SWE 760

Lecture 11 – Detailed Real-Time Software Design

Reference:
H. Gomaa, Chapter 14 - *Real-Time Software Design for Embedded Systems*, Cambridge University Press, 2016

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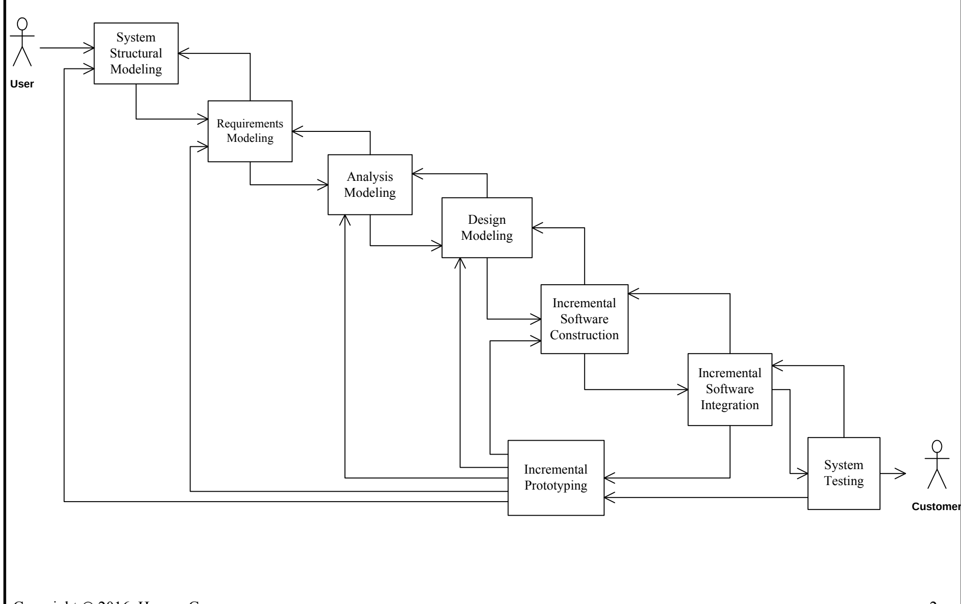
Figure 4.1 COMET/RTE life cycle model



Software Modeling for RT Embedded Systems

1 Develop RT Software Requirements Model
- Develop Use Case Model

2 Develop RT Software Analysis Model
- Develop state machines for state dependent objects
- Structure software system into objects
- Develop object interaction diagrams for each use case

3 Develop RT Software Design Model
- Design of Software Architecture for RT Embedded Systems
- Apply RT Software Architectural Design Patterns
- Design of Component-Based RT Software Architecture
- Design Concurrent RT Tasks
- **Develop Detailed RT Software Design**
- Analyze Performance of Real-Time Software Designs

Detailed Software Design

- Detailed Design of composite tasks
  - Active object that contain nested passive objects
  - Designed using task clustering criteria
  - Internal design of composite task
  - Design class interfaces of nested classes
- Design details of task synchronization
  - Passive objects accessed by more than one task
- Design connector classes
  - Address details of inter-task communication

Example of Design of Composite Task Containing Passive Objects

- Temporal clustering and device I/O objects
  - Temporal clustering task
    - Polled I/O
    - Activated periodically
    - Two passive devices
  - Information hiding objects
    - Device I/O Objects
      - Hide details of how to read from device
  - Operations executed in thread of control of task

Fig 14.3a Before task clustering

Figure 13.12a Example of temporal clustering
- periodic I/O tasks before temporal clustering

