Model-Based Software Design and Adaptation

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Dynamic Software Adaptation in Safety Critical Systems

- Safety Critical Systems
  - Highly available, Time critical
- Examples: air traffic control systems, spacecraft, automotive and aircraft control systems
- Challenge
  - Evolve the configuration of software application at run-time
  - Application must be operational during dynamic reconfiguration

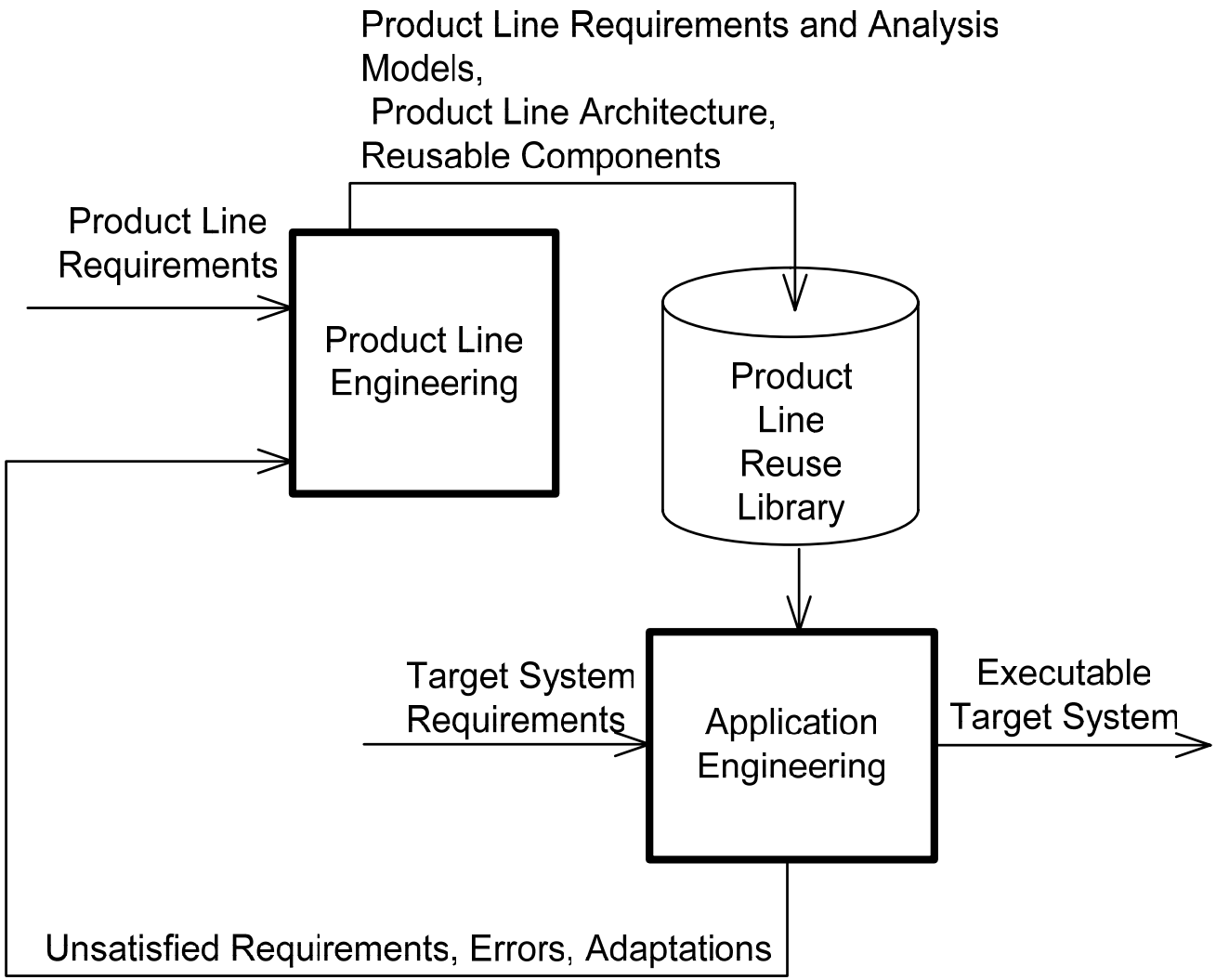
Approach

- Most software product line research aimed at deriving different family members from
  - Product line architecture + implementation
  - At Configuration Time
  - NOT at Run Time
- Research approach
  - Model all configurations of safety critical system as product line members
  - Dynamically change from one family member to a different family member at Run Time
  - Develop Software Reconfiguration Patterns

