State Machine Based Design for Embedded Systems

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Topics

- What is a state machine?
  - Mealy, Moore, and UML state machines
- Unified Modeling Language (UML) state machine concepts
  - States
  - Events
  - Actions and transitions
  - Run-to-completion execution
- Creating clean designs with state machines
- Using the Quantum Platform (QP) with state machines
- Detailed design of a washing machine
- Break
- Demo/Exercise

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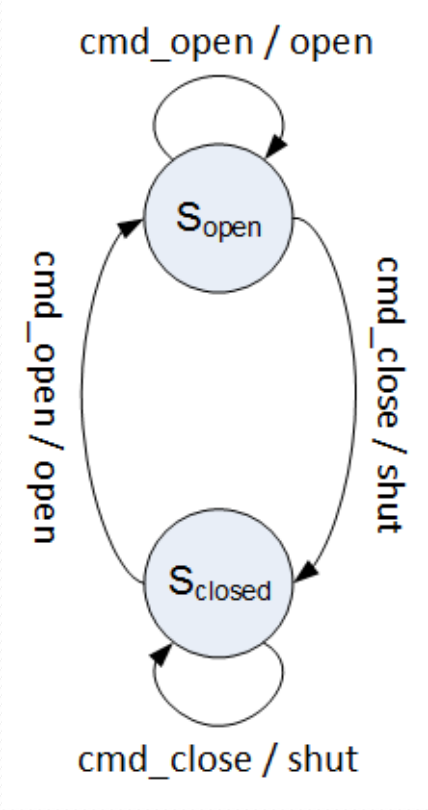
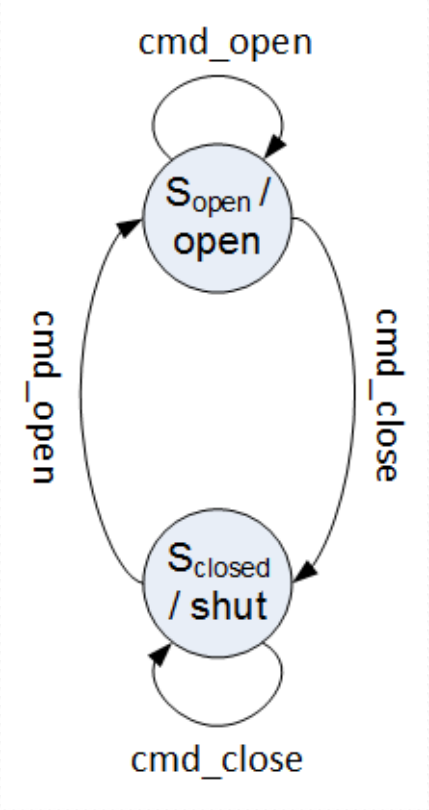
Old-school state machines

Mealy state machine



Moore state machine

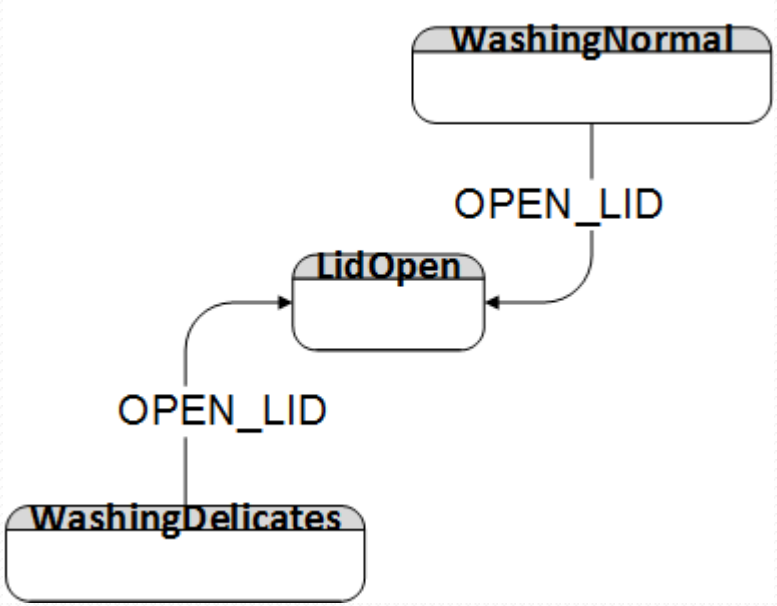


UML state machines

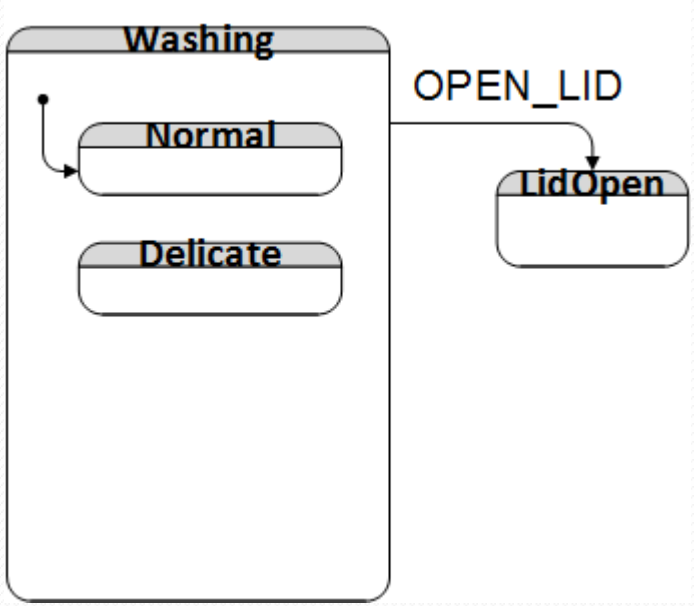
- Modified Harel statechart which incorporates aspects of both Moore and Mealy machines. [4]
- Support actions based on event as well as state entry and exit.
- Includes the concept of Hierarchical State Machines (HSMs).

UML state machines

Finite State Machine (FSM)



Hierarchical State Machine (HSM)



UML state machines

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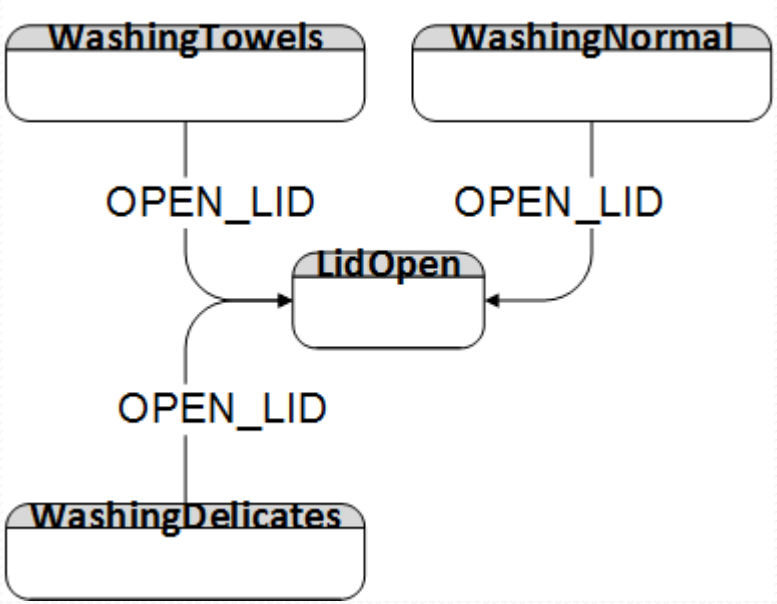

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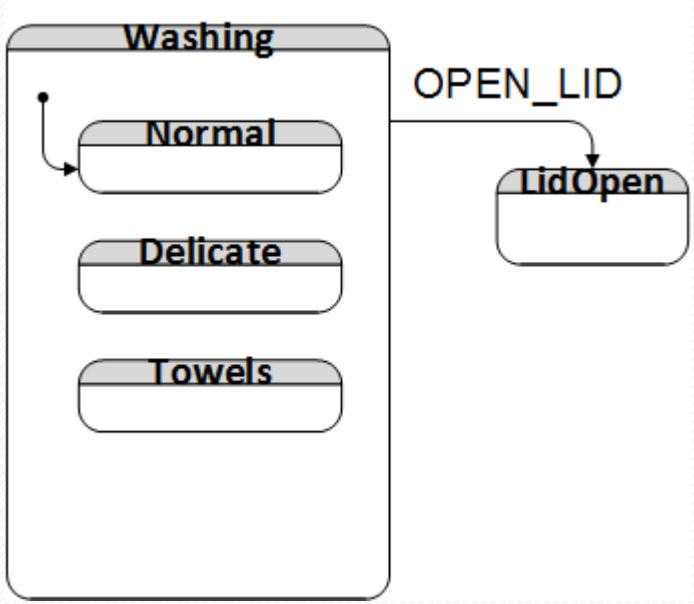

