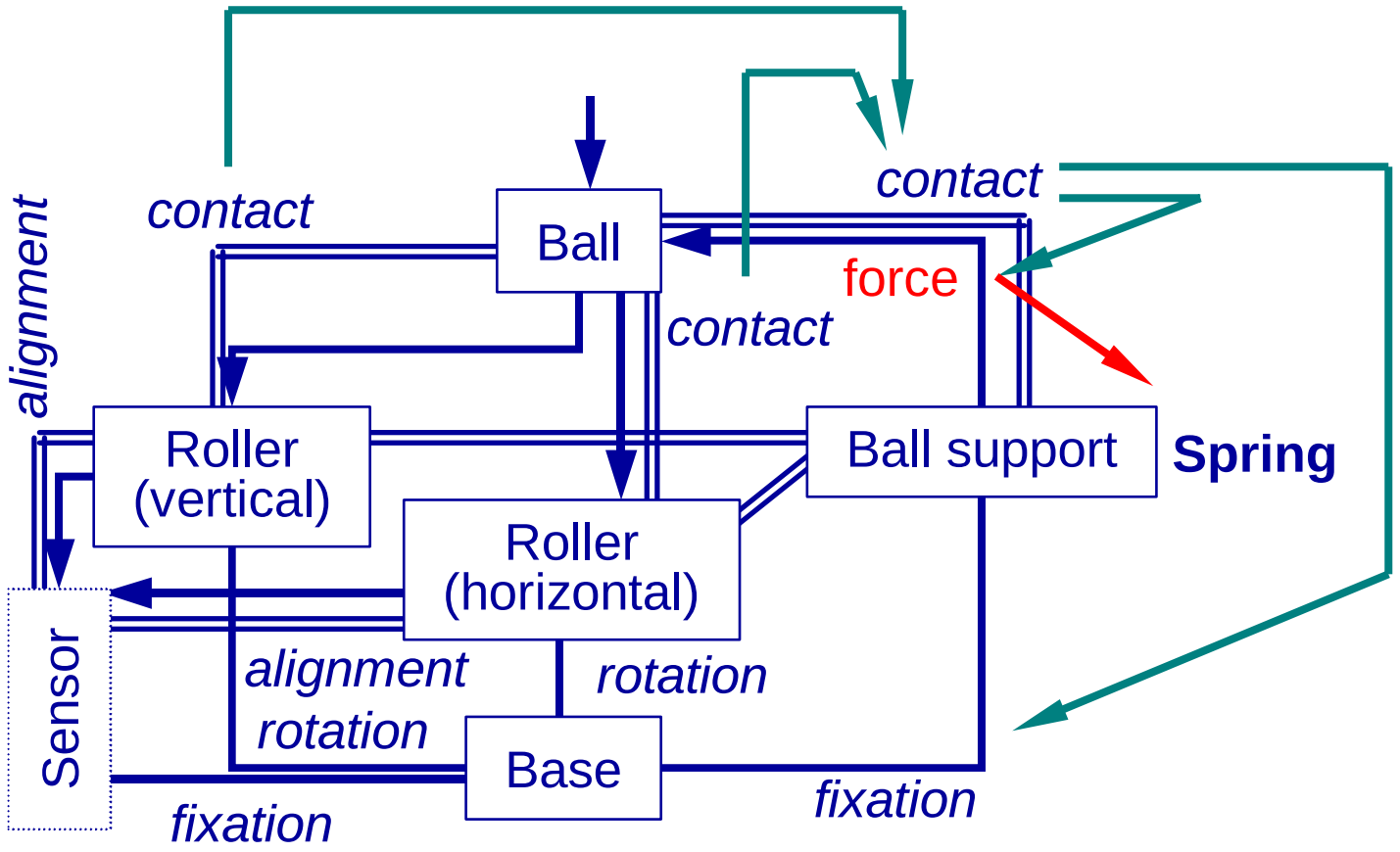
Example: Pointing Device Functional Relation

FMEA
Fault in component → System



Example: Pointing Device Functional Relation

Dependency



Example: Pointing Device FMEA Chart

Part / IF	Defects	Factor	Effects on Function		
			Detection of Motion	Signal to PC	…
Component					
Ball	Low Friction	Wear	NG		
		Dust	NG		
H. Roller	Low Friction	Wear	NG		
		Dust	NG		
Sensor	Screened	Dust		NG	
Circuit	Stochastic			NG	
…					
Interface					
Roller / Base	Bad Alignment	Wear of Bearing	NG		
Roller / Sensor	Bad Alignment	Roller Shape		NG	
Roller / Ball	Bad Alignment	Roller Shape	NG		
…					

- Failure Analysis
  - Generative
  - Functional constraints are simplified as interfaces.
- Failure Factor

  → Component

Example: Pointing Device Discussion on a Prototype System

- All the possible modes are expanded by a program.
- Did this approach help designers to perform FMEA?

  → Yes, but not so much.
  - Propagation → Reduced

    Input Local Relations → Entire System
  - Amount of Input → Not Reduced
    - Designers still have a lot of things to input for executing FMEA.
    - Input procedures are separated from design.

    → Concerns by designers can be utilized.
- Limitations
  - Relations between failure factors of component and changes in properties have to be specified.
  - Relations have to be manually input by designers.
  - Failure mode with multiple failure factors cannot be handled.
  - **Static Description**: Dynamic behavior of a system is not handled.

Extensions for More Precise Evaluation

- Construction of Functional Relation Models
  - Designer's Consideration
  - If it is integrated into design procedure, the amount of input tasks is reduced.
  - Feature, Assembly Model, Tolerance
- Classification of Functional Relations for Failure Analysis

  → **Not Matured**
  - More investigations are necessary.
- Failure Propagation – Generative Approach
  - Effective algorithms are necessary.
- Dynamic Behavior
  - Integration of Behavior Simulation
  - State

Conclusions

- Achievement
  - Functional relations are expressed for computer aided FMEA.
  - Possible failure can be generated as a loss of functional stream.
  - If **local** functional relations are modeled, failure of a system is derived if the relations can be described in static ways.
- Limitations of the Approach
  - Dynamic behavior is not handled.
  - Side-effects are not derived. (No descriptions, no outputs.)
  - If a system is large, it becomes difficult to execute failure analysis programs.

End.

Thanks for Your Kind Attention.

Expectations of Representation of Functional Relations for Quality Management

- Functional Relation
  - Serviceability → Repair
  - Modularity → Upgrade
- Inheritance of Functional Relations
  - Abstract description → Concrete Description
    - Consistent Description Method for Design Process
  - Relations in Hierarchical Models → Expanded

Basic Ideas

- Designers consider many things.
  - Reasons, Constraints
  - Failure potential
- If those information is expressed in some ways, failure analysis could be made easier.
  - Analysts do not need to trace designer's intention from scratch.
  - Functional relations can be utilized.
- Designers also utilize such information for;
  - Finding out Modular Structure
  - Avoiding Side-effects

On this Research…

- We have just started with a simple example.
- We will improve this approach in a framework of Quality Management through product life cycle.

Reasoning

- Just Generating All the Possible Modes.
- It should be refined in some ways.
- Matching
  - Patterns
  - Defect Libraries ← Relation