Dependability-Oriented Requirements Engineering

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Overview

- Dependability
  - Software Development for Dependable Systems
  - Fault Tolerance and Recovery
  - Exceptions
  - Idealized Fault-Tolerant Component
- Dependability-Focused Requirements Engineering Process
  - Motivation
  - Context-Affecting Exceptions
  - Safety and Reliability Handlers
  - Service-Affecting Exceptions
  - Dependability Assessment
- Conclusion & Future Work

Dependability

Dependability

Property of a computer system such that reliance can be justifiably be placed on the service it delivers[1]

Availability, *reliability*, *safety*, maintainability, confidentiality, integrity

Safety: Lack of catastrophic failures[2]

Reliability: Aptitude to provide service as long as required[2]

[1] J. C. Laprie, A. Avizienis, and H. Kopetz, editors. Dependability: Basic Concepts and Terminology. Springer-Verlag New York, Inc., Secaucus, NJ, USA, 1992.

[2] J.-C. Geffroy and G. Motet: Design of Dependable Computing Systems. Kluwer Academic Publishers, 2002.

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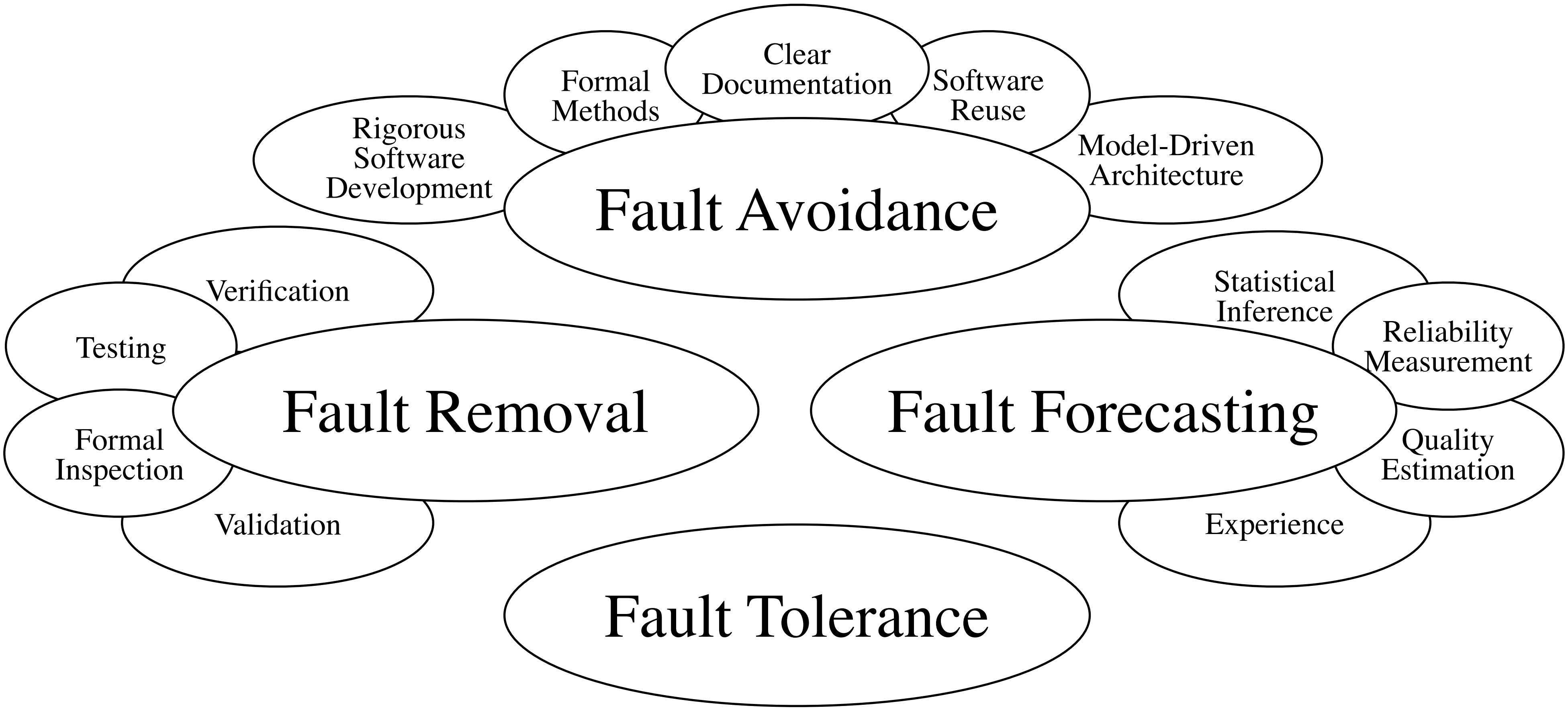
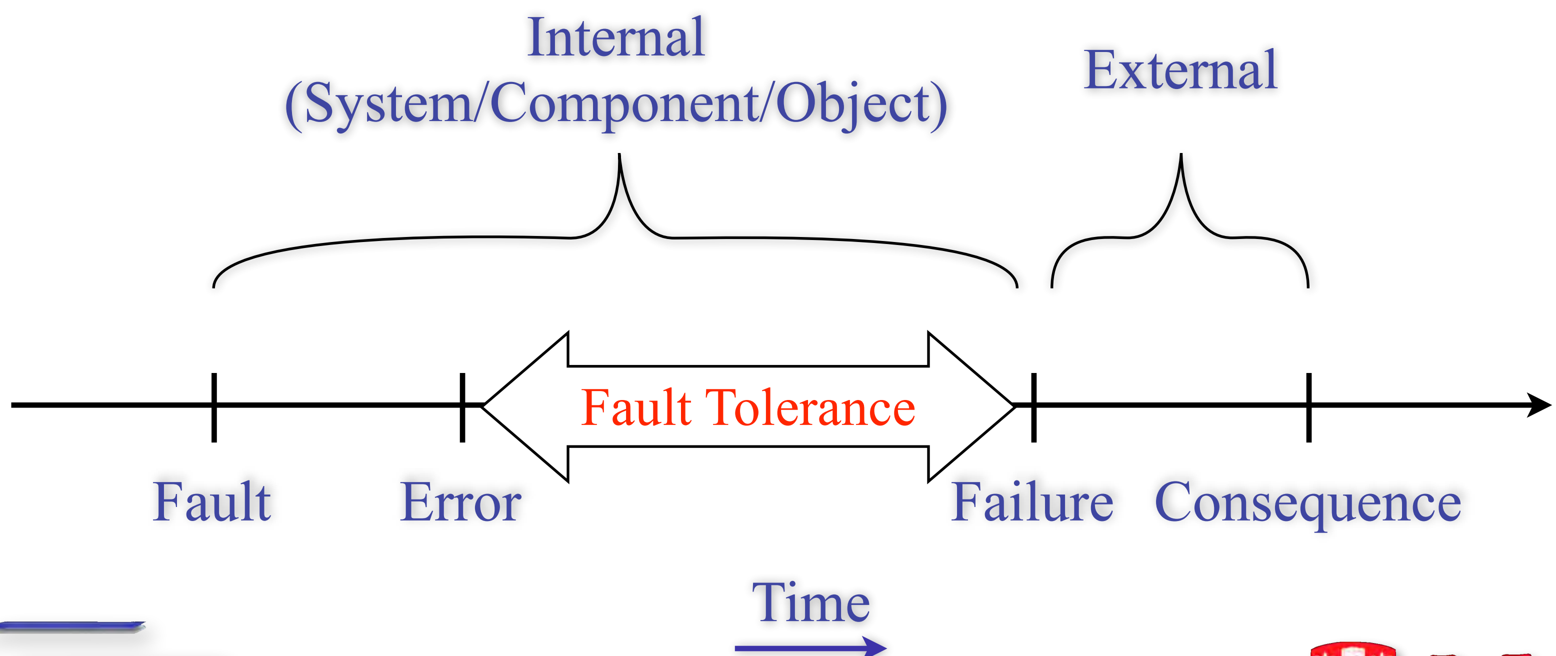
Reliable Software Development



Fault Tolerance

- Continue to provide service in the presence of faults of underlying components or the environment



Recovery

- Error detection
  - Identify erroneous state
- Error diagnosis
  - Assess the damage
- Error containment / isolation
  - Prevent further damage / error propagation
- Error recovery
  - Substitute the erroneous state with an error-free one
- Backward and Forward Error Recovery

Exceptions

- *Programming language feature*
- Exceptional situation in which normal processing can not continue
- Exception Handling Systems[1]
  - Define exception handling *contexts*
  - Provide a means to *signal* exceptions
  - Define exception *handlers*
  - *Attach* handlers to contexts
- Hierarchical model