UML state machines

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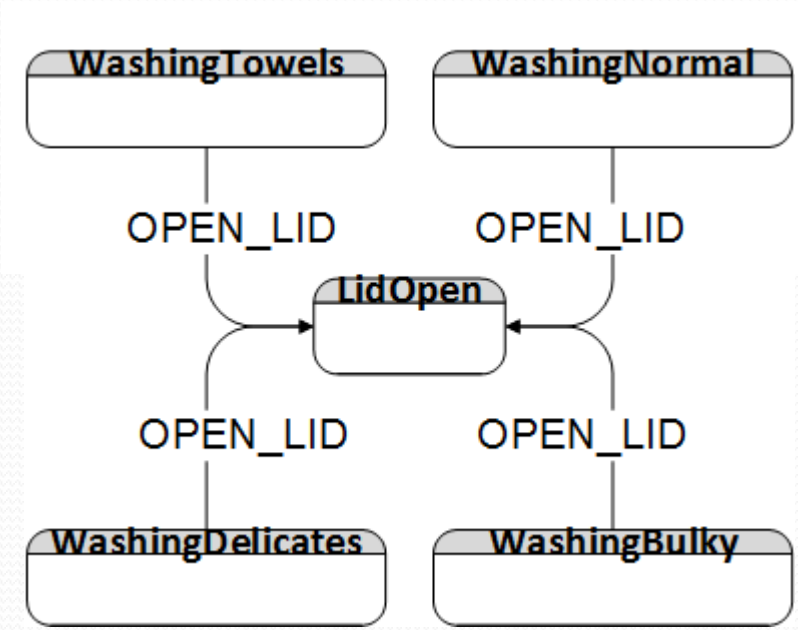

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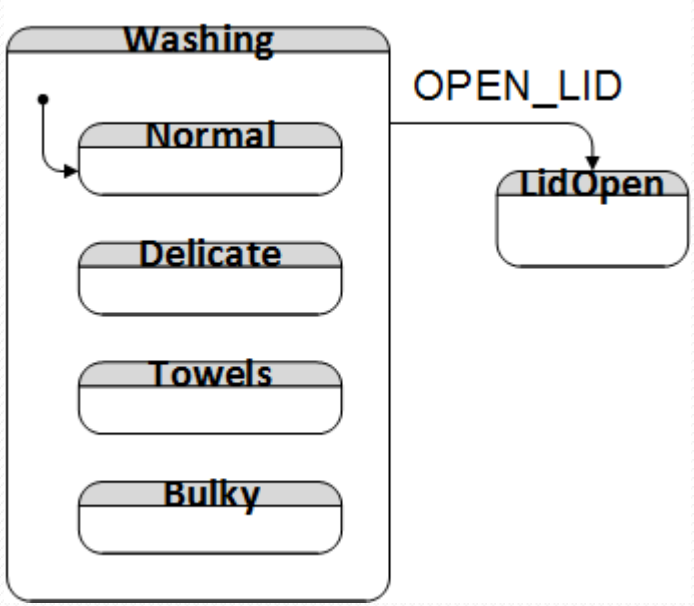
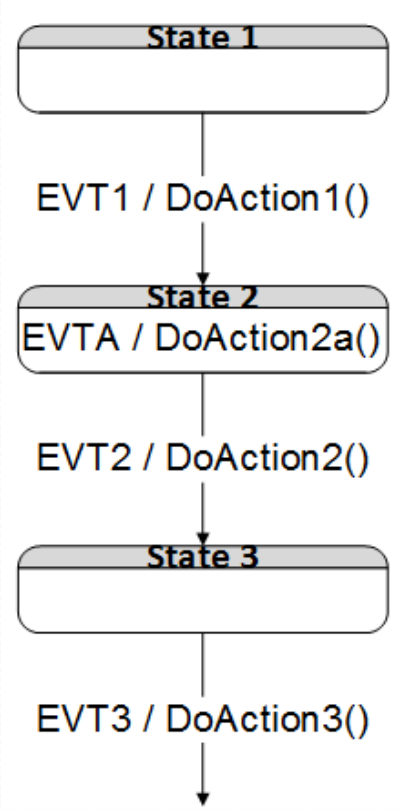
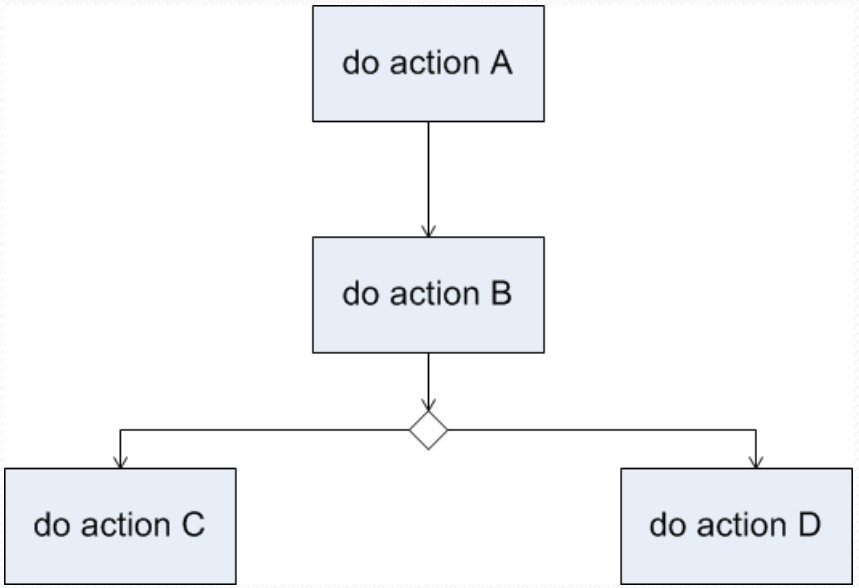


State Diagrams Versus Flow Charts

UML state chart



Flow chart



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UML statecharts

- A **state** (rounded boxes) represents the context and history of the system.