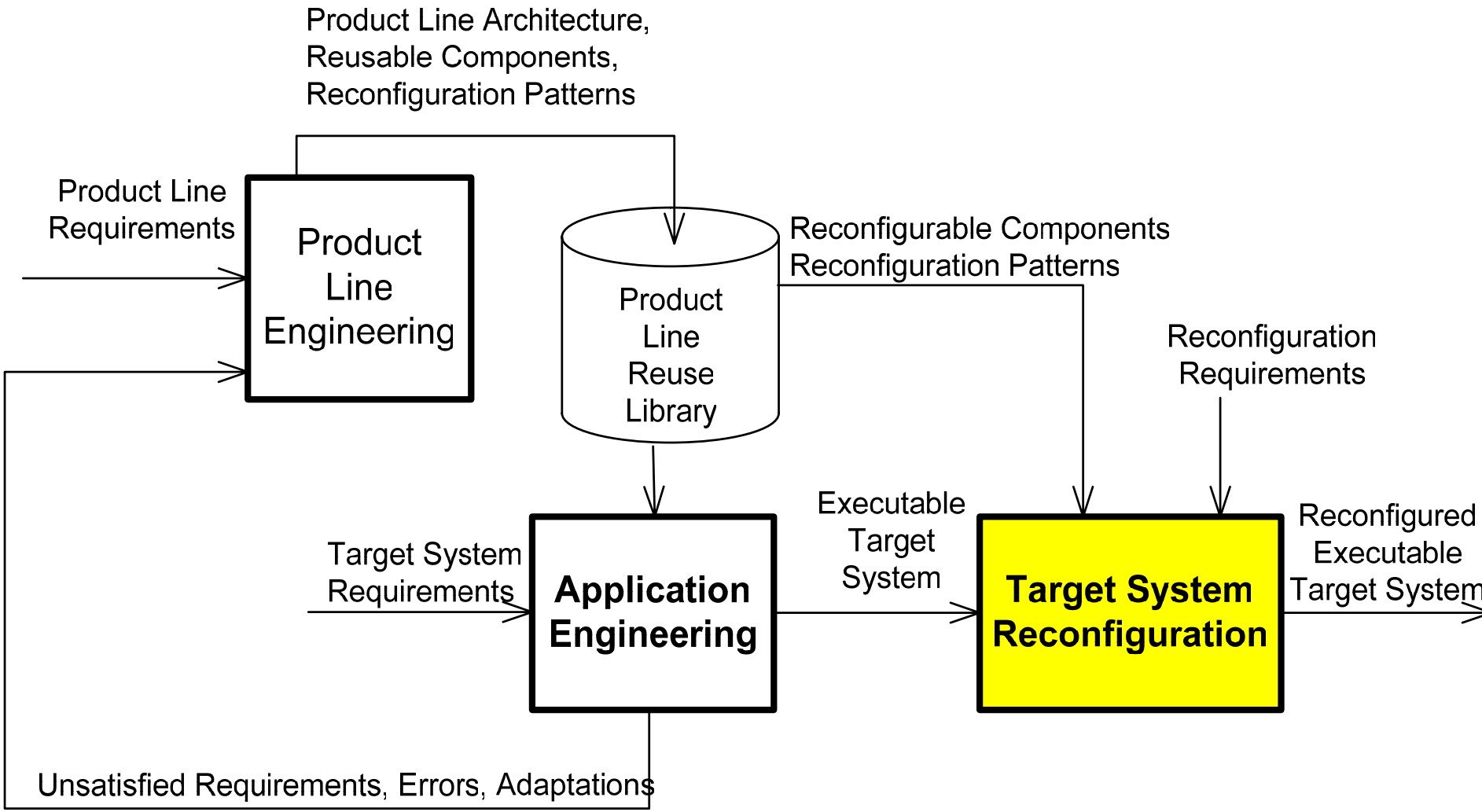
Related Work

- Dynamic Reconfiguration Environments
  - Dynamically change a software configuration to a new configuration
    - Conic / Regis (Imperial College)
    - C2 (UC Irvine)
- Software Design and Architectural Patterns
  - Systematic reuse concepts for the design of applications
    - Gamma et al, Buschmann et al
- Reusable and Configurable Product Line Architectures
  - Product line design methods and tools (GMU EDLC/KBSEE)
  - KOALA (Philips)
  - FAST (Lucent)
  - PULSE/KOBRA (Fraunhofer)

Evolutionary Product Line Life Cycle - Build, then Deploy



Reconfigurable Evolutionary Product Line Life Cycle
Reconfigure *after* Deployment



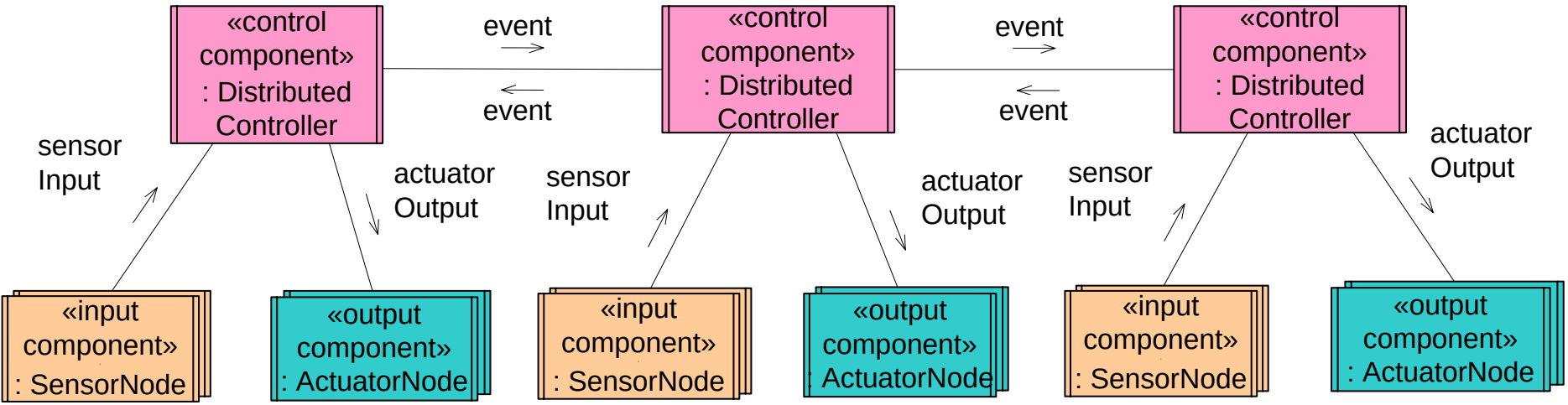
Software Architectural Patterns

- Software Architectural Patterns [Buschmann, Shaw]
  - Recurring architectures used in various software applications
- Goal: Design Software Architecture from
  - Software Architectural Patterns
- Architectural Structure Patterns
  - Address structure of major subsystems
- Architectural Communication Patterns
  - Reusable interaction sequences between components