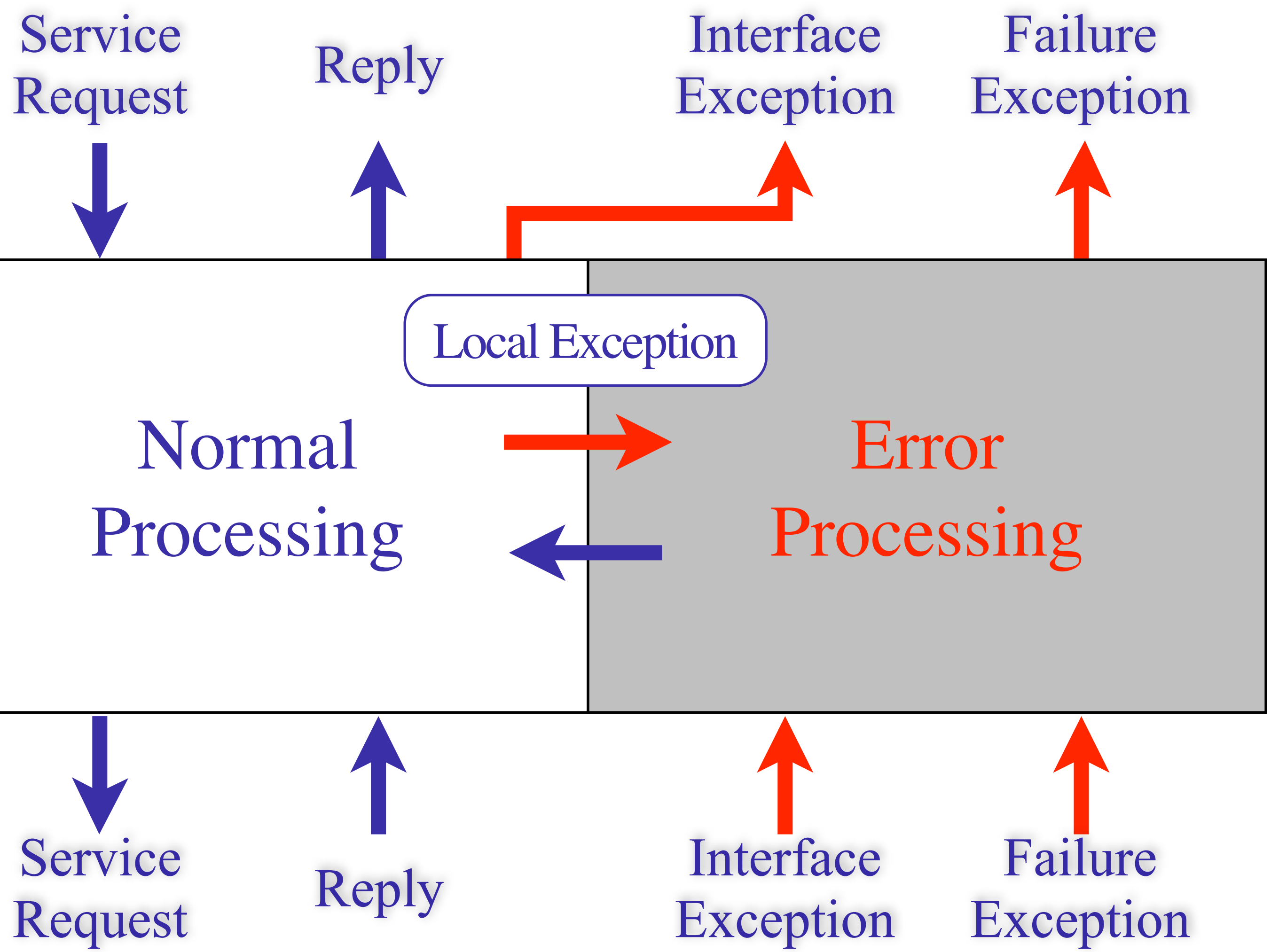
[1] C. Dony: Exception Handling and Object-oriented Programming: Towards a Synthesis. In 4th European Conference on Object–Oriented Programming (ECOOP '90). ACM SIGPLAN Notices, ACM Press.

Exception Occurrence

- At run-time, signaling an exception amounts to
  - Identify the kind of exceptional situation
  - Interrupt the usual processing
  - Look for a relevant handler
  - Invoke the handler with occurrence information
- Handling amounts to establishing a coherent state and to either
  - Resumption model[1]:
    - Continue the program after the signaling statement
  - Termination model[1]:
    - Discard the context between the signaling statement and the handler
  - Signal a new exception to the enclosing context

[1] J.B. Goodenough: Exception Handling: Issues and a Proposed Notation. Communications of the ACM 18 (1975), p. 683 – 696.

Idealized Fault-Tolerant Component[1]

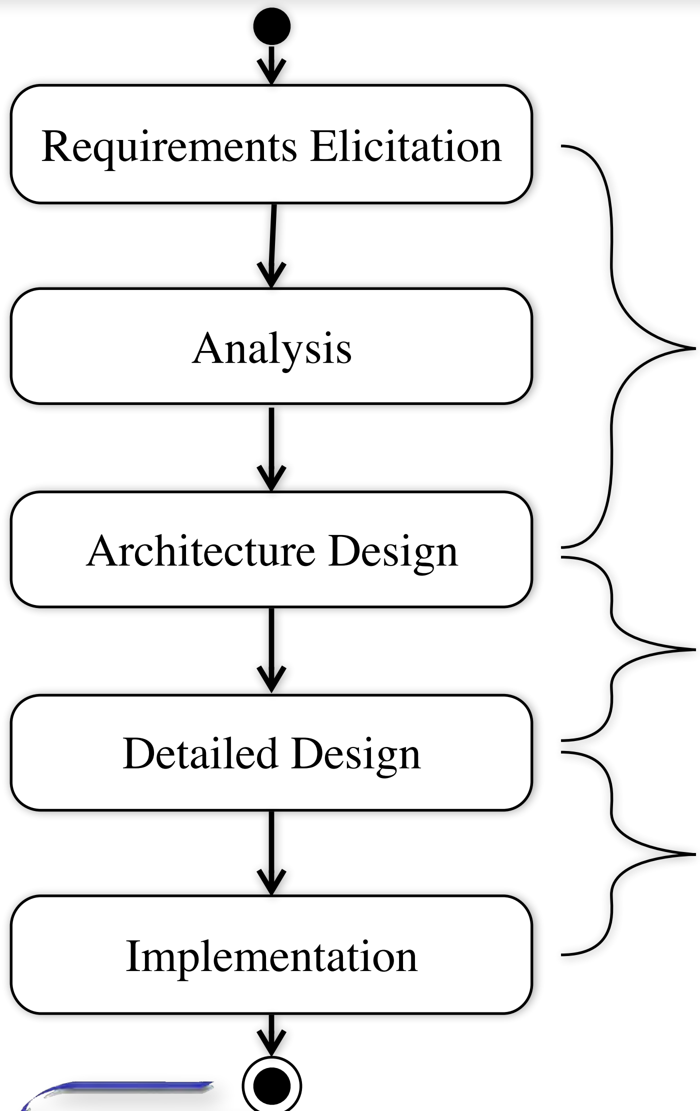


[1] Lee, P. A.; Anderson, T.: "Fault Tolerance - Principles and Practice", in Dependable Computing and Fault-Tolerant Systems, Springer Verlag, 2nd ed., 1990.

Advantages of Exception Handling

- Provides clear identification of exceptional situations / conditions
- Separates normal behavior from exceptional behavior
- Hierarchy
- Recursion
- Object-oriented Exceptions
  - Polymorphic Handling

E & SD: Current State of the Art



? Coordinated Exception Handling (e.g. CA Actions) ?

Exception Concepts Unclear

? Idealized Fault-Tolerant Component ?