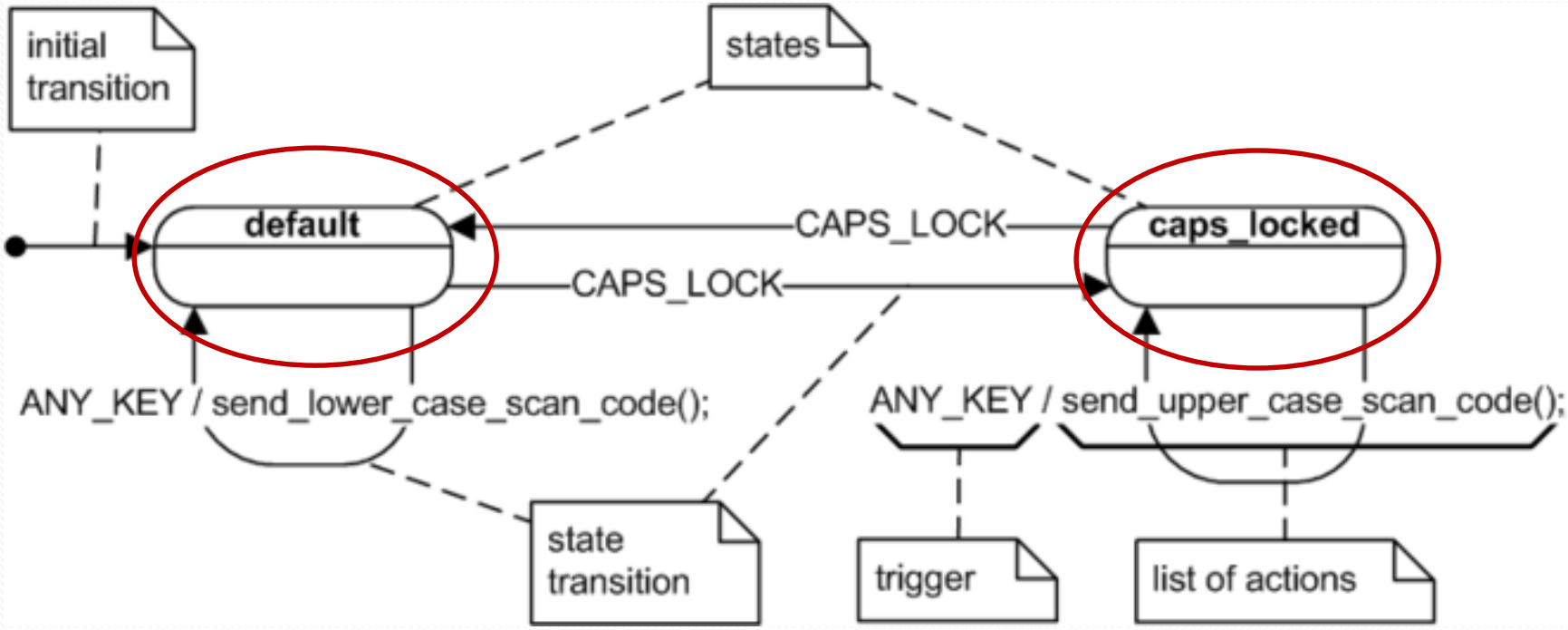

Figure:
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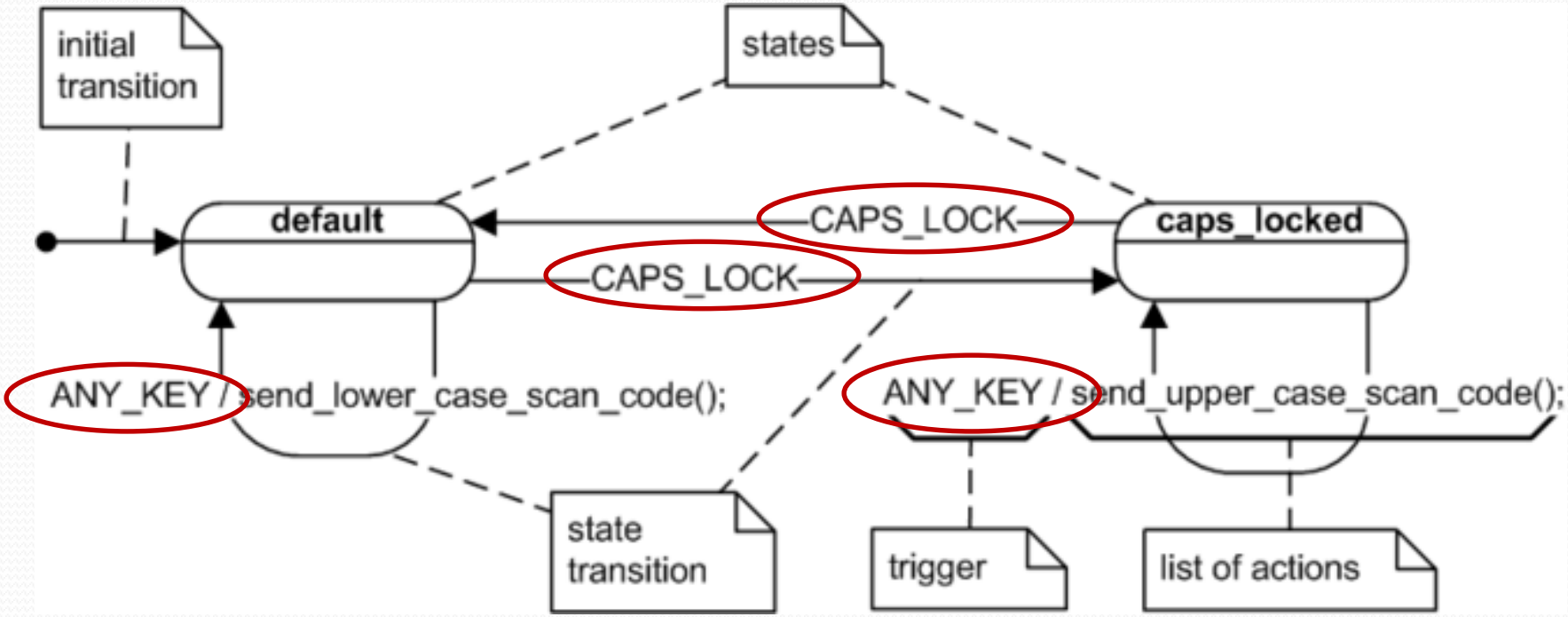
UML statecharts

- An **event** (all caps text) is something that happened in the system.



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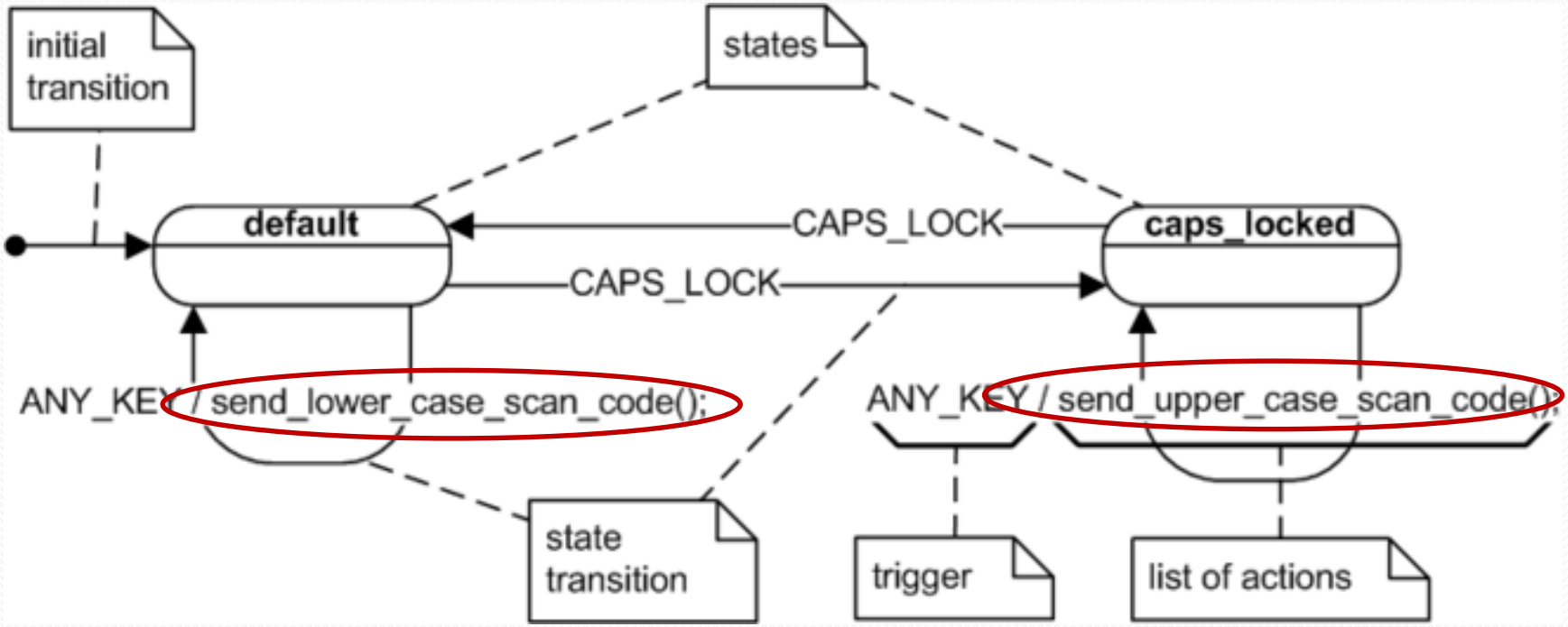
UML statecharts

- Event **actions** are optionally included after the event.



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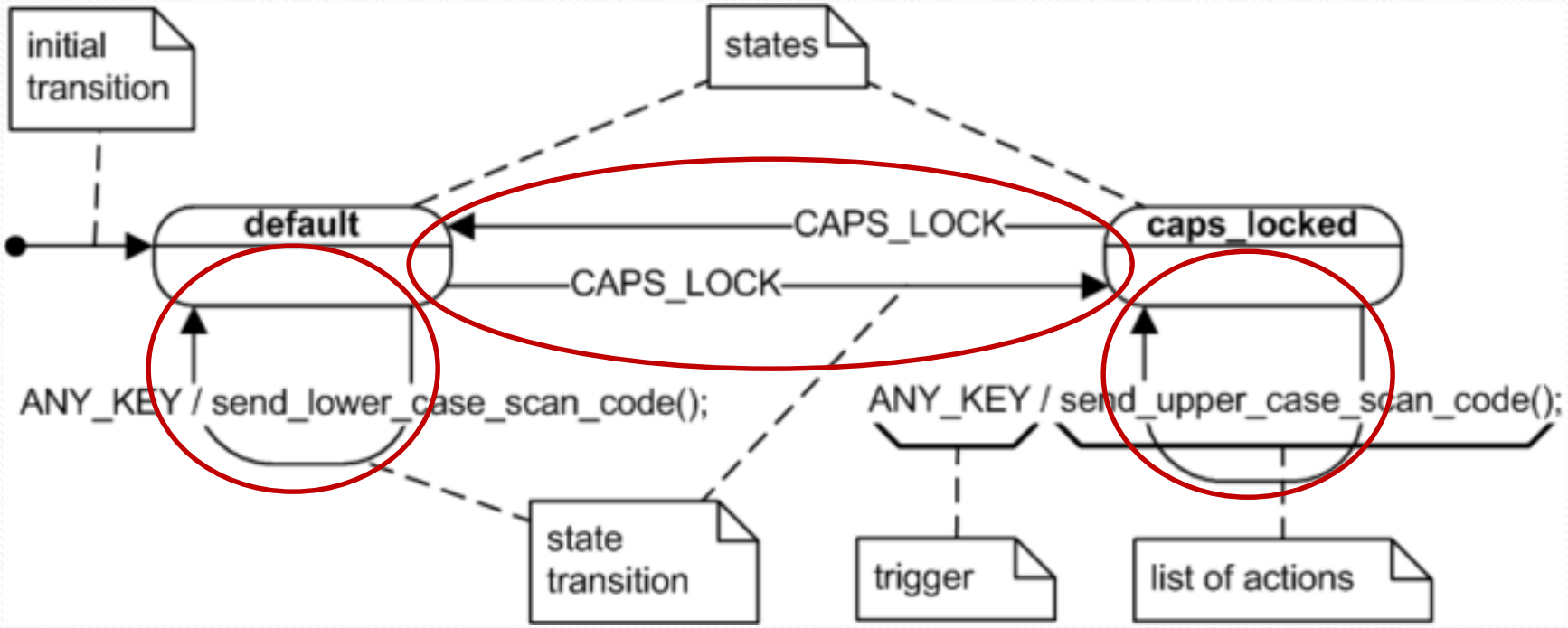
UML statecharts

- **Transitions** (arrows) are how we move between states.