Architectural Structure Patterns for Software Product Lines

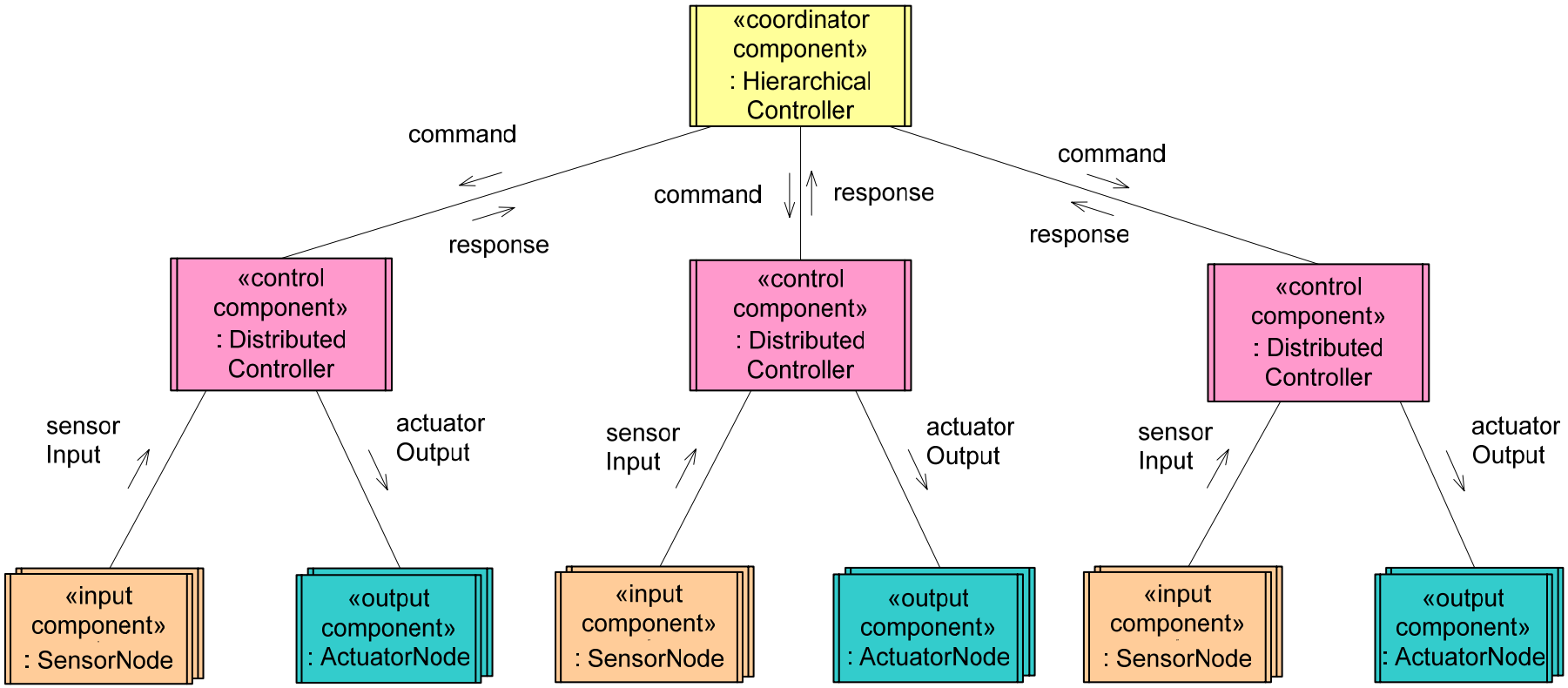
- Layered patterns *very important for evolution*
  - Layers of Abstraction
  - Kernel
- Client/Server patterns
  - Basic Client/Server
  - Client/Broker/Server
  - Client/Agent/Server
- Control Patterns *very important in RT Design*
  - Centralized Control
  - Distributed Control
  - Hierarchical Control

Distributed Control Pattern



- Several control components
- Control is distributed among components
- Each component controls part of system
  - Receives sensor input from input components
  - Executes state machine
  - Controls external environment via output components
  - Communicates with other control components to provide overall control

Hierarchical Control Pattern



- Hierarchical Controller
  - Provides high level control
  - Sends commands to lower level control components

Architectural Communication Patterns for Software Product Lines

- Asynchronous communication patterns
- Synchronous communication patterns

- **Very important for evolutionary design:**

Concurrent component

- Broker Communication Patterns
  - Broker forwarding
  - Broker handle
  - Discovery