Not Many Guidelines on Designing with Exceptions

Exceptions Well Understood

Requirements Elicitation & Use Cases

- Requirements Elicitation performed to discover the system functionality, properties and qualities
- Use Cases capture interactions between the system and the environment to achieve user goals
- Actors - entities that interact with the system
  - Primary actor - initiates the use case
  - Secondary actors - needed by the system to provide the functionality
- Designed to be understood by non-technical parties
- Consist of (textual) descriptions and Use Case Diagrams

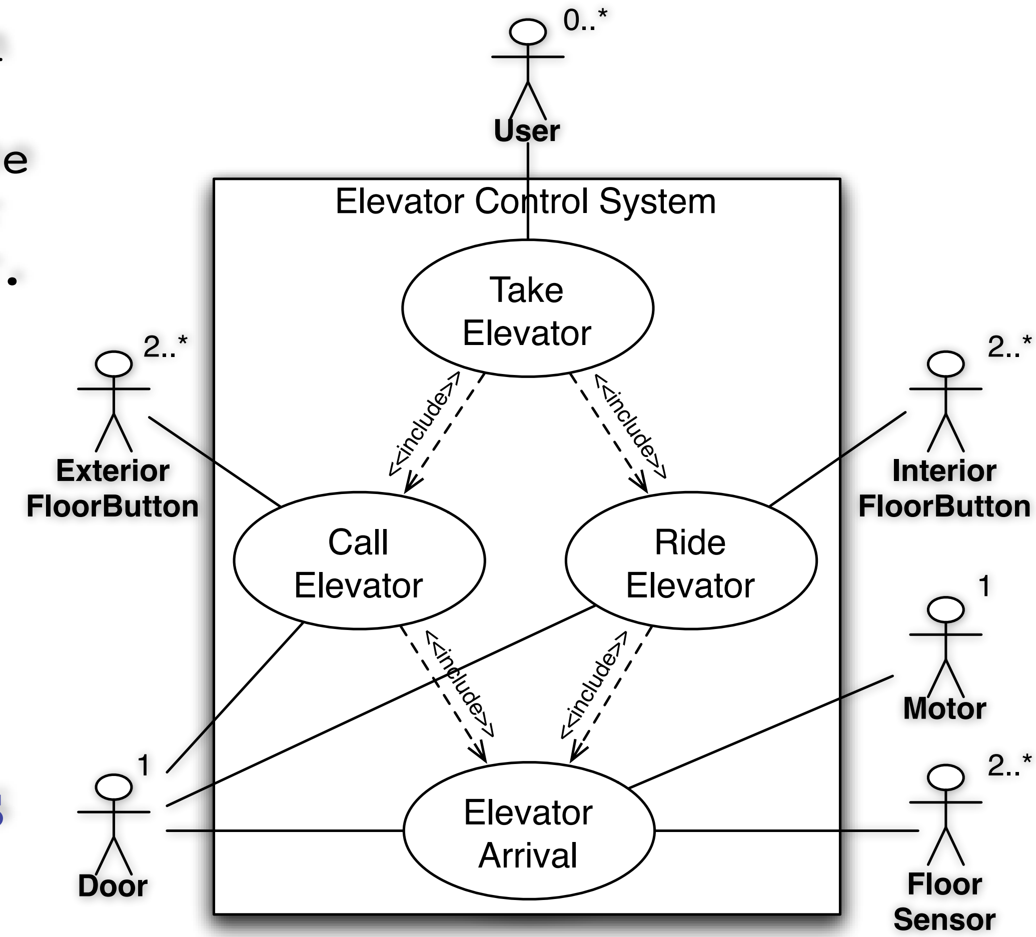
Single-Cabin Elevator Example

Use Case: TakeElevator
Scope: Elevator Control System
Primary Actor: User
Intention: The intention of the *User* is to take the elevator to go to a destination floor.
Level: User Goal
Main Success Scenario:

1. *User* **Call[s]Elevator**
2. *User* **Ride[s]Elevator**

Extensions:

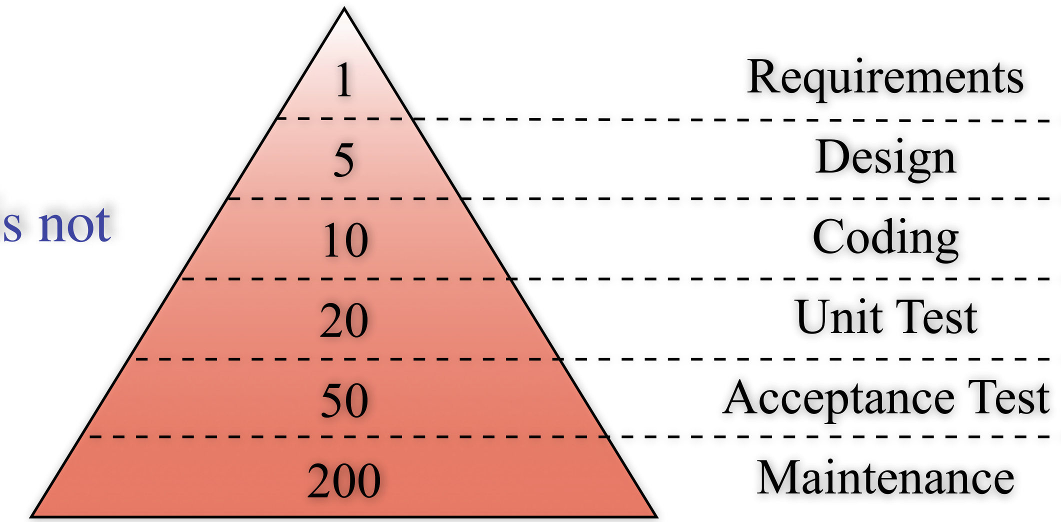
1a. Cabin is already at *User's* floor…
1b. *User* is already inside…



- Main success vs. extensions
- Hierarchy

Importance of “Good” Requirements

- Faults / omissions made at the requirements stage are expensive to fix later
  - Stated requirements might be implemented, but the system is not one that the customer wants
- Need to determine and establish the precise expectations of the customer!
  - Also for exceptional situations!



Relative Cost to Repair a Defect at Different Lifecycle Phases [Davis 93]

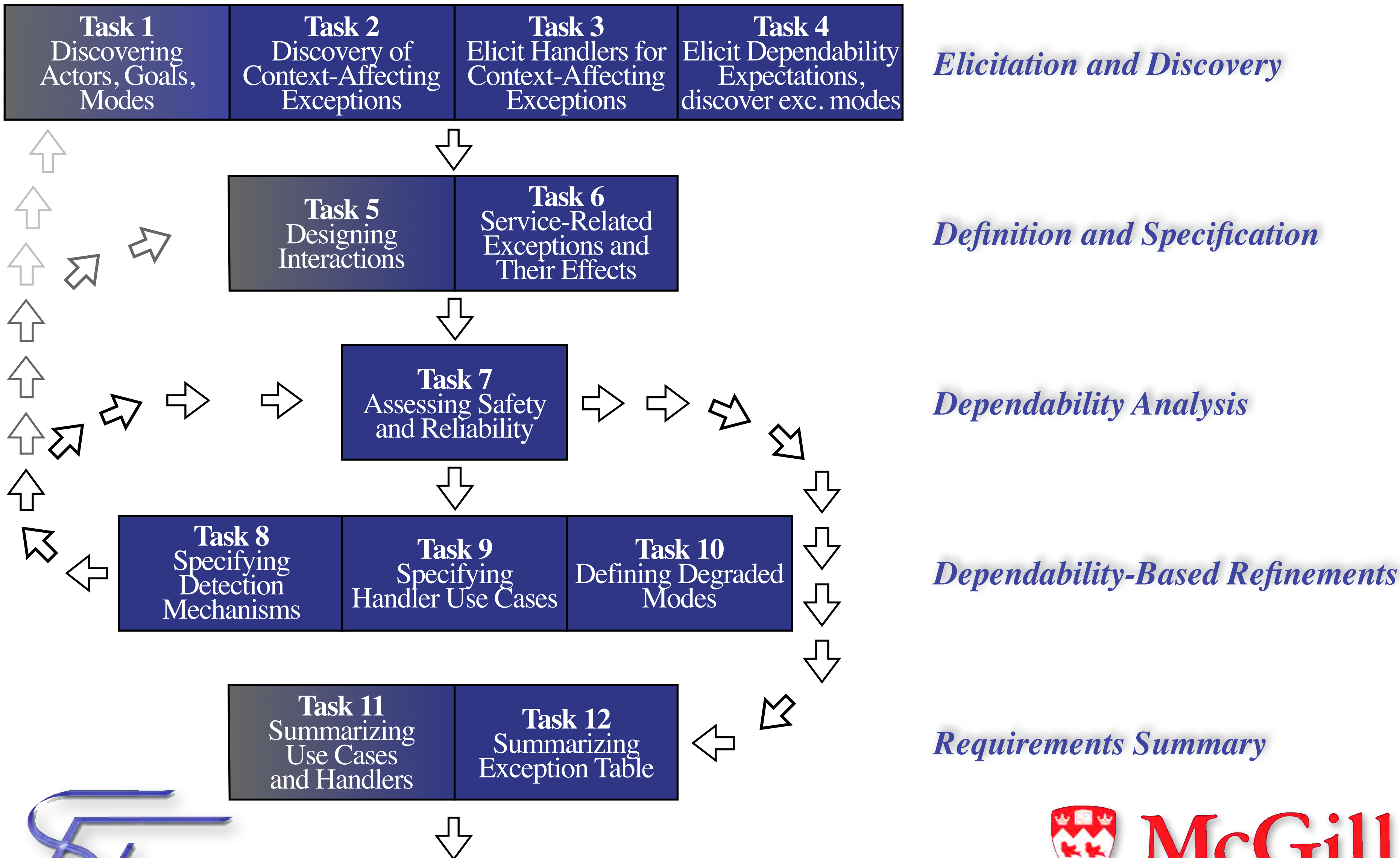
Fault Assumptions

- System (to be built) fault-free
- Faults in the environment
  - Actors fail to provide input to the system
  - Actors fail to provide requested service to system
  - Communication failure
  - Protocol violations
- These situations may interrupt the flow of normal interaction that leads to the fulfillment of the user goal