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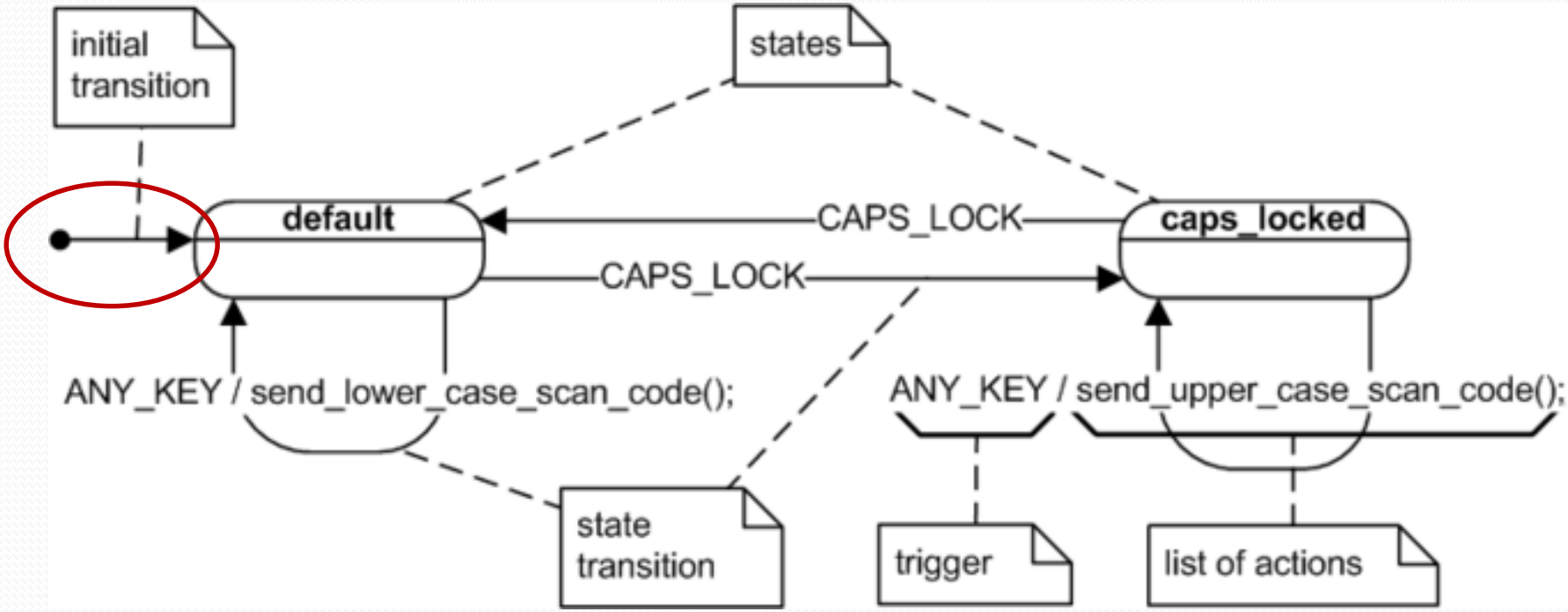
UML statecharts

- An **initial transition** (arrow with a dot) indicates which state is the starting point of the state machine.



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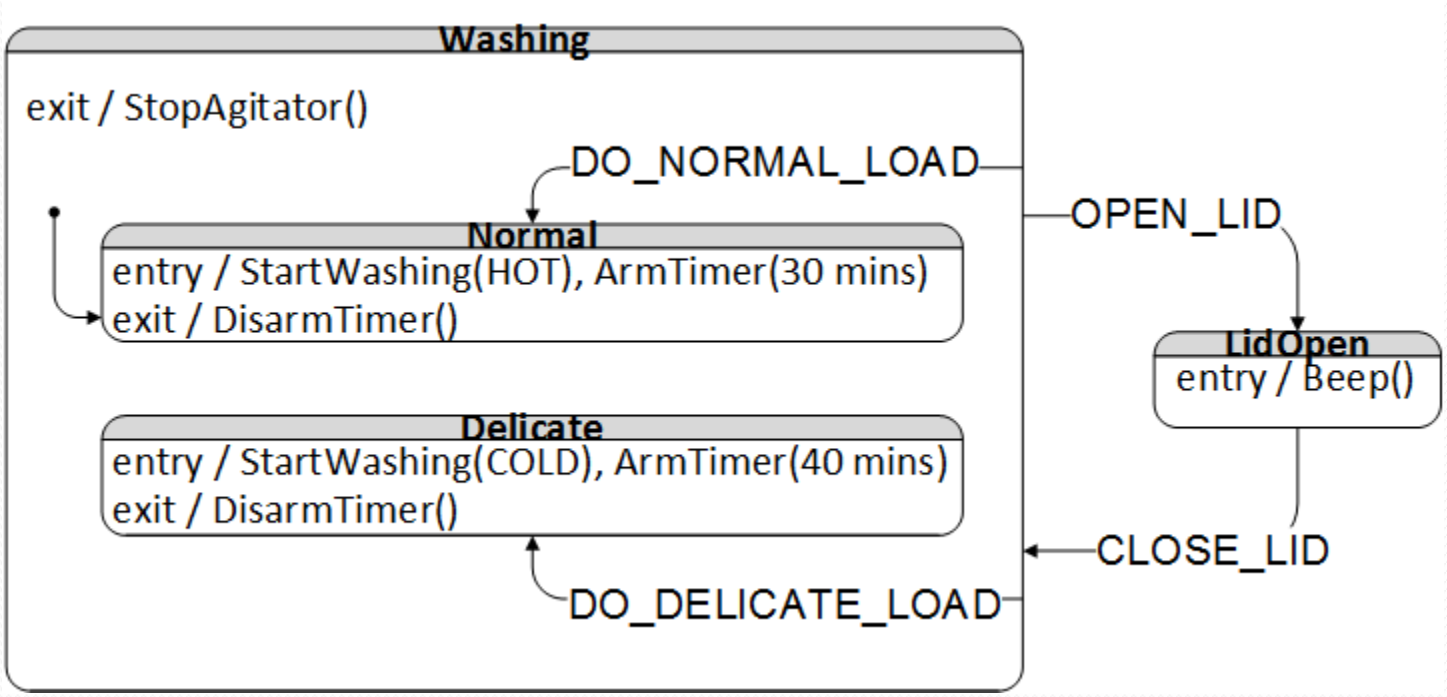
Entry and Exit Actions

- Associated with the entry and exit of the state, rather than an event
- Guaranteed initialization and cleanup



Internal Transitions

- Internal transitions are used for events that do not cause a transition to another state.

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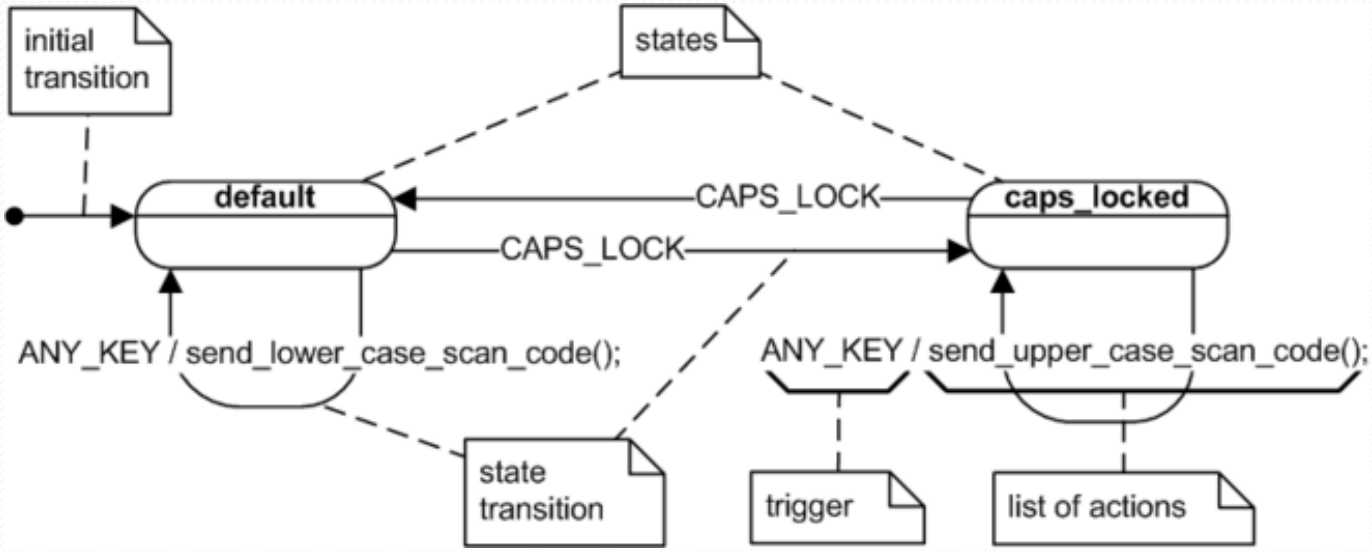

