Using Architectural Properties to Model System-Wide Graceful Degradation

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Scalable Graceful Degradation

- **Graceful degradation can increase system dependability**
  - Individual component and subsystem failures reduce functionality but do not cause a system failure
  - Non-critical features shed while critical features are preserved

- **Current practice for specifying graceful degradation: [Herlihy91]**
  - Specify a “relaxation lattice” of system constraints
    - Constraints are relaxed as failures occur
  - Lattice is exponentially complex with number of constraints
  - Must specify a specific system response for each lattice point

- ***IDEA:* Exploit system decomposition into subsystems and components**
  - *Goal:* Create a more scalable model for graceful degradation

Focus: Dependable Embedded Systems

- **Embedded systems are increasingly software driven**
  - Complex software systems necessary to implement more features and functionality
  - “Smart” sensors and actuators encourage more distributed/networked systems
- **But, they have high dependability requirements…**
  - System failures have high consequences (loss of life, money)
  - Software patch or upgrade is often impractical
- **… and are extremely cost sensitive**
  - System-wide replication for dependability is cost prohibitive

How can we get scalable, graceful degradation for them?

Utility and Graceful Degradation

- ***Utility*** **- measure of system's usefulness**
  - Different for each problem domain
  - Incorporate functionality, reliability, performance, etc.

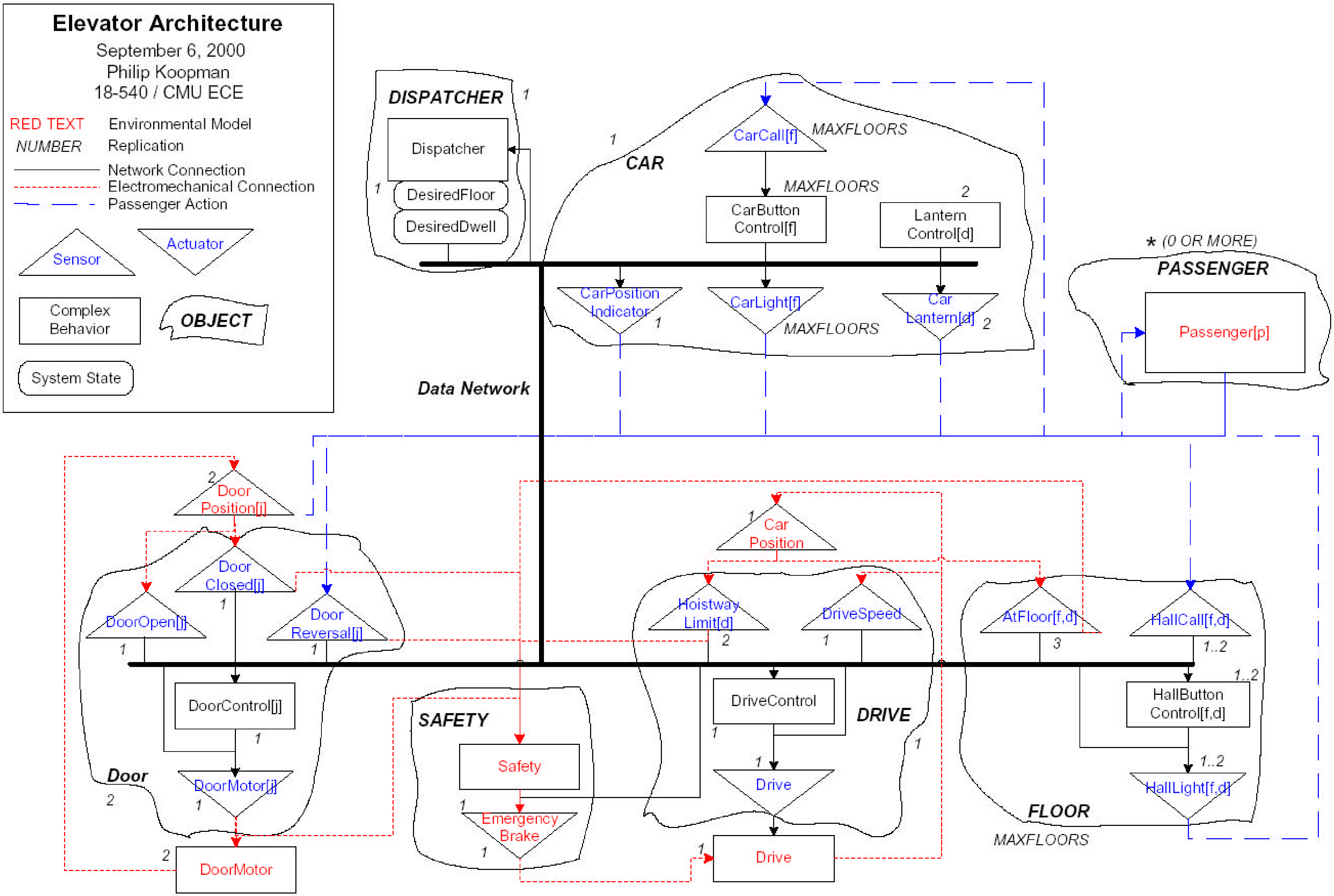
- **System Utility is a function of component utilities**
  - Maximum Utility – All system components working
  - Some Utility – degraded system operation
  - Zero Utility – System failure