Motivation for Dependablity-Focused RE

- The major cause of common faults are flawed specifications [Bishop 95]
  - Incompleteness
  - Ambiguity
- Non-identified exceptional situations can lead to
  - Lack of functionality
  - Unreliable system behavior
  - Unexpected system behavior
    - Operation faults
- Idea: extend use case-based requirements elicitation to discover dependability requirements and specify how to deal with exceptional situations

Process Overview



Task 1: Discovering Actors, Goals and Modes

1.1 Brainstorm services/goals and outcomes

1.2 Brainstorm actors

1.3 Classify services/goals and actors

1.4 Decompose services into subgoals

1.5 Brainstorm operation modes

- An *operation mode* is defined by the set of services that the system offers when operating in that mode
  - Example: cell-phone with child-safe mode

Task 2: Discovering Context-Affecting Exceptions

2.1 Brainstorm context-affecting exceptions

2.2 Define new exceptional detection actors

- Context-Affecting Exceptions
  - Exceptional situation arising in the environment that affect the context in which the system operates
    - Temporary situation or permanent situation
  - Cannot be detected by the system
    - Exceptional actors signal the situation to the system
  - System safety threatened
  - User goals change
- Example
  - Fire outbreak in an elevator, signalled by a smoke detector

Discovering Context-Affecting Exceptions

- Discovered in a top-down manner
- System Level
  - What situation prevents the system from being operational?
    - Operational needs: power source, accessibility, connectivity
  - What situation prevents the system from providing safe service? In these situations, should the system provide some other service?
    - Emergencies, safety concerns, malicious behavior
- User-goal Level / Subfunction-level Goal
  - What situations / conditions / changes in the environment prevent the system from satisfying a primary actor's goal (or subgoal)? In such situations, can the system partially fulfill the service?
  - What situations take priority over the primary actor's goal?
  - What situations / conditions / changes in the environment could make the primary actor change his goal? In such situations, how can the primary actor inform the system of the goal change?

Results of Task 2

- For each discovered context-affecting exception
  - Define a name
  - Elaborate a short description describing the situation
  - Identify new system services, i.e. exceptional goals
    - These services are triggered by the occurrence of the exception
  - Exceptional actors
    - Exceptional primary actors detect the occurrence of the exception and signal it to the system
    - Exceptional secondary actors are actors needed by the system to handle the exception

Task 3: Eliciting Handlers for CA Exceptions

3.1 Discover and classify exceptional services

3.2 Decompose exceptional services into subgoals

3.3 Discover new exceptional secondary actors

- For each context-affecting exception, a handler use case outline is defined that describes the exceptional service that is provided by the system, (i.e. how the system is supposed to react in that situation)
  - Handlers are classified as safety or reliability handlers
  - Linked to the context in which they are
- Example
  - Fire outbreak in an elevator, signalled by a smoke detector
    - Safety handler directs elevator cabin down to the ground floor

Task 4: Eliciting Dependability Expectations

4.1 Eliciting dependability expectations for each service

4.2 Document provided reliability and safety of mandatory secondary actors

4.3 Discover exceptional modes of operation

- For each goal / service that the system provides, *expected* safety and reliability is specified
  - Reliability specified with "chance of success", e.g. 99.97%
  - Safety specified with "chance of safety violation", e.g. 0.0002%
    - Depending on the application, different safety levels can be defined, e.g. DO-178B
    - This is where discussions on "acceptable risk" should take place among stakeholders

Exceptional Modes

- Dependable systems should not offer services they can not provide in a reliable and safe way

➡ When an exceptional situation is encountered, reliability and safety of future service provision should be evaluated

➡ If system cannot guarantee dependable service provision, a mode switch is necessary

Operation Mode = Set of Offered Services
(with defined minimal reliability and safety)

(Emergency Modes, Degraded Modes, etc..)

Task 5: Designing Interactions

5.1 Design goal interaction steps

5.2 Specify goal outcomes

5.3 Define new (exceptional) secondary actors

5.4 Design handler interaction steps

5.5 Specify handler outcomes

5.6 Add mode switches to handler steps, if needed

- Possible goal and handler outcomes
  - <<success>>, <<failure>>, <<abandoned>>, <<degraded>>

Elevator Arrival Example

Use Case: ElevatorArrival

Intention: System wants to move the elevator to the User's destination floor.

Level: Subfunction

Main Success Scenario:

1. *System* asks *Motor* to start moving in the direction of the destination floor.
2. *FloorSensor* informs *System* that elevator is approaching destination floor.
3. *System* requests *Motor* to stop.
4. *System* requests *Door* to open.

Use case ends in <<success>> *FloorReached*.

- Write detailed interaction scenarios for each use case and handler
- Each step is either an *input interaction* or an *output interaction*

User Emergency Example

Handler Use Case: UserEmergency

Handler Class: Safety

Contexts & Exceptions: TakeElevator{EmergencyStop}

Intention: User wants to stop the movement of the cabin.

Level: User Goal

Frequency & Multiplicity: Since there is only one elevator cabin, only one User can activate the emergency at a given time.

Primary Actor: User (interacts by means of Emergency Button)

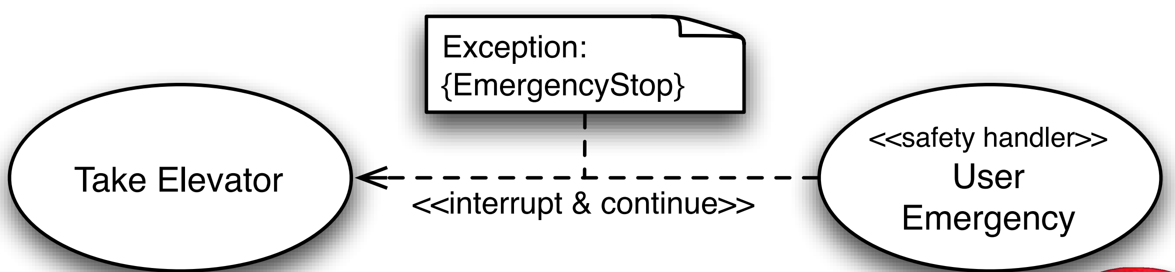
Main Success Scenario:

1. *System* initiates Emergency Brake.

New Exceptional Facilitator Actor

System clears all pending requests.

3. User informs *System* that emergency is over by toggling the *Emergency Button*.
4. *System* deactivates *Emergency Brakes* and awaits the next request.



Fault Assumptions

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- Faults in the environment
  - Actors fail to provide input to the system
  - Actors fail to provide requested service to system
  - Communication failure
  - Protocol violations
- These situations interrupt the flow of normal interaction that leads to the fulfillment of the user goal

Task 6: Defining Service-Related Exceptions

6.1 Document expected reliability and safety for actors

6.2 Annotate subgoal and handler steps with reliability and safety

6.3 Define service-related exceptions

- Consider the importance of each interaction step
  - Reliability:
    How essential is the interaction step for the successful completion of the user goal / subgoal?
    - Annotate essential steps with a <<reliability>> tag and specify the success probability, if known
  - Safety:
    Does the failure of this interaction step threaten system safety?
    - Annotate critical steps with a <<safety>> tag and an appropriate safety level
- Consider feasibility of each interaction step
  - Is it possible for the system to be in a state in which the execution of the step is impossible?
  - Are there service-related exceptional situations in which an entire sub-goal cannot be executed?