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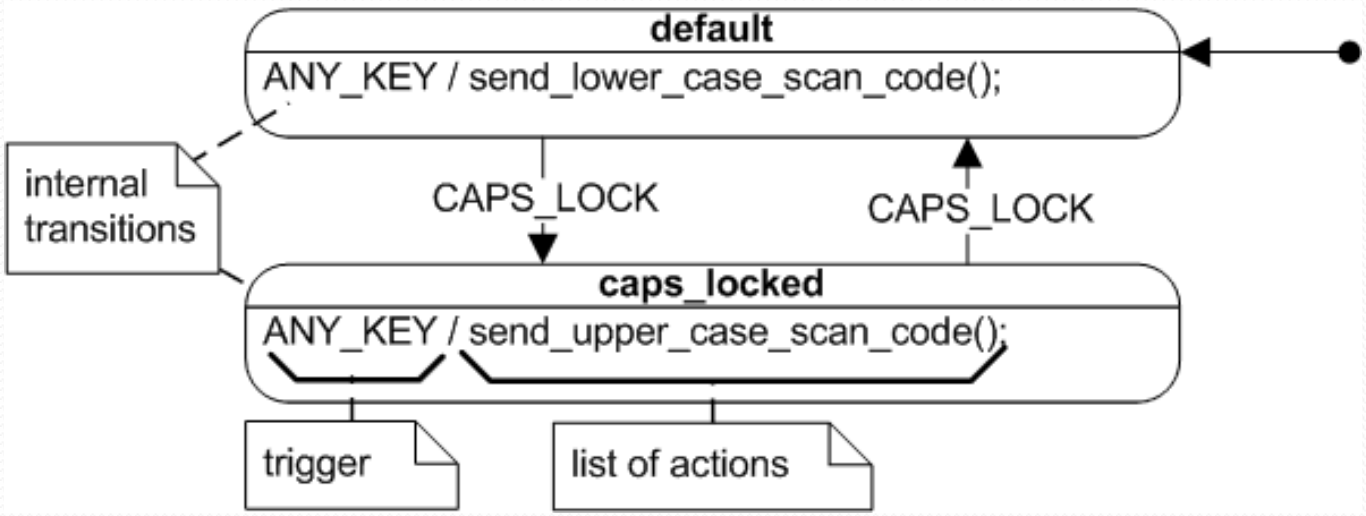

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Run To Completion (RTC)

- Run-to-completion semantics mean that a state machine must always go from one stable configuration all the way to another stable configuration. [2]
  - Processing an event = 1 RTC step
  - Transitioning between states = 1 RTC step
- How do we deal with this?
  - Event queues
  - Events generally handled in FIFO manner

Drawbacks of UML state machines

- Difficult to represent the sequence of processing
- Overhead associated with management of event queues, dispatching events
- Challenging to keep the state chart documentation and the code in sync

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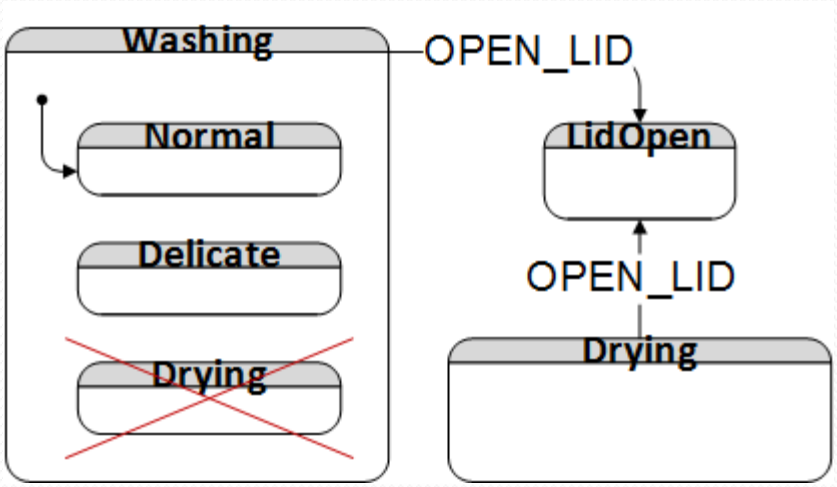
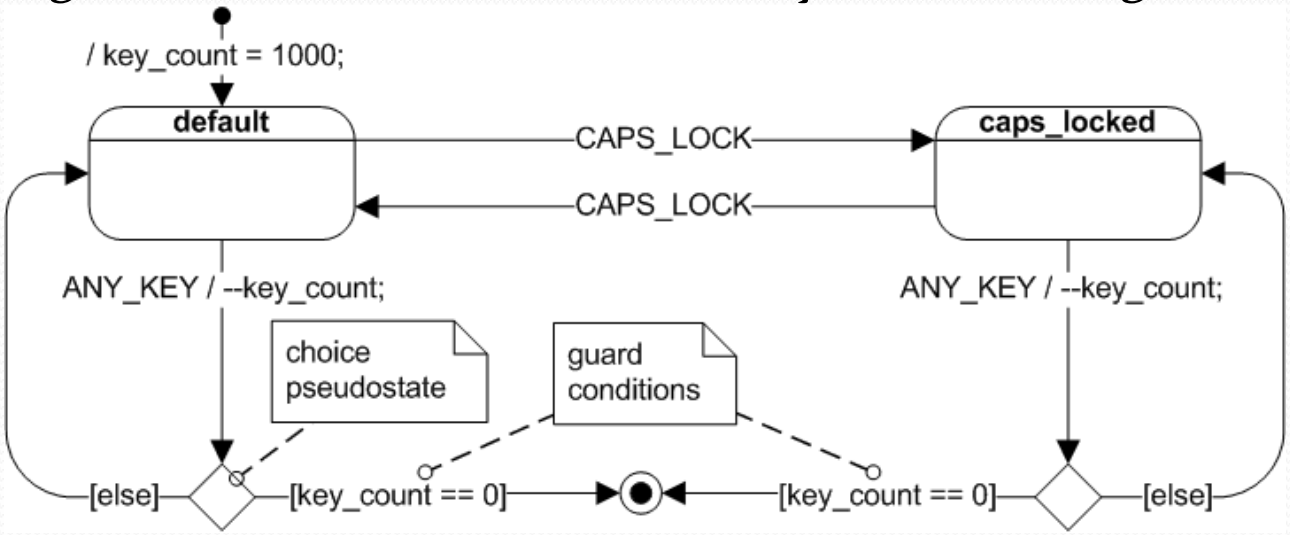
Liskov Substitution Principle (LSP)

- The behavior of a substate should be consistent with its superstate.
- Allows for more efficient use of abstraction



Extended State Machines

- Supplement your state machine with variables to create *extended state machines*.
  - Qualitative aspects = state
  - Quantitative aspects = extended state variables
- A change in variable does not necessarily cause a change in state



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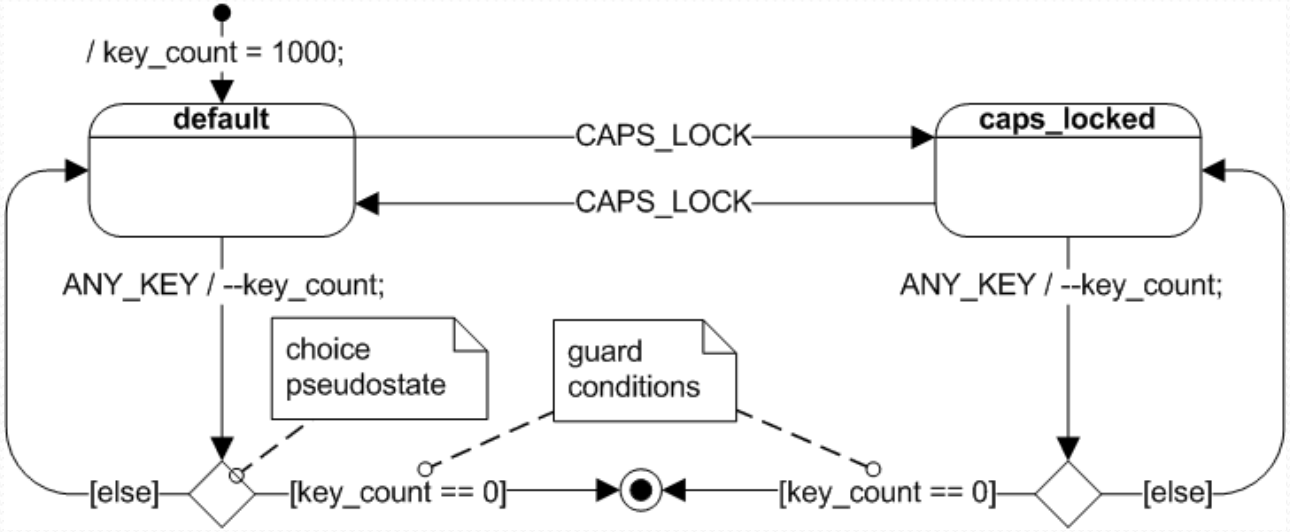
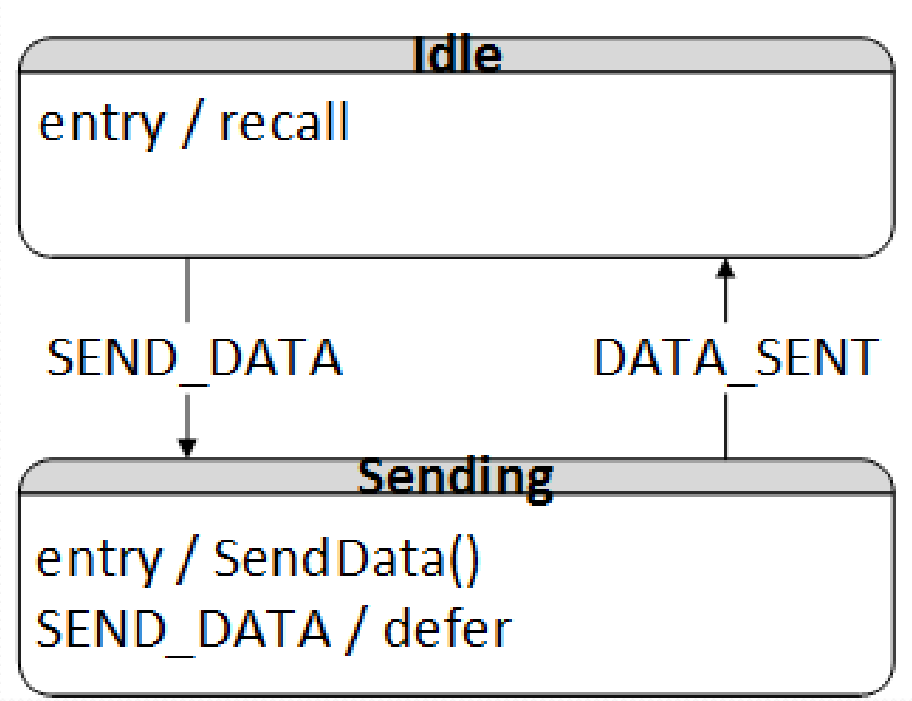
Extended State Machines