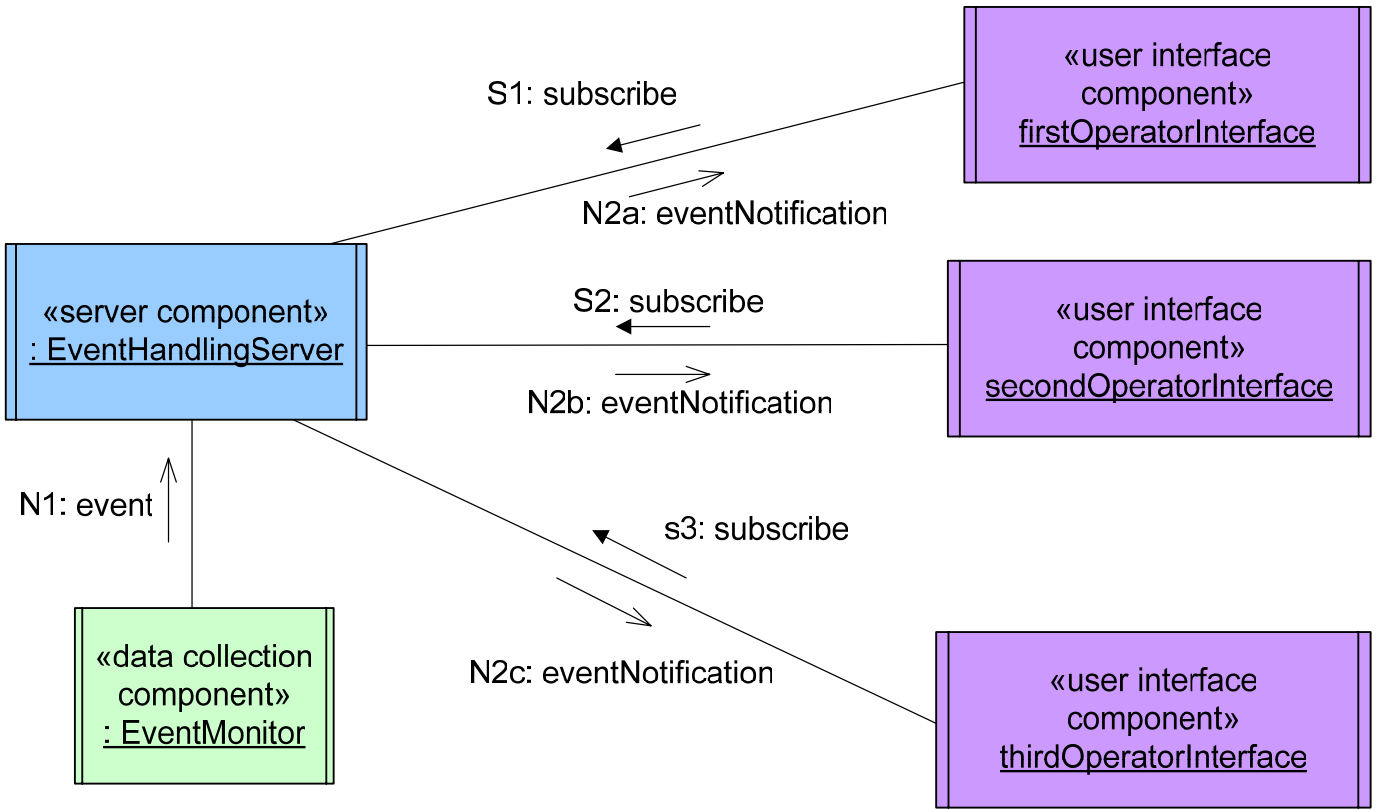
Asynchronous message

Synchronous message

Response to synchronous message

- Group Communication Patterns
  - Broadcast
  - Subscription/notification

Subscription/Notification Pattern



- Subscription/Notification Pattern
  - Client subscribes to join group
  - Receives messages sent to all members of group