Different Source of Problems

- Input Problems
  - If omission of input from an actor can cause the goal to fail different options of handling the situation have to be considered.
    - Prompt again after timeout
    - Use default input
    - Temporary system shutdown for safety reasons
- Output Problems
  - Whenever an output triggers a critical action of an actor, then the system must make sure that it can detect eventual communication problems or failure of an actor to execute the requested action.
    - Example: Motor fails to stop.
    - Additional hardware or timeouts might be necessary to ensure reliability.
    - Example: Movement Sensor (exceptional detection actor)

Results of Task 6

- For each discovered service-related exception
  - Define a name
  - Elaborate a short description describing the situation
  - Add exceptions to the exceptions section of the use cases and handlers

Elevator Arrival Example

Use Case: ElevatorArrival

Intention: System wants to move the elevator to the User's destination floor.

Main Success Scenario:

1. System asks Motor to start moving in the direction of the destination floor.
   Reliability: 99%
2. FloorSensor informs System that elevator is approaching destination floor.
   Reliability: 98% Safety-index: 2 (minor effects)
3. System requests Motor to stop.
   Reliability: 99% Safety-index: 4 (catastrophic effects)
4. System requests Door to open. Reliability: 97%

Exceptions:

Exception{MissedFloor}, Exception{MotorFailure}, Exception{DoorStuckClosed}

Reliability numbers do not reflect reality!

Task 7: Dependability Assessment

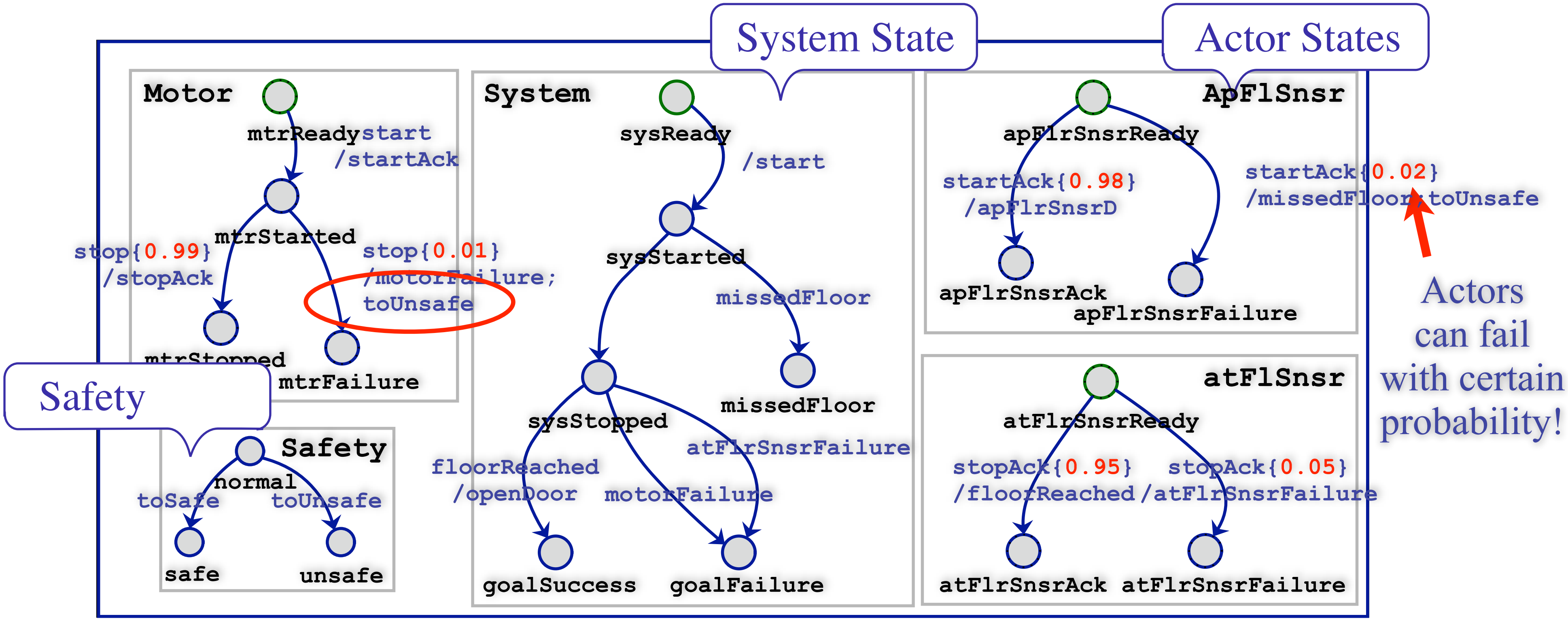
7.1 Map use cases and handlers to DA-Charts

7.2 Perform reliability and safety analysis

7.3 Compare dependability analysis results with expected dependability values

- DA-Chart comprise:
  - A *System* component
    - Input interactions are mapped to events
    - Output interactions are mapped to transition actions
  - One *orthogonal component for each actor*
    - Input interactions are mapped to probabilistic transition actions
    - Output interactions are mapped to probabilistic events
  - A *safety status* component
    - Failed safety-critical interactions trigger *toUnsafe* events

Dependability Assessment Charts



Sequencing according to use case, goalSuccess/goalFailure states
Fault-free - no probabilities

Tool Support

- Tool support for DA-Charts based on $AToM^3$
  - DA-Chart support built by extending the state chart meta-model with probabilities
- Analysis done by mapping DA-Charts to Markov chains
  - Safety = Probability to end up in the *Safe* state
  - Reliability = Probability to end up in the *GoalSuccess* state
- Elevator Arrival
  - Safety: 97.02%   Reliability: 92.169
- Careful: These numbers represent "best achievable" safety / reliability, not actual!

Refining Dependability

- What can be done if the calculated dependability is lower than the expected dependability?
- Determine "weak" steps
- Either increase reliability of step
  - Buy better hardware
  - Make communication links more reliable
  - Replicate hardware
  - ➡ No effects on requirements / use case structure
- Or redesign interactions to decrease importance of step
  - Continue with task 8 and task 9

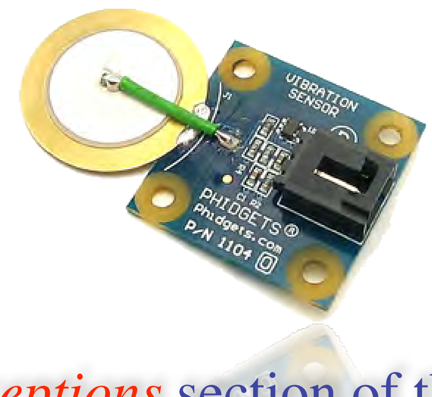
Task 8: Specifying Detection Mechanisms

8.1 Add detection actors

8.2 Add detection interaction steps for standard use cases and revisit goal outcomes

8.3 Add detection interaction steps for handlers and revisit handler outcomes

- Before recovery measures can be taken, the exceptional situation has to be detected
- Detection might require:
  - Additional secondary actors
  - Additional hardware, so called *detector actors*
    - Sensors
  - Timeouts
- The occurrence of an exception is documented in the *exceptions* section of the use case template



Elevator Arrival Example

Use Case: ElevatorArrival

Intention: System wants to move the elevator to the User's destination floor.

Level: Subfunction

Main Success Scenario:

1. System asks Motor to start moving towards the destination floor.
2. FloorSensor notifies System that elevator is approaching destination floor.
   Reliability: 98% Safety-index: 2
3. System requests Motor to stop. Reliability: 99% Safety-index: 4
4. AtFloorSensor informs System that elevator is stopped at destination floor.
   Reliability: 95%
5. System requests Door to open. Reliability: 97%
6. DoorSensor notifies System that door is open. Reliability: 95%

Exception:

2a. Exception{MissedFloor}

4a. Exception{MotorFailure}

6a. Exception{DoorStuckClosed}

Very often, timeouts have to be used to detect the exception

Task 9: Specifying Handler Use Cases

- Depending on the application domain (and the opinion of the stakeholders), a handler use case performs additional interactions to
  - Continue to provide the original service (reliability handler)
  - Offer a degraded service instead (reliability handler)
  - Take actions that prevent a catastrophe (safety handler)
  - Bring the system to a safe halt (safety handler)
- Behaviour should be intuitive to the people that interact with the system

Task 10: Defining Degraded Modes

- Evaluate the effects of each service-related exception on future service provision
- If promised reliability and safety levels cannot be maintained, a degraded operation mode should be defined

- After completing task 10, the process returns to task 5 (i.e. 5.4 Design Handler Interaction Steps), and then dependability is re-assessed

Example Refinement: Emergency Brake

Handler Use Case: EmergencyBrake

Handler Class: Safety

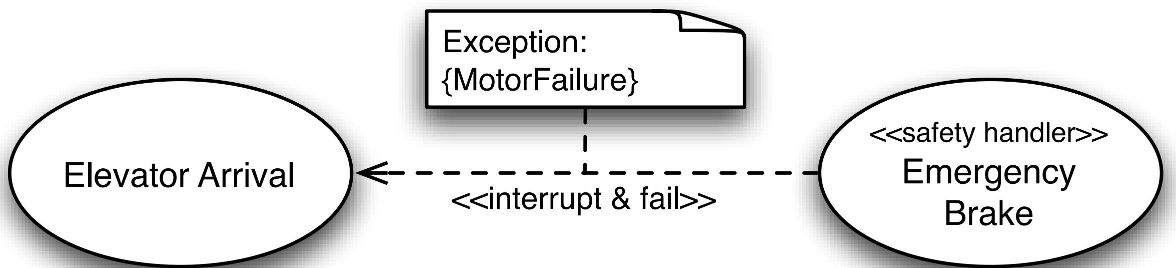
Context & Exception: ElevatorArrival{MotorFailure}

Intention: System wants to stop operation of elevator and secure the cabin.