- UML indicates conditional behavior using guard conditions
  - DO_SOMETHING_IND[status==OK] / do something
  - DO_SOMETHING_IND[status!=OK] / do something else
- Avoid abuse of variables to avoid spaghetti



Event Deferral

- When you're too busy to handle an event, defer it.



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A Framework for UML State Machines

- Requirements:
  - Run-To-Completion semantics
  - Hierarchical states
  - Entry and exit actions
  - Events with custom parameters
  - Efficient and lightweight enough for embedded systems
- Quantum Platform (QP) satisfies the above requirements
  - C/C++ implementation
  - Open Source
  - Commercial licenses available

The QHsm Class

- Manages the movement between states
- Interface methods:
  - `Q_HANDLED` – used to indicate that an event was processed by the current state
  - `Q_SUPER` – passes the current event to the parent state for processing. Typically used when an event was NOT handled by the current state.
  - `Q_TRAN` – transitions to another state
- Reserved event signals:
  - `Q_ENTRY_SIG` – event signaling entry actions
  - `Q_EXIT_SIG` – event signaling exit actions
  - `Q_INIT_SIG` – event signaling nested initial transitions

Class interface and description are from [9].

Active Objects in QP

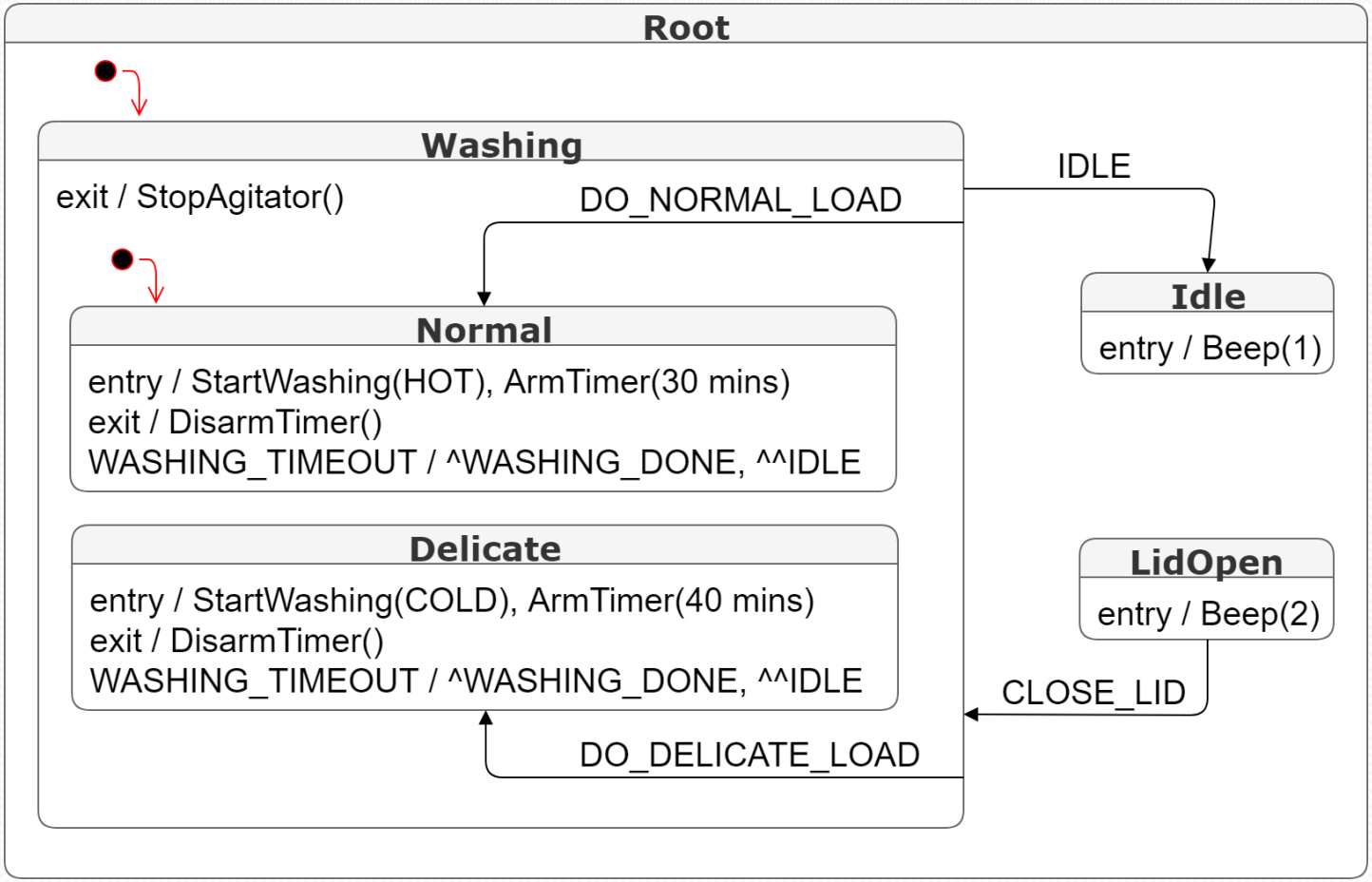
- Characteristics of Active Objects:
  - A state machine that has its own thread of execution
  - An object that encapsulates the behavior of the state machine
  - Contains its own event queue

The QActive Class

- Manages the event queues
- Derived from QHsm
- Intended as a base class for the Active Objects in your design
- Interface:
  - `Subscribe(sig)` – subscribes for delivery of signal, sig, to the active object
  - `post/postLIFO` – posts an event directly to an event queue, FIFO or LIFO
  - `defer` – defers an event to a separate queue
  - `recall` – recalls an event from a separate queue to the main event queue

Class interface and description are from [9].

Example: AOWashingMachine



Class Declaration

```
class AOWashingMachine : public QActive
{
public:
    AOWashingMachine();
    virtual ~AOWashingMachine();

private:
    QEvt const *m_mainEventQueue[MAIN_QUEUE_SIZE];
    QTimeEvt m_cycleTimer;

    // State functions
    static QState Idle(AOWashingMachine *me, QEvt const *pEvent);
    static QState LidOpen(AOWashingMachine *me, QEvt const *pEvent);
    static QState Washing(AOWashingMachine *me, QEvt const *pEvent);
        static QState Normal(AOWashingMachine *me, QEvt const *pEvent);
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    // Helper functions
    void StartWashing(UINT time);
};
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    // Helper functions
    void StartWashing(UINT time);
};
```

The QEvt Class

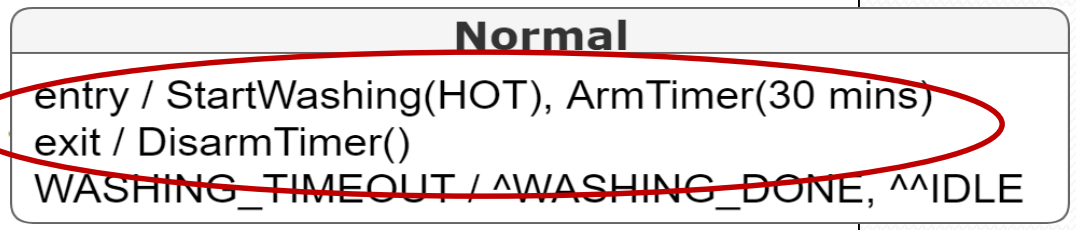
- Represents events (without parameters)
- Serves as the base class for derivation of events with parameters

```
struct EWashingDone : public QEvt
{
    int status;
};
```

Class interface and description are from [9].

