Software Architectures for Graceful Degradation in Embedded Systems

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Software Architecture for Graceful Degradation

- **Introduction**
  - Software architecture and embedded systems
  - Graceful degradation
  - RoSES product family architecture

- **Example system: an elevator architecture**
  - Elevator Functionality
  - System sensors/actuators
  - Standard elevator architecture
  - Preliminary architecture for graceful degradation

- **Architectural concerns and evaluation**

- **Summary**

- **Future Questions**
Can we develop software architectures to promote graceful degradation in embedded systems?

Software Architecture
- Overall structure of system
- Decompose system into components and connectors
- Provide ability to reason about system at high level
- Several architectural styles/patterns have been identified

Embedded Systems
- Added system complexity/features is driving larger, more complex software
- Safety-critical, dependability
- Limited hardware resources, extremely cost-sensitive
- Traditional software architectural styles may not be appropriate
Graceful Degradation

- Individual component failures reduce functionality; do not cause system failure
  - Method to achieve robustness, safety, dependability

- Goal: Achieve graceful degradation without explicitly specifying all failure scenarios a priori
  - How can the system’s software architecture influence graceful degradation?

- Possible approaches
  - Highly distributed
  - No single point of failure
  - Components are decoupled and autonomous
  - Redundancy (not as effective for software)

- Case Study: Elevator System
RoSES Product Family Architecture

- Different component configurations provide certain levels of functionality
- Specify architecture with minimum functionality as base configuration
- Focus on architecture for valid component configurations, not reconfiguration problems (Bill Nace’s work)

![Product Family Diagram]

- # Components Installed:
  - N-1
  - N
  - N+1
  - N+2
  - N+3

- Product Family:
  - Standard Product A
  - Standard Product B
  - Standard Product C
  - Standard Product D

- Icons:
  - = Product Variant
  - = Add or Remove a Component
Architectural Decisions

- **Explicitly specify component interfaces**
  - Construct all possible messages to be passed between components
  - Helps determine which components need to communicate

- **Partition Functionality**
  - Separate critical and non-critical functionality
  - Make critical components as autonomous as possible

- **Constrain component configurations**
  - Each component has minimal input/output interface
  - Critical components must be present for base functionality
Elevator Functionality

- **Must transport people between floors**
  - Move car slowly in shaft
  - Stop at every floor
  - Open doors at each floor

- **Must ensure safety**
  - Do not crush people between doors
  - Do not crush people between floor and elevator
  - Do not run car at unsafe speeds
  - Do not trap people in the elevator

- **Optimizations**
  - Only stop on requested floors
  - Provide feedback to passengers
  - Minimize travel time, wait time
Elevator System Sensors and Actuators

**Sensors**

- Elevator position and speed
  - AtFloor[f,d](v)
  - HoistwayLimit[d](v)
  - DriveSpeed(s,d)
- Door sensors
  - DoorClosed[j](v)
  - DoorOpen[j](v)
  - DoorReversal[j](v)
- Passenger requests
  - CarCall[f](v)
  - HallCall[f,d](b)

**Actuators**

- Elevator control
  - DoorMotor[j](m)
  - Drive(s,d)
  - EmergencyBrake(b)
- Button lights
  - CarLight[f](k)
  - HallLight[f,d](k)
- Passenger feedback
  - CarLantern[d](k)
  - CarPositionIndicator(f)

**Control System State**

- DesiredFloor(f,d)
- DesiredDwell(n)
Standard Elevator Control Architecture

- Hierarchical control in layers, modules interdependent
- Vulnerable to single component failures

Diagram:
- Dispatcher
- Safety
  - Drive Control
  - Door Control
  - Hall Call Control
  - Car Call Control
- Sensors/Actuators
- Emergency Brake
- Car Call Buttons/Lights
- Door Call Buttons/Lights
- Hardware Components

Intelligence

Control

Servo
Elevator Architecture: Product 1 (Base)
Elevator Architecture: Product 2

- Add real-time network, buttons

![Diagram of elevator architecture with components such as Drive Control, Door Control, Car Call Control, Hall Call Control, Safety, Sensor, Actuator, and Software Component. Arrows indicate controls, listens to, listens/broadcasts, and network connections.]
Elevator Architecture: Product 3

- Add passenger feedback lights
Elevator Architecture: Product 4

- Add Dispatcher for optimization
Elevator Control System

- Main controllers are autonomous
  - Drive Controller
  - Door Controller
  - Safety

- Other controllers provide “advisory” information
  - HallCall buttons
  - CarCall buttons
  - Dispatcher

- Main controllers follow advice when available
  - Must pass internal consistency checks
  - In absence of advice, perform base functionality
Architectural Concerns (1)

Cost vs. Safety/Dependability

- Adding additional redundant sensors
  - Necessary to ensure safety for main controllers
  - Could add more for each secondary controller, but cost prohibitive

- Network
  - Could be a single point of failure
  - Without it need exponentially more sensors for more features
  - Could add secondary network to increase dependability
Architectural Concerns (2)

- **Abstract sensor/actuator interface for components**
  - Components can access sensors from physical link or network without modifying code
  - Logical interface separates software concerns from hardware concerns

- **System Configurations**
  - Designed into architecture to constrain configuration options
  - Reconfiguration “hardwired”
  - System should survive components failing in arbitrary order
Evaluation

How can I evaluate my architectural design?

- Can’t build working elevator and test it
- Simulation of a distributed network

Simulation framework exists from ECE 540/549 class

- Build executable system from my architecture
- Fault injection mechanisms to fail components during system operation
- Measure performance delivering passengers for each configuration
Summary

- Embedded Systems need methods to ensure safety, dependability, robustness
  - Graceful Degradation
- System’s software architecture may strongly influence whether graceful degradation is achievable
- Design a software architecture for an elevator system
  - Distributed
  - Decoupling of components
  - Product family structure
  - Some hardware replication
- Build executable system and test it
- How well does it promote graceful degradation?
Future Questions

◆ Can we develop an architectural style specifically for graceful degradation?
  • Embedded systems have special concerns
    – Cost
    – Constrained resources

◆ Can we apply it to multiple domains?
  • Elevator
  • Automobile navigation system
  • Drive-by-Wire