Level: Subfunction

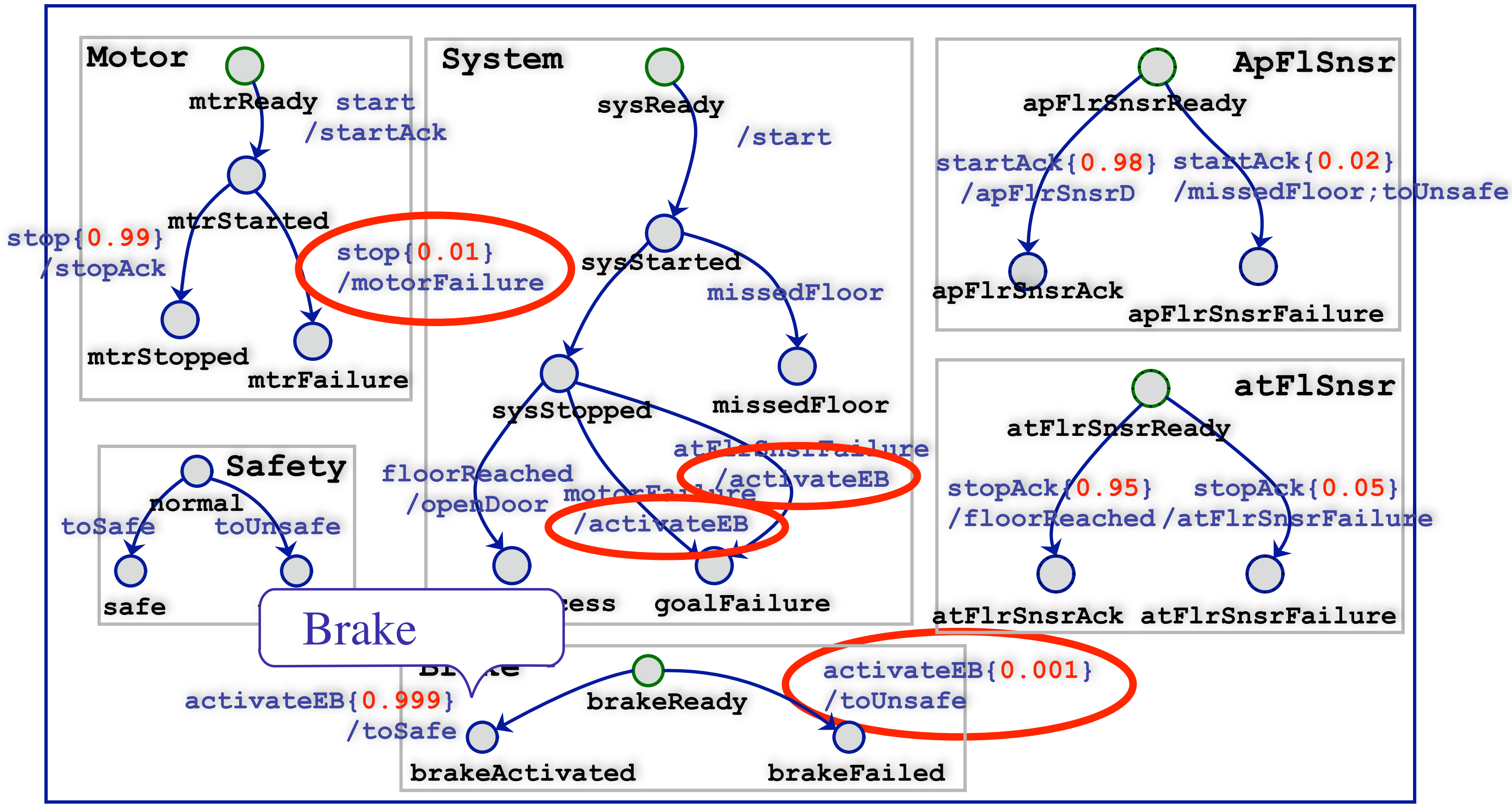
Main Success Scenario:

1. System stops Motor.
2. System activates EmergencyBrakes.
   Reliability: 99.99% Safety-index: 4
3. System turns on the EmergencyDisplay.

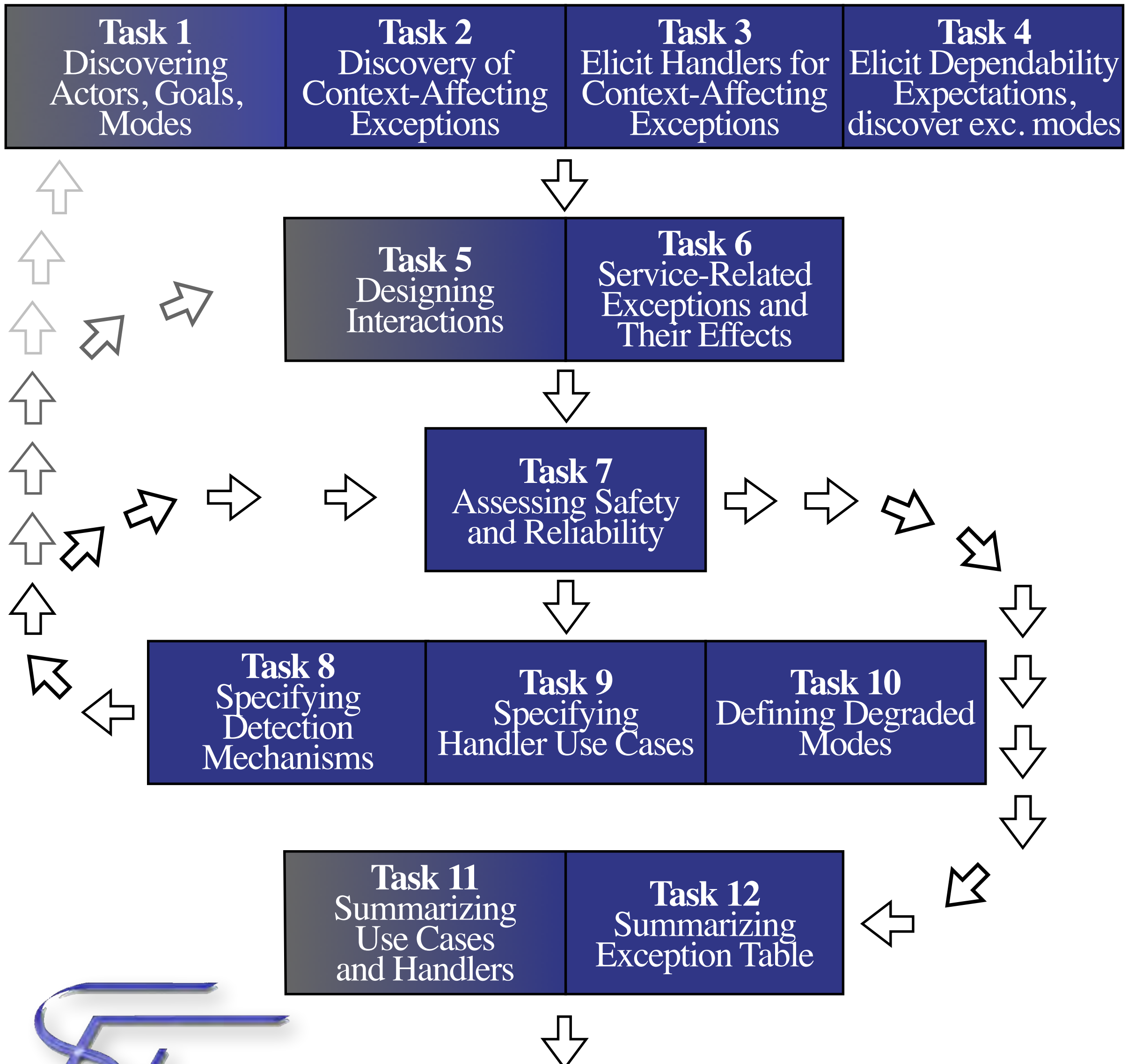


Reliability numbers do not reflect reality!