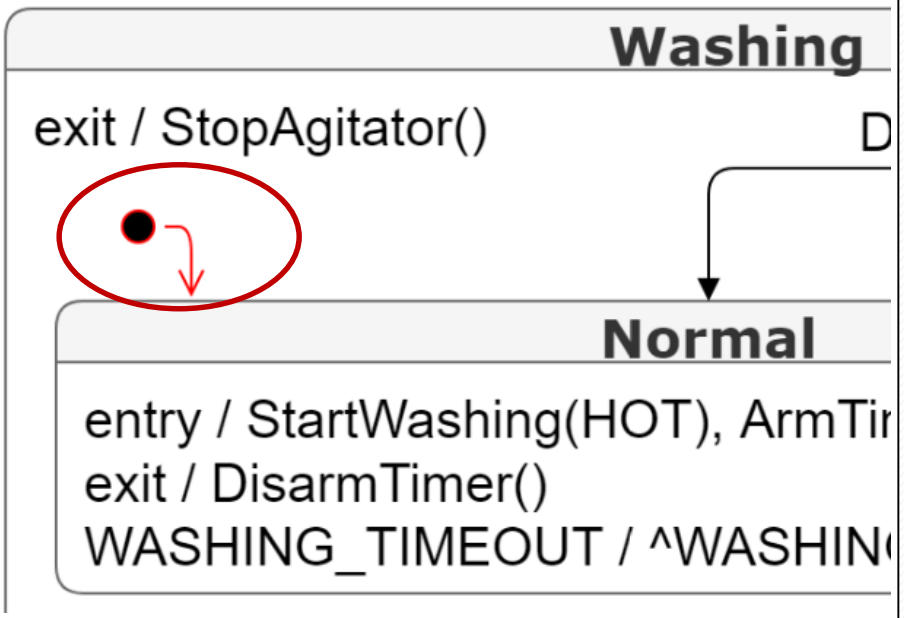
Entry and Exit Handlers

```
QState AOWashingMachine::Normal(AOWashingMachine *me, QEvt const *pEvent)
{
    switch (pEvent->sig)
    {
        //.....................................................
        case Q_ENTRY_SIG:
        {
            me->StartWashing(HOT);
            me->ArmTimer(30);
            return Q_HANDLED();
        }
        //.....................
        case Q_EXIT_SIG:
        {
            me->DisarmTimer();
            return Q_HANDLED();
        }
        //.....................................................
            . . .
    }
    return Q_SUPER(&AOWashingMachine::Washing);
}
```



Initial transition

```
QState AOWashingMachine::Washing(AOWashingMachine *me, QEvent const *pEvent)
{
    switch (pEvent->sig)
    {
        //.....................
        case Q_ENTRY_SIG:
        {
            return Q_HANDLED();
        }
        //.....................
        case Q_EXIT_SIG:
        {
            me->StopAgitator();
            return Q_HANDLED();
        }
        //.....................
        case Q_INIT_SIG:
        {
            return Q_TRAN(&AOWashingMachine::Normal);
        }
```



The QF Class

- Combines framework services
- Static members only
- Not to be instantiated
- Maintains a list of registered active objects
- Interface:
  - `onIdle` – idle mode callback function
  - `publish` – publishes an event to ALL active objects

Class interface and description are from [9].

Publishing Events

```
QState AOWashingMachine::Normal(AOWashingMachine *me, QEvt const *pEvent)
{
    switch (pEvent->sig)
    {
        //.....
            . . .
        //.....................................................
        case WASHING_TIMEOUT:
        {
            QF::publish(Q_NEW(QEvt, WASHING_DONE));
            me->postLIFO(Q_NEW(QEvt, IDLE));
            return Q_HANDLED();
        }
    }
    return Q_SUPER(&AOWashingMachine::Washing);
}
```

Normal

entry / StartWashing(HOT), ArmTimer(30 mins)
exit / DisarmTimer()
WASHING_TIMEOUT / ^WASHING_DONE; ^^IDLE

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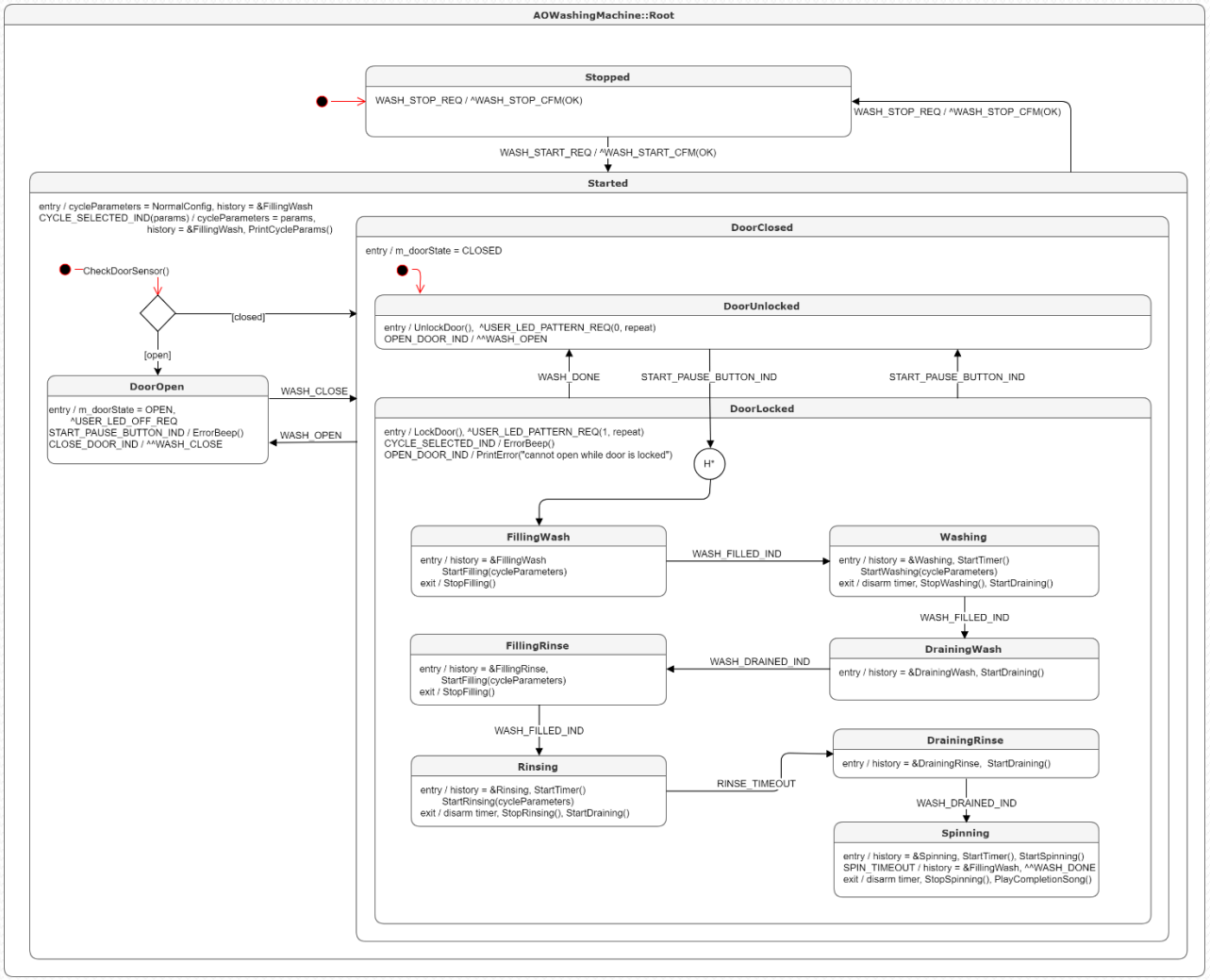
Enhanced AOWashingMachine



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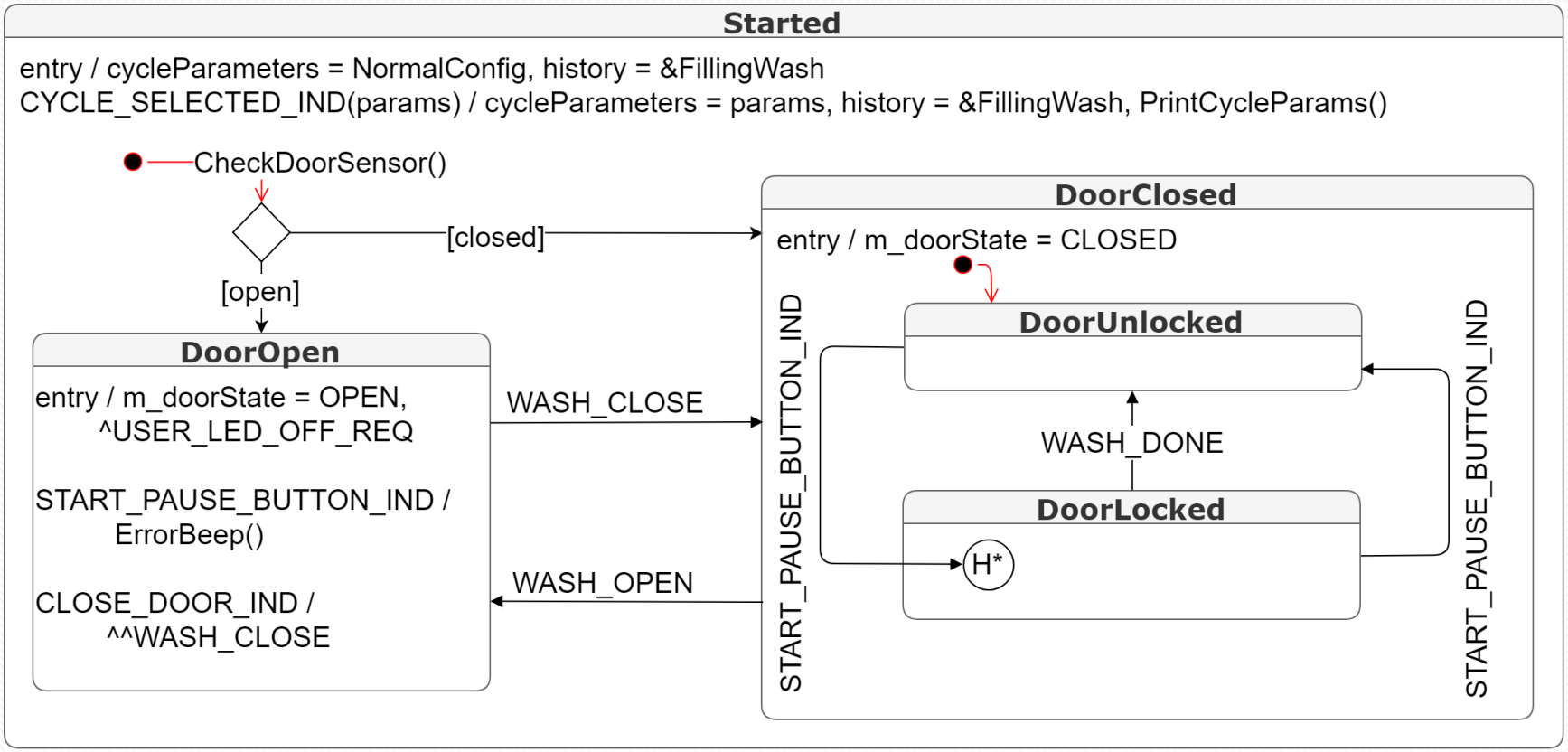