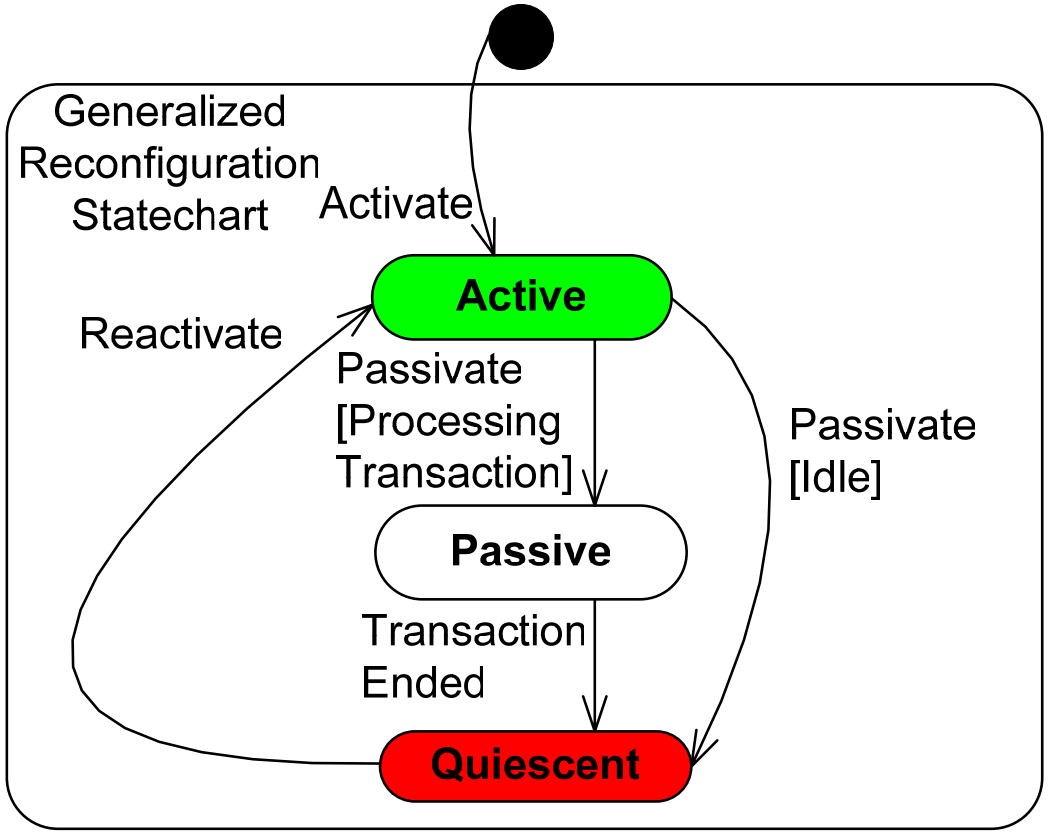
Software Reconfiguration Patterns

- Concept
  - Design software architecture based on software architectural patterns
  - For every software architectural pattern
    - Design a software reconfiguration pattern
- Reconfiguration Pattern
  - Specifies how a set of components cooperate to change the system configuration to a new configuration
- Characteristics of Reconfiguration Pattern
  - Reconfiguration state machine model
    - Component transitions to a state where it can be removed and replaced
  - Reconfiguration Collaboration model
    - Component interactions to change configuration

Reconfiguration State Machine Model

- Basic Model is based on Kramer/Magee
  - Component transitions to a state where it can be reconfigured
  - Active State: Component is operational
  - Passive State: Component
    - Is not participating in a transaction that it initiated
    - Still participating in other transactions
  - Quiescent State: Component
    - Idle
    - Not participating in any transactions
    - Ready to be removed from configuration

Reconfiguration State Machine



Software Reconfiguration Patterns

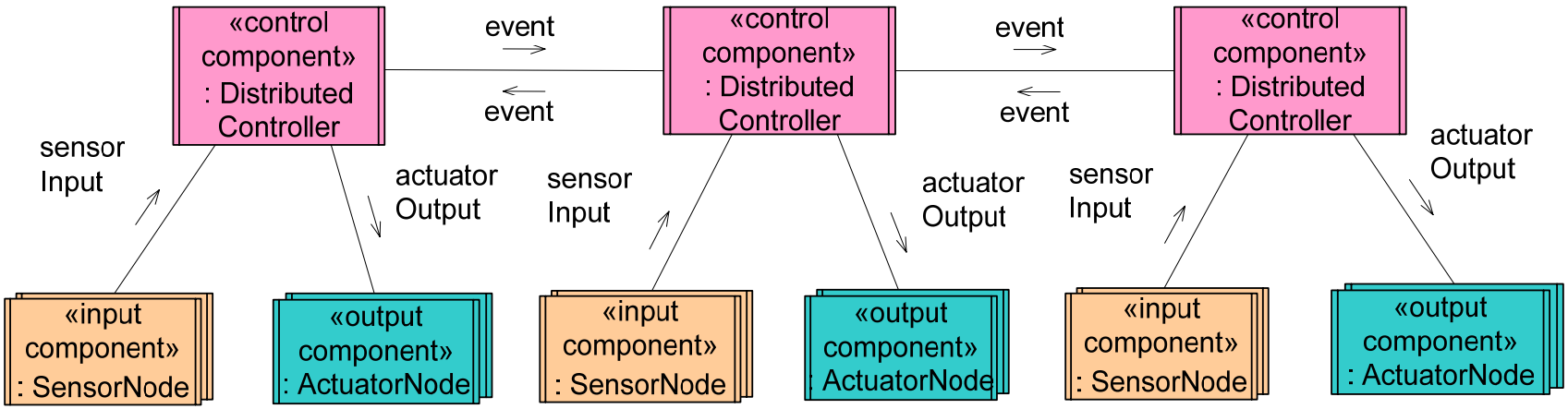
- Approach
  - Develop reconfiguration patterns for well-known software architectural patterns
  - Build software product line architectures using
    - Software architectural patterns
    - Software reconfiguration patterns
- Software Reconfiguration Patterns developed
  - Master-Slave pattern
  - Centralized Control pattern
  - Client / Server pattern
  - Decentralized Control pattern