Task 7: Dependability Assessment



DREP Overview (again)

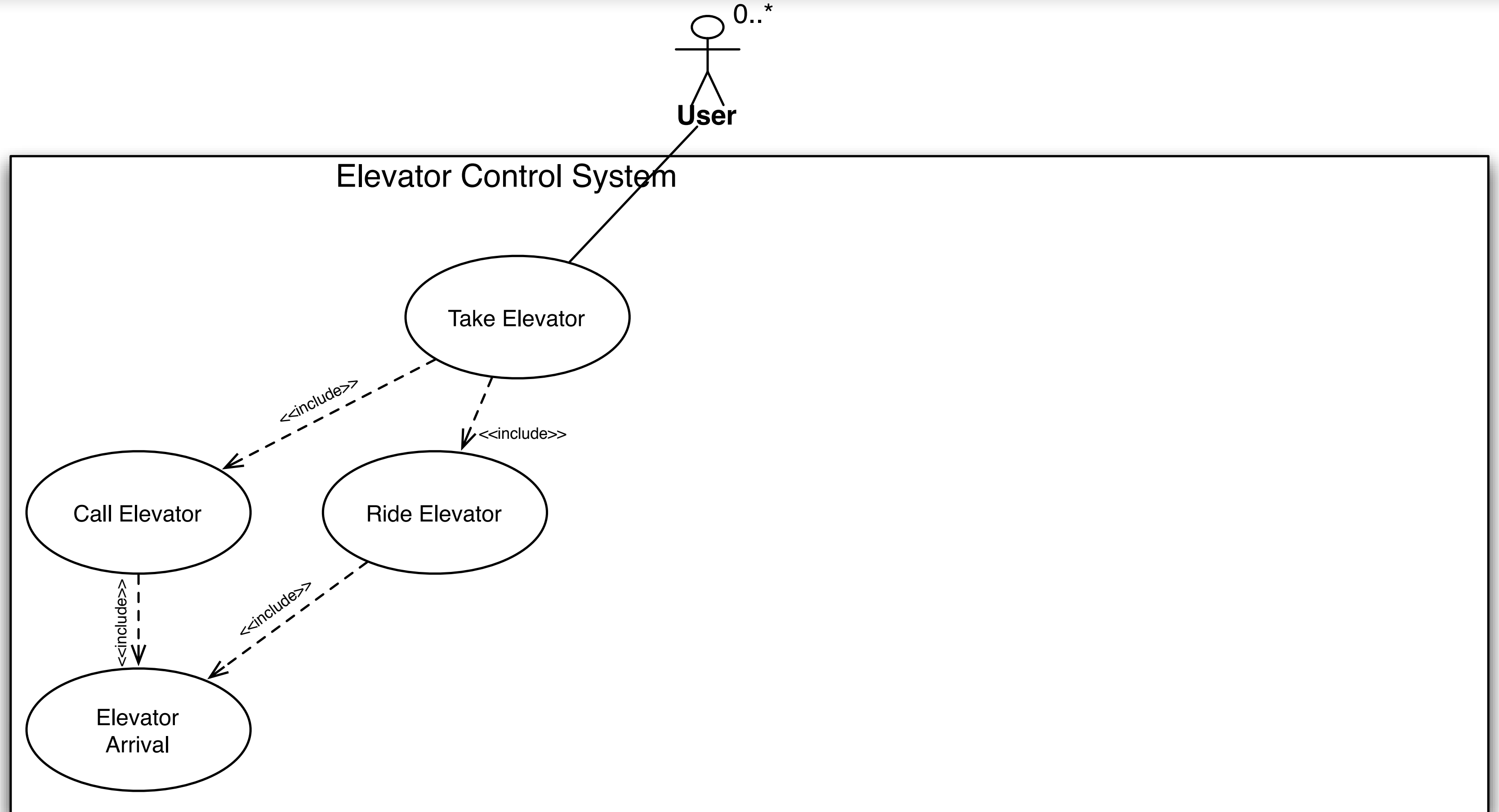


When should a developer stop refining?

When the assessed dependability is acceptable!

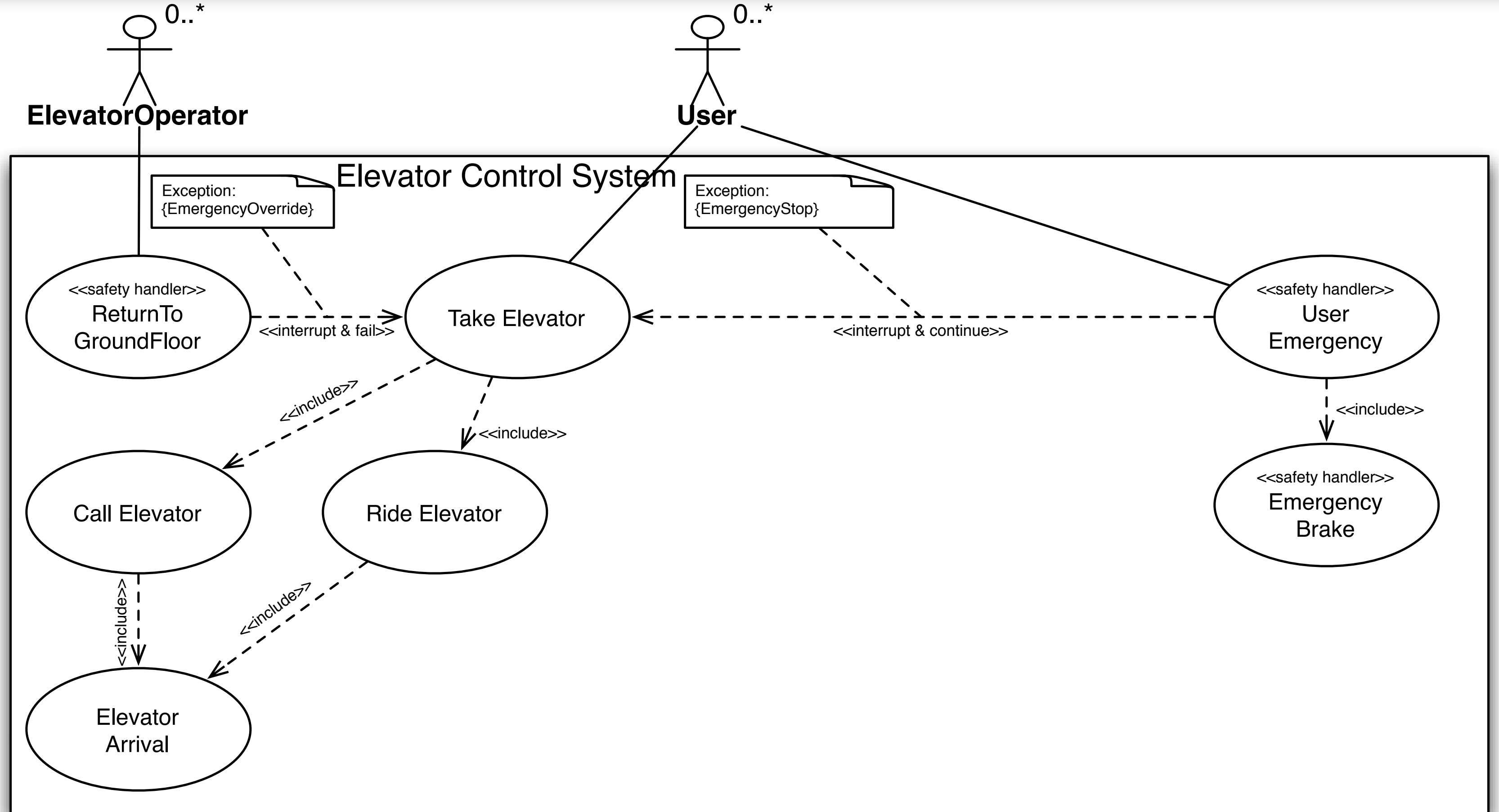
Finally: Build summary use case diagram and exception table