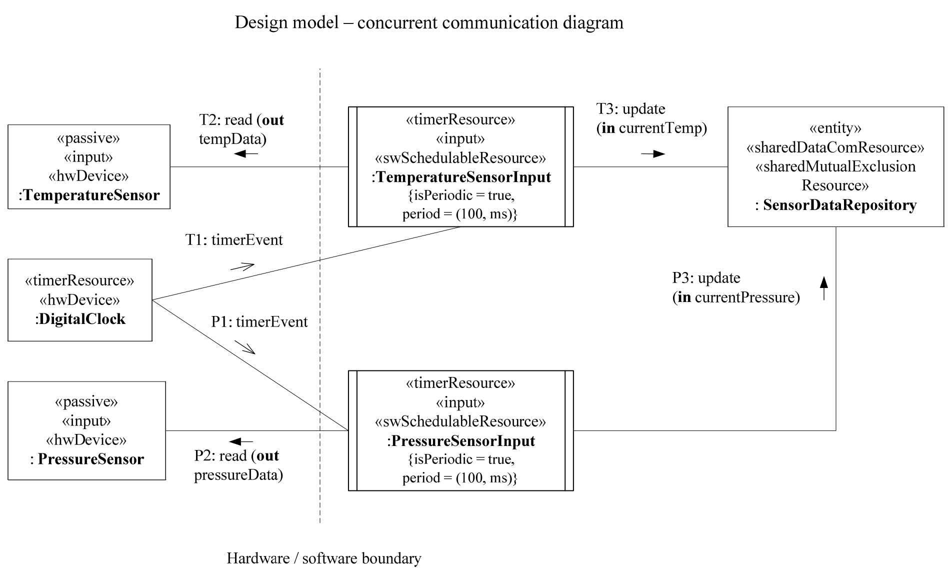
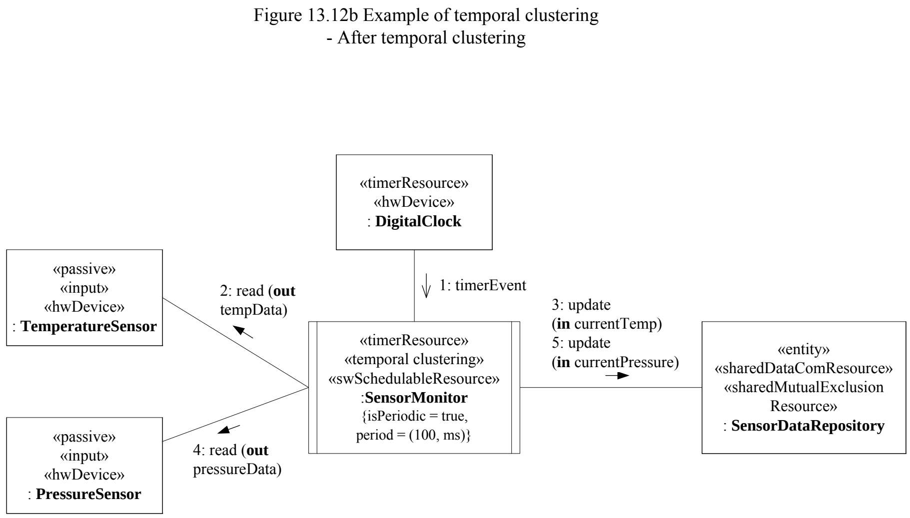