Software Reconfiguration Patterns

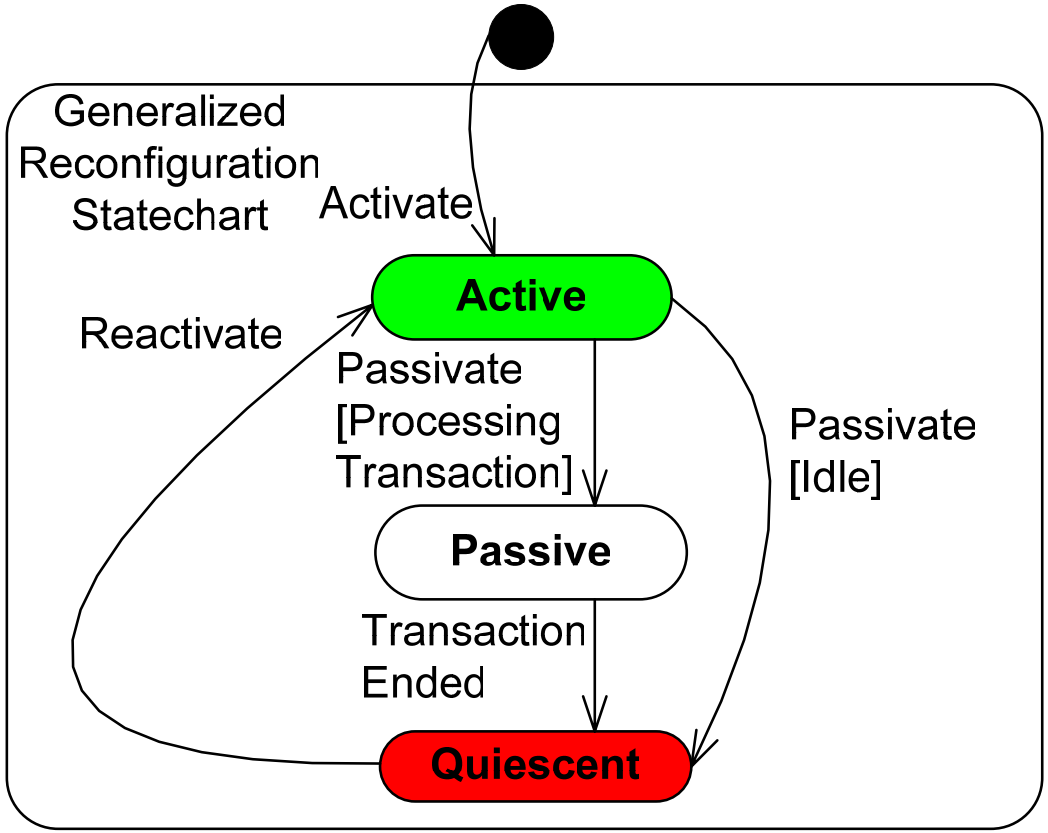
- Master-Slave pattern
  - Master component can be replaced after receiving responses from all Slave components
  - Slave components can be replaced after Master is quiescent
- Centralized Control pattern
  - Removing or replacing any component in the system requires the Central Controller to be quiescent
- Client / Server pattern
  - Client can be added or removed after completing a transaction
  - Server can be removed or replaced after completing current transaction (s)
- Decentralized Control pattern

Decentralized Control Reconfiguration Pattern

- Decentralized Control components communicate with each other
  - Components must notify each other if going quiescent
  - Component can cease to communicate with neighbor but can continue with other processing