Task 11: Use Case & Handler Summary



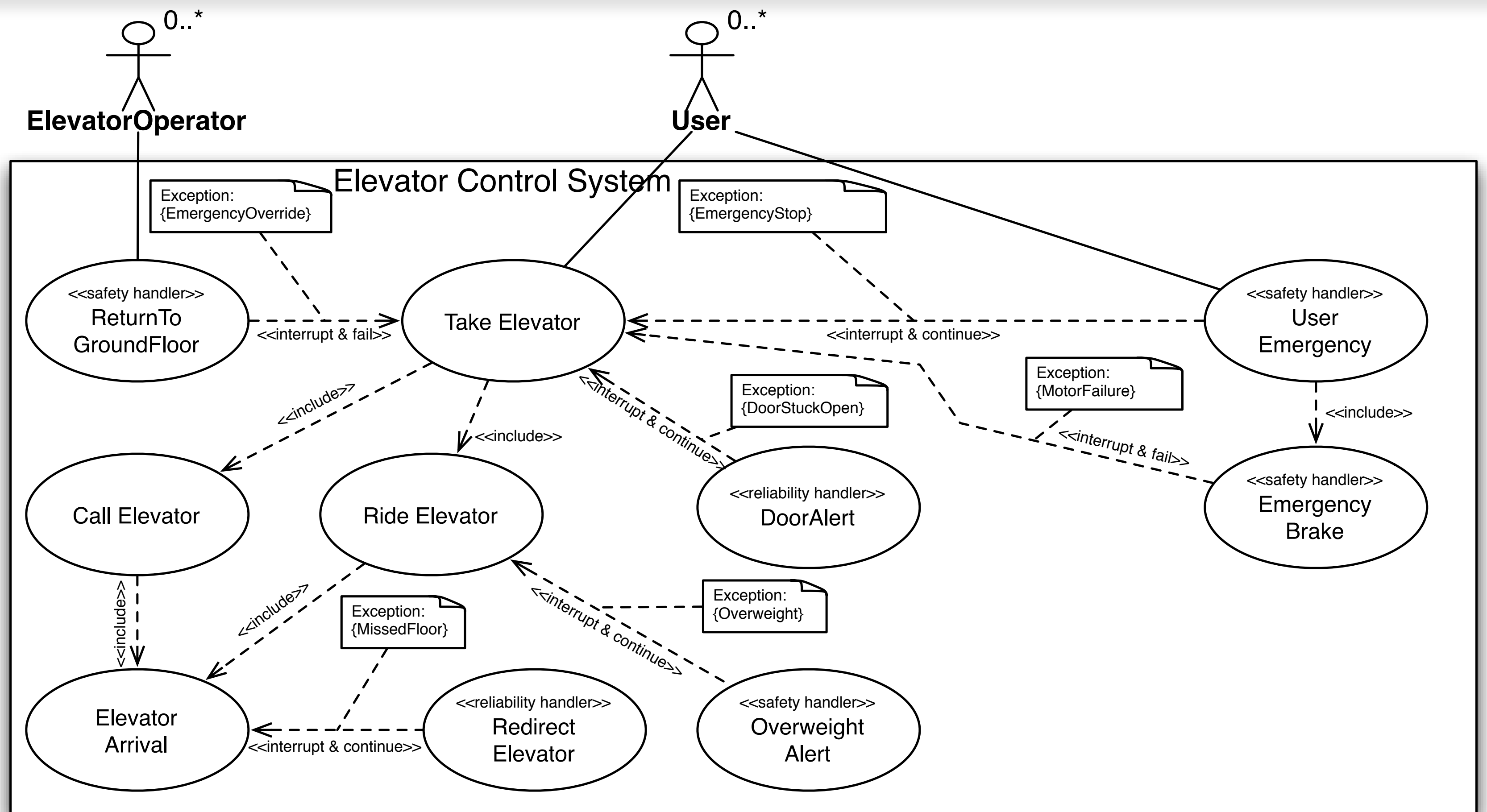
Main Scenario & Alternatives

Use Case & Handler Summary (2)



Environment-related Exceptions
Environment Handlers

Use Case & Handler Summary (3)



Service-Related Exceptions
Detection Mechanisms & Handlers

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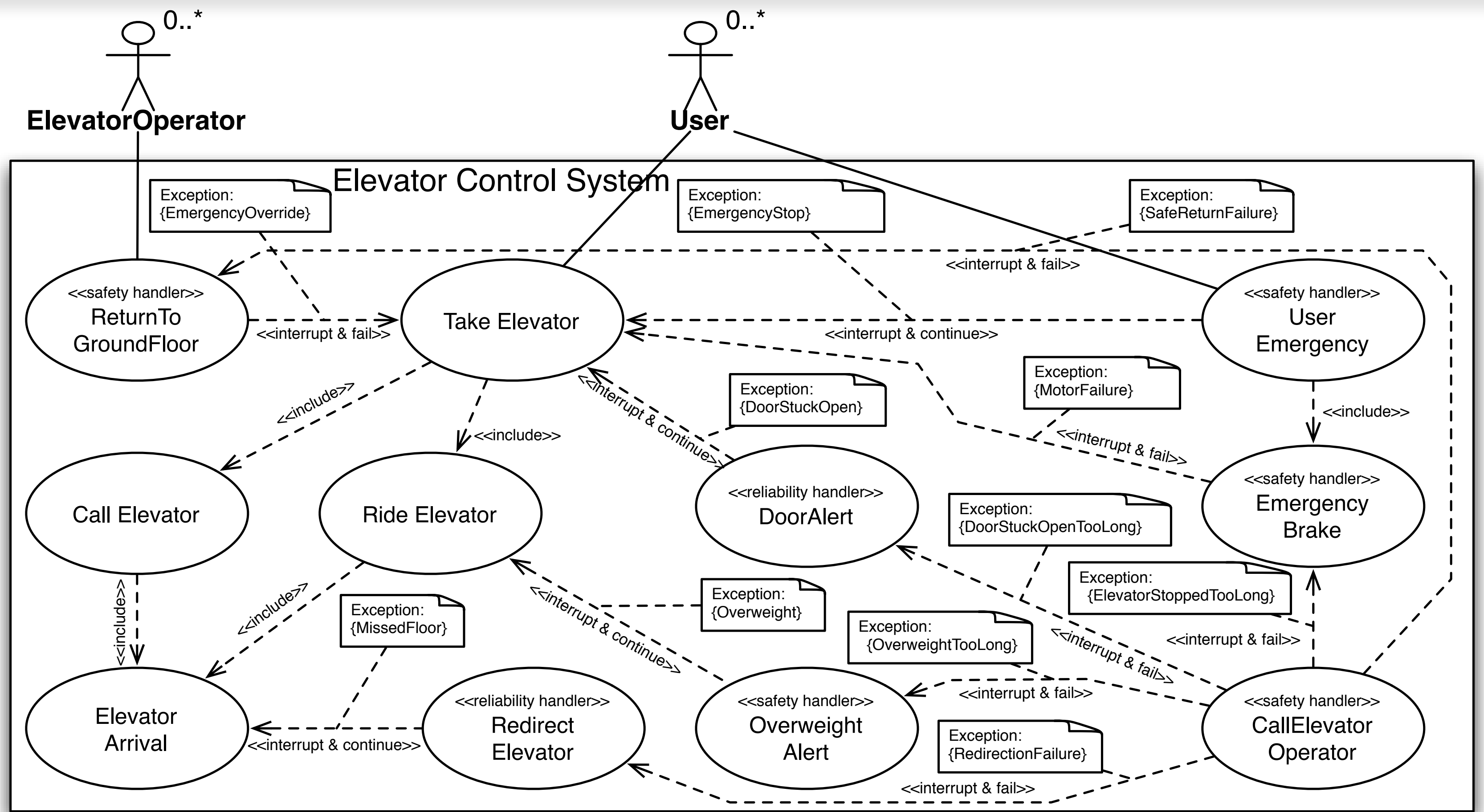
Use Case & Handler Summary (4)



Refined Version that takes into account Exceptions within Handlers

Task 12: Exception Summary

Exception	Description	Context	Handler	Detection
EmergencyStop	An emergency situation in the elevator cabin makes the User want to stop the elevator	TakeElevator	UserEmergency	Triggered by User actor pressing the emergency button
MotorFailure	Due to a motor or communication failure, the motor does not respond to requests	TakeElevator - or - ReturnToGround Floor	EmergencyBrake	Sensor detects cabin is approaching a floor beyond destination floor - or - timeout expires, and no sensor information has been sent
...				

Conclusion

- Focussing on dependability during requirements engineering is essential
  - Discover the users expectations during exceptional situations
  - Predict achievable dependability before investing in any further development activities
- DREP
  - Dependability-aware Requirements Engineering Process
  - Tasks focus the developer on different aspects of dependability
  - Step-by-step instructions
  - Iterative - guided refinement until dependability is achievable
- Dependability-aware Modeling Notations
  - Separate exceptional from normal behaviour
  - Separation enables separate quality control / development / priority
- Tool support

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