Fig 14.3b After task clustering



Device I/O Class

Originally determined in Analysis Model

- Provides virtual interface to device

Hides actual interface to real world device

Insulate users of class from changes to real world device

- Input, Output, I/O class

Supports virtual interface via operations

Impact of changes to real world interface

- Specification of operations is unchanged
- Internals of operations change

Figure 14.3c Example of temporal clustering and input objects

Figure 14.3c Design of nested input classes

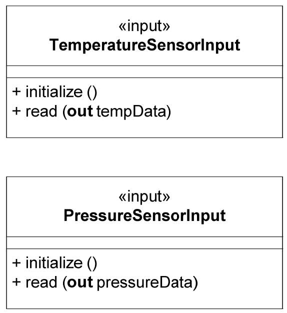
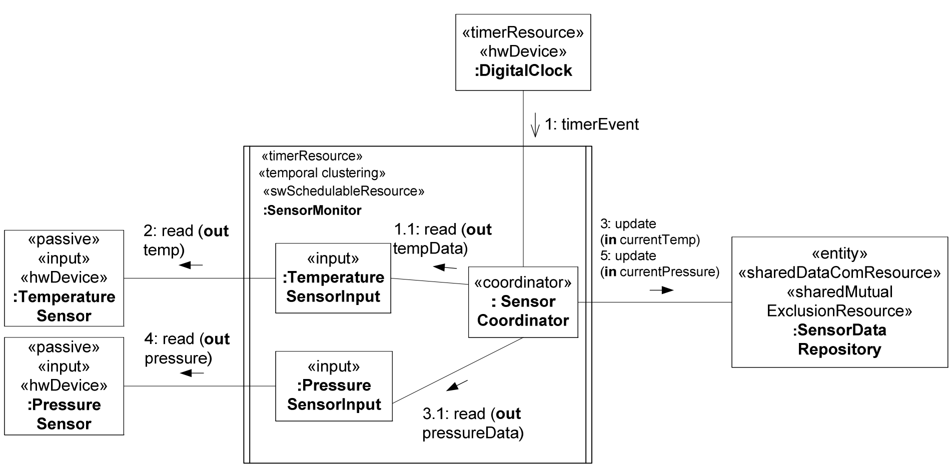


Figure 14.3 Example of temporal clustering and input objects

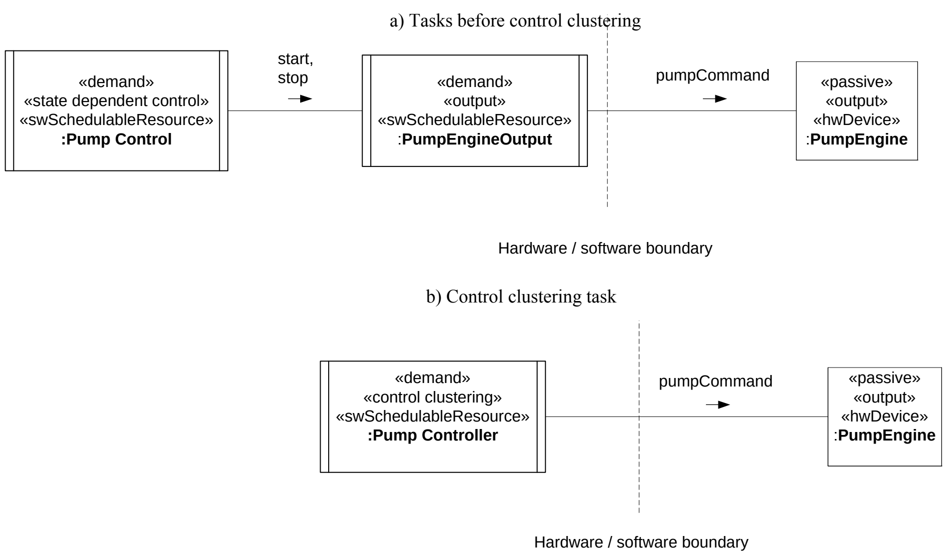
Figure 14.3d Temporal clustering task with nested input objects



Example of Design of Composite Task Containing Passive Objects

- Control clustering task and passive objects
  - Control clustering task
  - Information hiding objects
    - State dependent control object
    - Device I/O Object
  - Operations executed in thread of control of control clustering task
- Concurrent access to classes
  - Classes inside task do not need synchronization
  - Classes outside task need synchronization

Figure 14.4 Example of Control Clustering with passive objects



State Machine Class

Hides contents of statechart / state transition table

- Maintains current state of object

Process Event Operation

- Called to process input event
- Depending on current state and conditions
  - Might change state of object
  - Might return action(s) to be performed