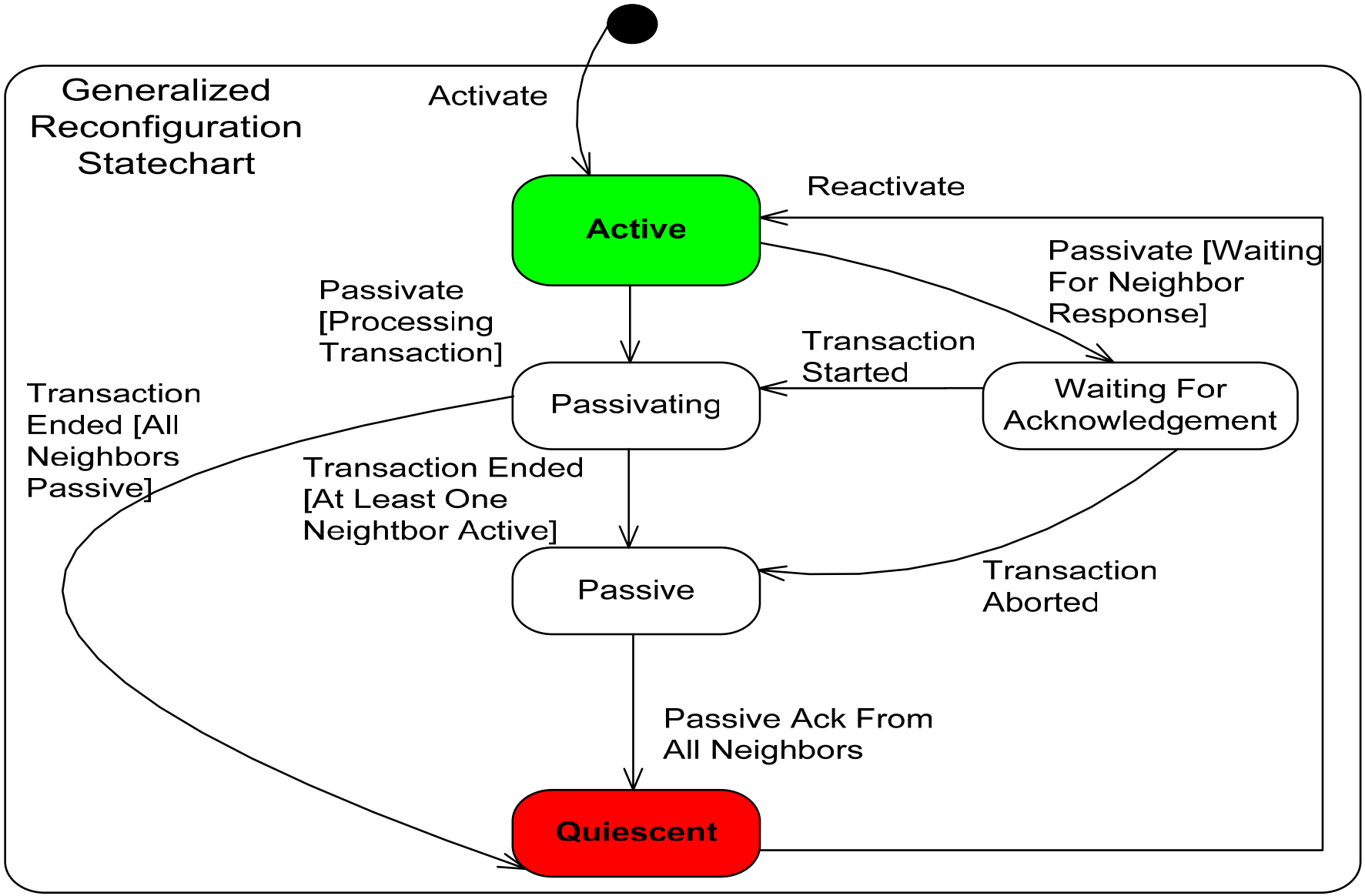
Reconfiguration State Machine



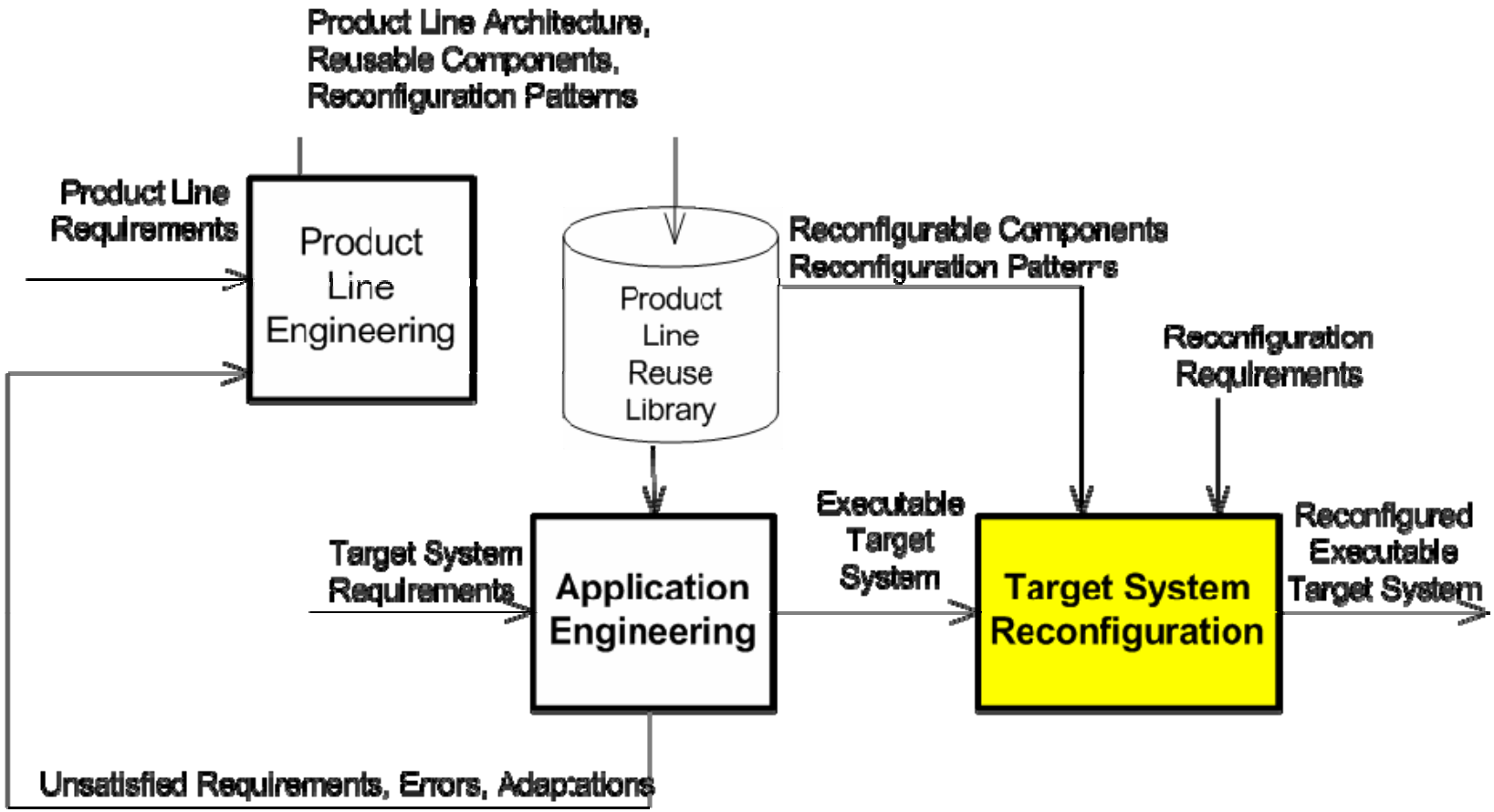
Component Reconfiguration State Machine

- New states to assist components in the reconfiguration process
- Needed for more complex component interactions
  - Passivating State: Component
    - Is disengaging itself from transactions
      - It is participating in
      - It has initiated
    - Is not initiating any new transactions
  - Waiting For Acknowledgement State:
  - Component has sent notification message (s) to disengage itself
    - To interconnected components