- **Graceful Degradation goal:**
  - Component failures proportionately reduce system utility
  - Ideally, each functional subsystem retains residual functionality
    - Previous work assumed whole-subsystem failures, not component failures

Key Is Handling System Configurations

- **Focus on software component configurations**
  - Assume individual software components either working or failed
  - 2^n possible configurations of n software components
    - Each configuration can be represented as a string of n bits
- **For sufficient graceful degradation we want:**
  - Many valid configurations
  - System bit string values with low Hamming distance have small differences in utility
- **Previous work considered the subsystem level**
  - What if instead we looked at fine grain component level?
  - “n” goes from a handful to perhaps hundreds
  - Analysis complexity is $O(2^n)$ – are we crazy?

Example Elevator System Architecture



Utility Analysis

- **Utility analysis for all system configurations is $O(2^n)$**
  - *But*, we are only interested in valid configurations
    - Correct sensors and actuators present for desired functionality

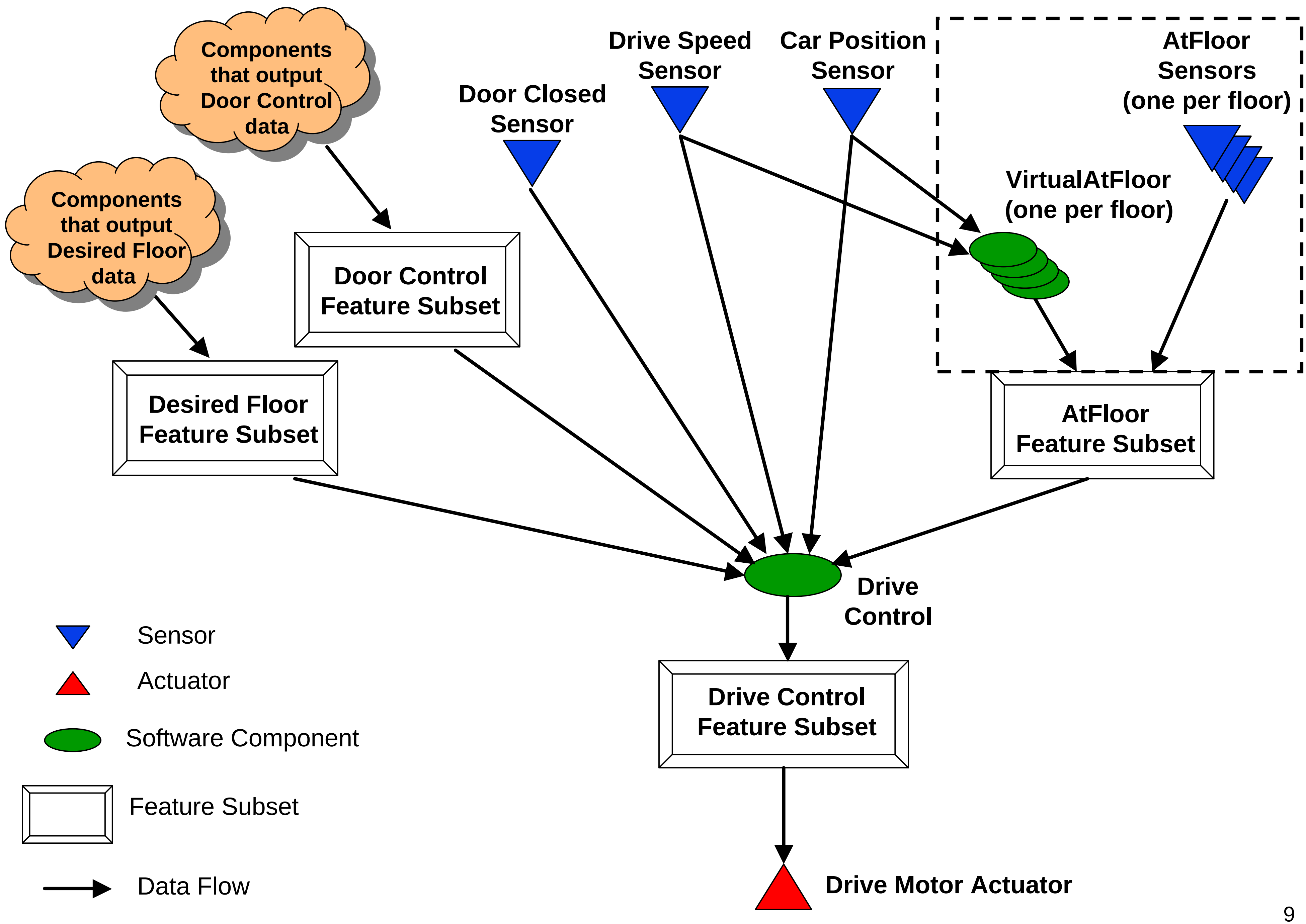
- **Software architecture constrains valid configurations**
  - Component and interface definitions
  - Organization of components into subsystems
  - Dependencies between subsystems

- **Develop system model for scalable analysis**
  - System data flow graph derived from interfaces among components
  - *Feature subsets* defined from subgraphs of components

Feature Subsets

- **A *feature subset* is a subset of components that outputs a set of system variables**
  - Defined by component output interfaces
  - A feature subset with $k << n$ components has 2^k configurations
  - Each feature subset defines (potentially overlapping) subsystems
- **Allow hierarchical definition of subsystems**
  - Feature subsets can contain other feature subsets as components
- **Identify critical and non-critical feature subsets**
  - System utility is zero when critical feature subset's utility is zero
- **Finding valid system configurations made easier:**
  - Only determine valid configurations for each critical feature subset
  - *Exploit fact that many systems have decoupled subsystems*

Drive Control Feature Subsets



Conclusions

- **Our system model for graceful degradation enables scalable system analysis**
  - Use feature subset definitions to simplify configuration analysis
    - Only consider subsets of each configuration bit string relevant to a feature subset
    - If average feature subset has k << n components, analysis reduces from $O(2^n)$ to $O(n/k * 2^k)$
  - Can determine all valid configurations without examining every possible component configuration
    - Encapsulate graceful degradation analysis within each subsystem

- **Model provides structured view of system-wide graceful degradation**
  - Identify system properties that improve graceful degradation
  - Identify critical subsystems that require extra redundancy
  - Basis to compare graceful degradation of similar configurations