Current State Operation

- Returns the state stored in state transition table

If state transition table changes
Only this class is impacted

Fig. 14.2: Example of State Machine class

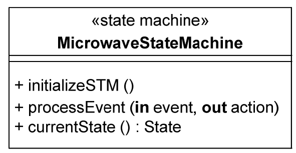


Figure 14.4c Design of nested state machine and output classes

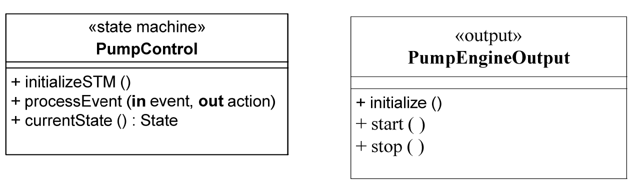
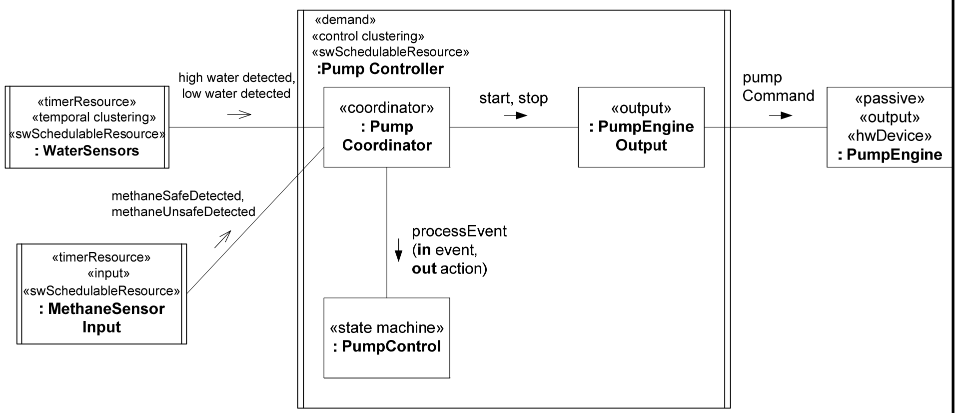


Figure 14.4 Example of control clustering task with passive objects

Figure 14.4d Control clustering task with nested passive objects

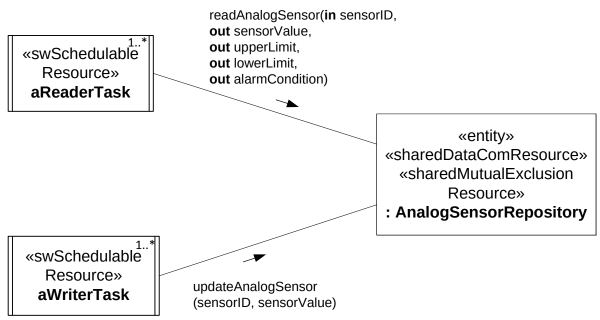


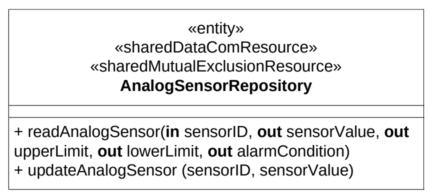
Synchronization of Tasks Interacting via Passive Objects

Task interaction via shared data
- Needs synchronization

Task interaction via passive data abstraction object
- Hides structure of data repository
- Hides synchronization from tasks
- Two possible solutions
  - Mutual exclusion
  - Multiple readers / multiple writers

Figure 14.5 Example of concurrent access to passive entity object





Information Hiding Objects Synchronization of Access

- Each information hiding object
  - Designed for application
- Mutually exclusive access to data repository
  - Only one task can access data repository at a time
  - Use binary semaphore
- Access by multiple readers / writers
  - Allows access to data repository
  - By many readers concurrently
    - Only one writer

Interaction Between Concurrent Tasks

- Mutual exclusion
  - Two or more tasks need to access shared data
  - Access must be mutually exclusive
- Binary semaphore
  - Boolean variable that is only accessed by means of two atomic (indivisible) operations
  - **acquire (semaphore)**
    - if the resource is available, then get the resource
    - if resource is unavailable, wait for resource to become available
  - **release (semaphore)**
    - signals that resource is now available
    - if another task is waiting for the resource, it will now acquire the resource