Reconfiguration State Machine



Dynamic Software Reconfiguration Framework



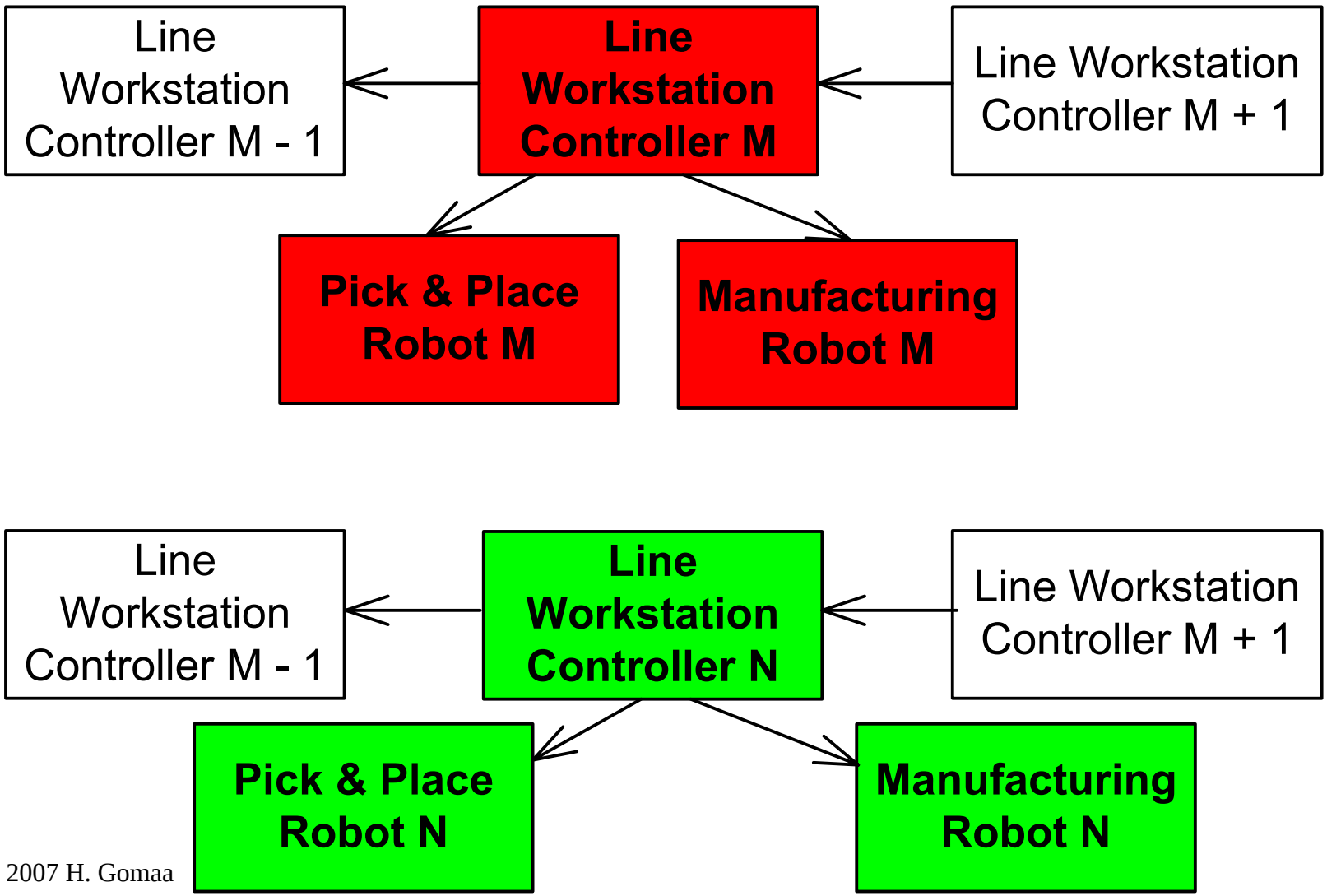
- Manages reconfiguration process
  - Different configurations are members of product line

Dynamic Software Reconfiguration

- Change Management Model
  - Reconfiguration steps to switch from old to new configurations
  - Drive components to
    - Full quiescence, e.g., to unlink and remove
    - Partial quiescence, e.g., to unlink
  - Change configuration commands
    - E.g., to replace component:
    - Quiesce, unlink, remove old component, insert new component, relink, restart
- Prototype developed using Rational Rose RT

Example of Dynamic Software Reconfiguration

- Reconfigurable factory automation SPL architecture
  - Uses: Master-Slave, Client / Server, & Decentralized Control patterns



Conclusions

- Goal
  - Dynamically change from one SPL family member to a different family member at Run Time
- Research Approach
  - Software Reconfiguration Patterns
- Dynamic Software Reconfiguration framework
  - Rose RT environment
- Future work
  - Develop additional reconfiguration patterns
  - Investigate issues of pattern interaction
  - Investigate performance issues in dynamic reconfiguration
  - Investigate unplanned or unexpected dynamic recovery and reconfiguration issues