Example of Mutual Exclusion (Page 276)

- Solution uses one binary semaphore

public readAnalogSensor (**in** sensorID, **out** sensorValue, **out** upperLimit, **out** lowerLimit, **out** alarmCondition)

-- Critical section for read operation.

acquire (sensorDataStoreSemaphore)

    sensorValue := sensorDataStore (sensorID, value)
    upperLimit := sensorDataStore (sensorID, upLim)
    lowerLimit := sensorDataStore (sensorID, loLim)
    alarmCondition := sensorDataStore (sensorID, alarm)

release (sensorDataStoreSemaphore)

end readAnalogSensor;

Example of Mutual Exclusion (Pages 276-277)

public updateAnalogSensor (**in** sensorID, **in** sensorValue)
-- Critical section for write operation.
acquire (sensorDataStoreSemaphore)
    sensorDataStore (sensorID, value) := sensorValue
    if sensorValue >= sensorDataStore (sensorID, upLim)
        then sensorDataStore (sensorID, alarm) := high
    elseif sensorValue <= sensorDataStore (sensorID, loLim)
        then sensorDataStore (sensorID, alarm) := low
        else sensorDataStore (sensorID, alarm) := normal
    endif;
release (sensorDataStoreSemaphore)
end updateAnalogSensor;

Example of Multiple Readers / Multiple Writers (Pages 277-278)

- Solution uses two binary semaphores and one integer

public readAnalogSensor (**in** sensorID, **out** sensorValue, **out** upperLimit, **out** lowerLimit, **out** alarmCondition)
-- Read operation called by reader tasks. Several readers are allowed
-- to access the data store providing there is no writer accessing it.
acquire (readerSemaphore)
    Increment numberOfReaders
    if numberOfReaders = 1 **then** acquire (sensorDataStoreSemaphore)
release (readerSemaphore)
    sensorValue := sensorDataStore (sensorID, value)
    upperLimit := sensorDataStore (sensorID, upLim)
    lowerLimit := sensorDataStore (sensorID, loLim)
    alarmCondition := sensorDataStore (sensorID, alarm)
acquire (readerSemaphore)
    Decrement numberOfReaders
    if numberOfReaders = 0 **then** release (sensorDataStoreSemaphore)
release (readerSemaphore)
end readAnalogSensor

Example of Multiple Readers / Multiple Writers (Pages 277-278)

```
public updateAnalogSensor (in sensorID, in sensorValue)
-- Critical section for write operation.
acquire (sensorDataStoreSemaphore)
    sensorDataStore (sensorID, value) := sensorValue
    if sensorValue >= sensorDataStore (sensorID, upLim)
        then sensorDataStore (sensorID, alarm) := high
    elseif sensorValue <= sensorDataStore (sensorID, loLim)
        then sensorDataStore (sensorID, alarm) := low
        else sensorDataStore (sensorID, alarm) := normal
    endif;
release (sensorDataStoreSemaphore)
end updateAnalogSensor;
```


Connector Classes

- Classes designed to provide inter-task communication and synchronization
- Message buffering monitor classes
  - Synchronized (mutually exclusive) operations
- Asynchronous message communication
  - Message Queue connector class
- Synchronous message communication without reply
  - Message Buffer connector class
- Synchronous message communication with reply
  - Message Buffer and Response connector class

Figure 14.6 Design of message queue connector object

• Asynchronous message communication
  - Use message queue connector class
  - Encapsulates message queue

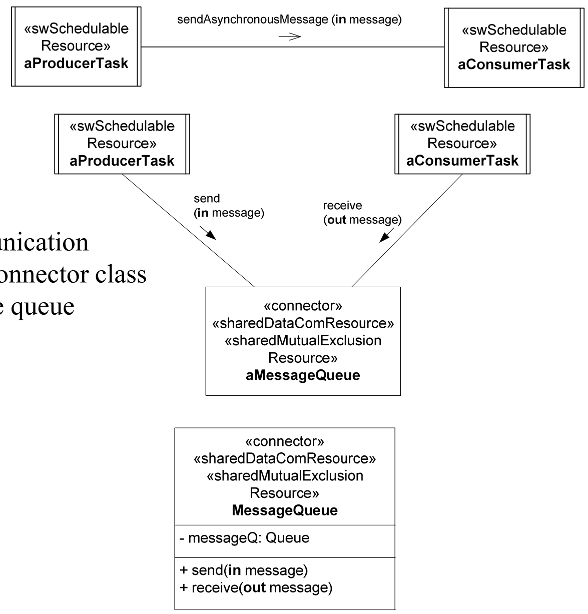


Figure 14.6 Design of a message queue connector

Synchronization within Connector Object

- Synchronization between tasks (Java threads)
  - When task enters synchronized operation, it acquires semaphore
  - Synchronization methods
    - Wait
      - Task is suspended, releases semaphore
    - Signal (Notify in Java)
      - Wake up a suspended task
  - Condition wait
    - Check condition for waiting, e.g.,
      - **while** messageCount = 0 **do wait**

Message Queue Connector Class (Pages 285 – 286)

monitor MessageQueue

-- Encapsulate message queue that holds max of maxCount messages

-- Monitor operations are executed mutually exclusively;

private maxCount : Integer;

private messageCount : Integer = 0;

public send (**in** message)

    while messageCount = maxCount **do wait;**

    place message in buffer;

    Increment messageCount;

    if messageCount = 1 **then notify;**

end send;

public receive (**out** message)

    while messageCount = 0 **do wait;**

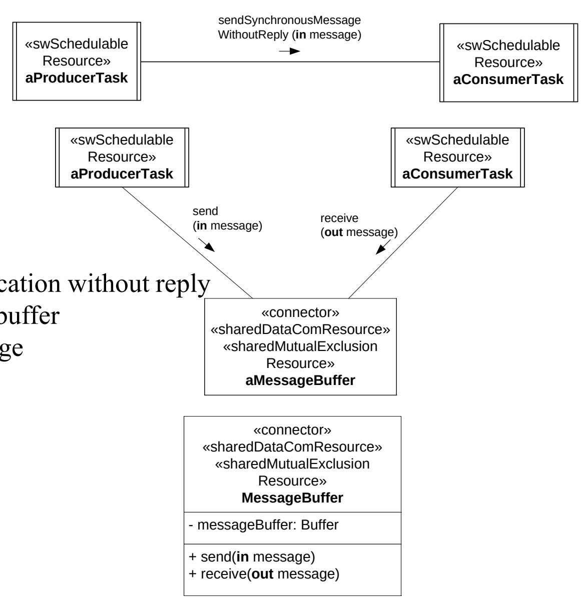
    remove message from buffer;

    Decrement messageCount;

    if messageCount = maxCount-1 **then notify;**

end receive;

Figure 14.7 Design of message buffer connector



- Synchronous message communication without reply
  - Encapsulates a message buffer
  - Holds at most one message

Figure 14.7 Design of a message buffer connector

Message Buffer Connector Class (Page 287)

```
monitor MessageBuffer
 -- Encapsulate a message buffer that holds at most one message.
 -- Monitor operations are executed mutually exclusively
private messageBufferFull : Boolean = false;
public send (in message)
    place message in buffer;
    messageBufferFull := true;
    notify;
    while messageBufferFull = true do wait;
end send;

public receive (out message)
    while messageBufferFull = false do wait;
    remove message from buffer;
    messageBufferFull := false;
    notify;
end receive;
end MessageBuffer;
```


Figure 14.8 Design of message buffer and response connector

- Synchronous message communication with reply
  - Encapsulates a message buffer
    - Holds one message
  - Encapsulates a response buffer
    - Holds one response

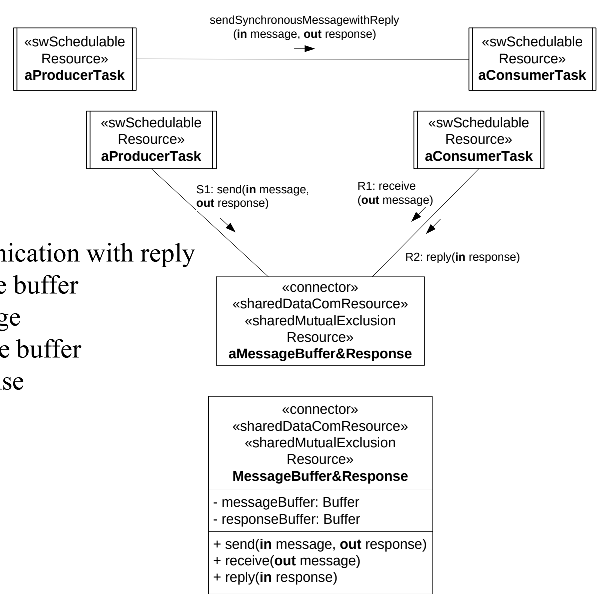


Figure 14.8 Design of a message buffer and response connector

Message Buffer & Response Connector Class (Pages 288 – 289)

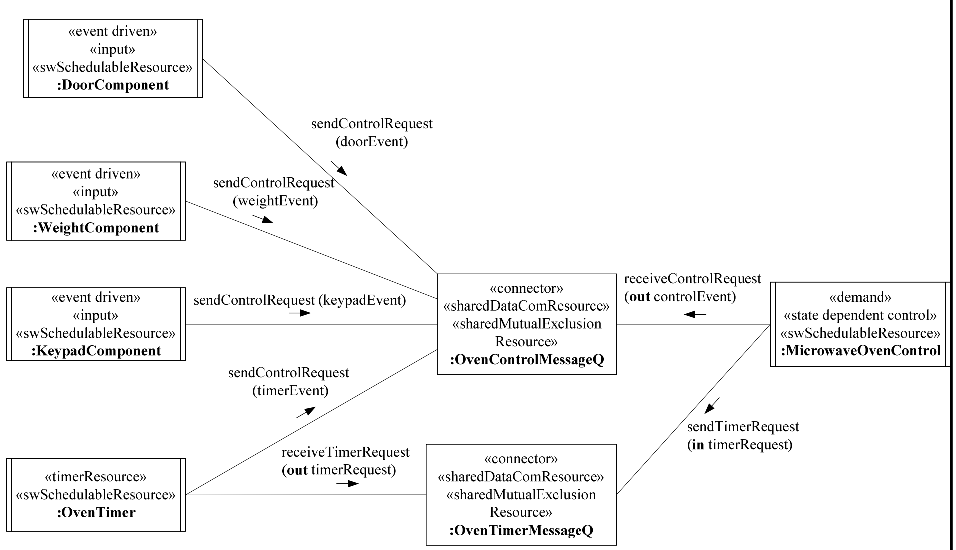
```
monitor MessageBuffer&Response
 -- Encapsulates a message buffer that holds at most one message
 -- and a response buffer that holds at most one response.
 -- Monitor operations are executed mutually exclusively.
private messageBufferFull : Boolean = false;
private responseBufferFull : Boolean = false;

public send (in message, out response)
    place message in buffer;
    messageBufferFull := true;
    notify;
    while responseBufferFull = false do wait;
    remove response from response buffer;
    responseBufferFull := false;
end send;

public receive (out message)
    while messageBufferFull = false do wait;
    remove message from buffer;
    messageBufferFull := false;
end receive;

public reply (in response)
    Place response in response buffer;
    responseBufferFull := true;
    notify;
end reply;
end MessageBuffer&Response;
```


Figure 14.9b Example of cooperating tasks using message queue connectors



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