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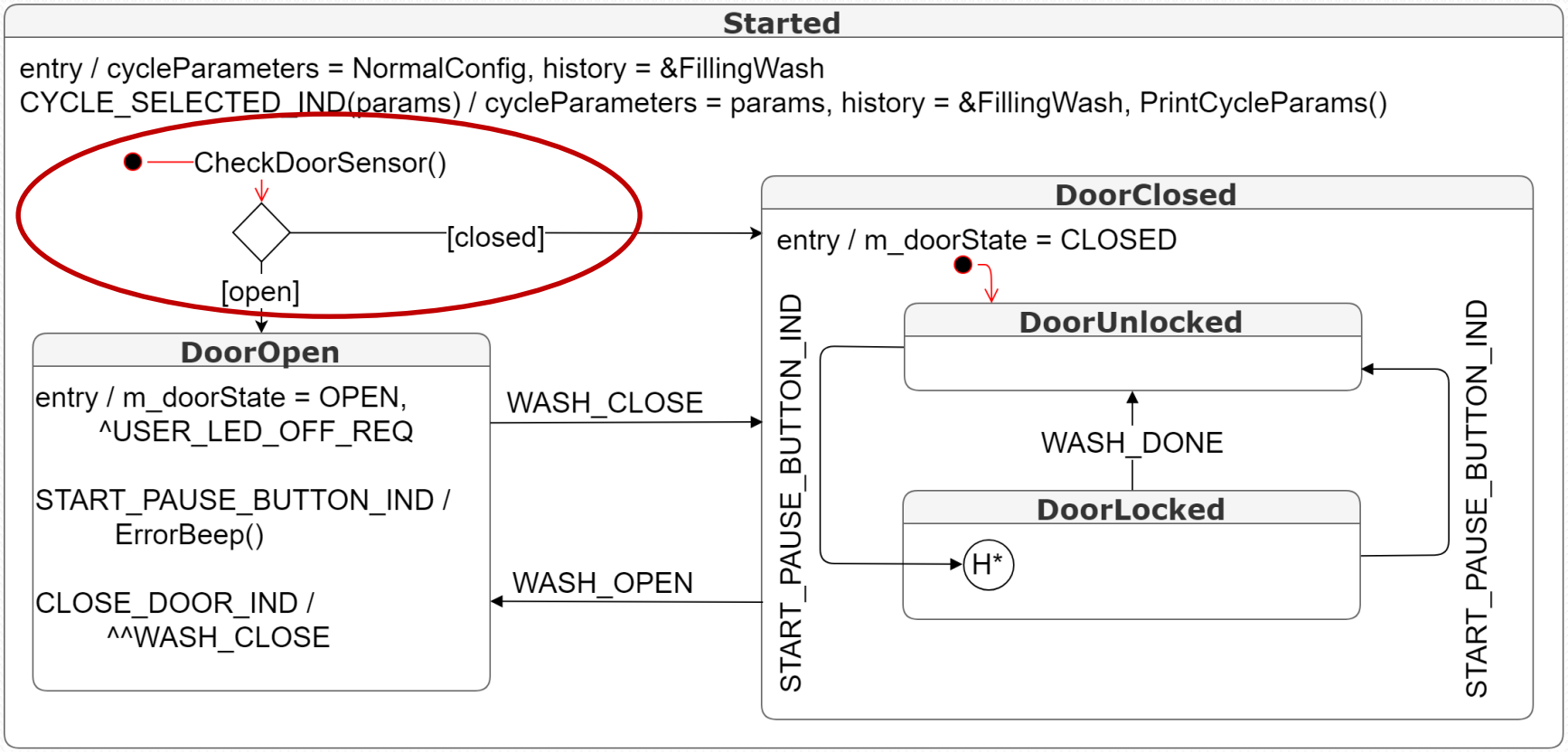

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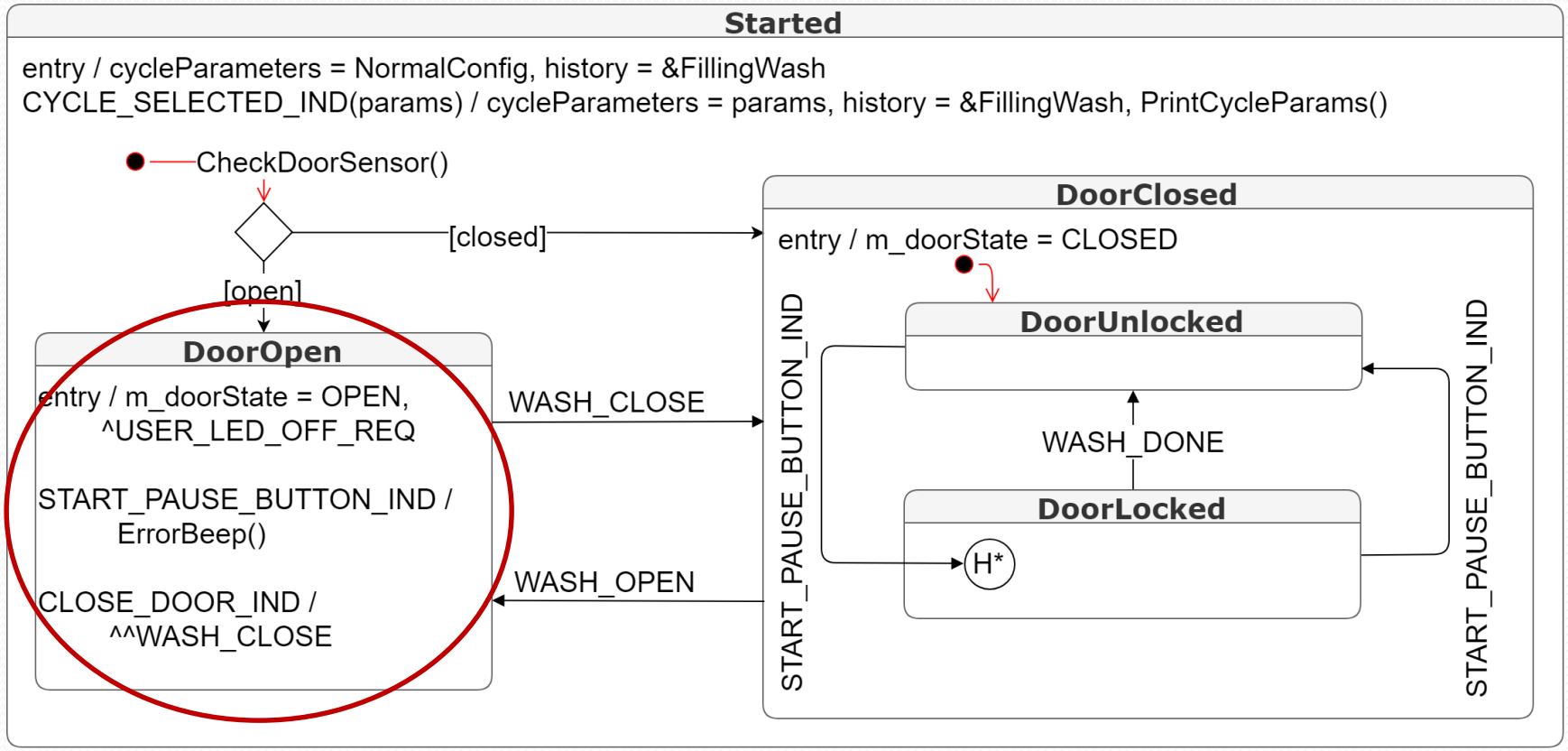

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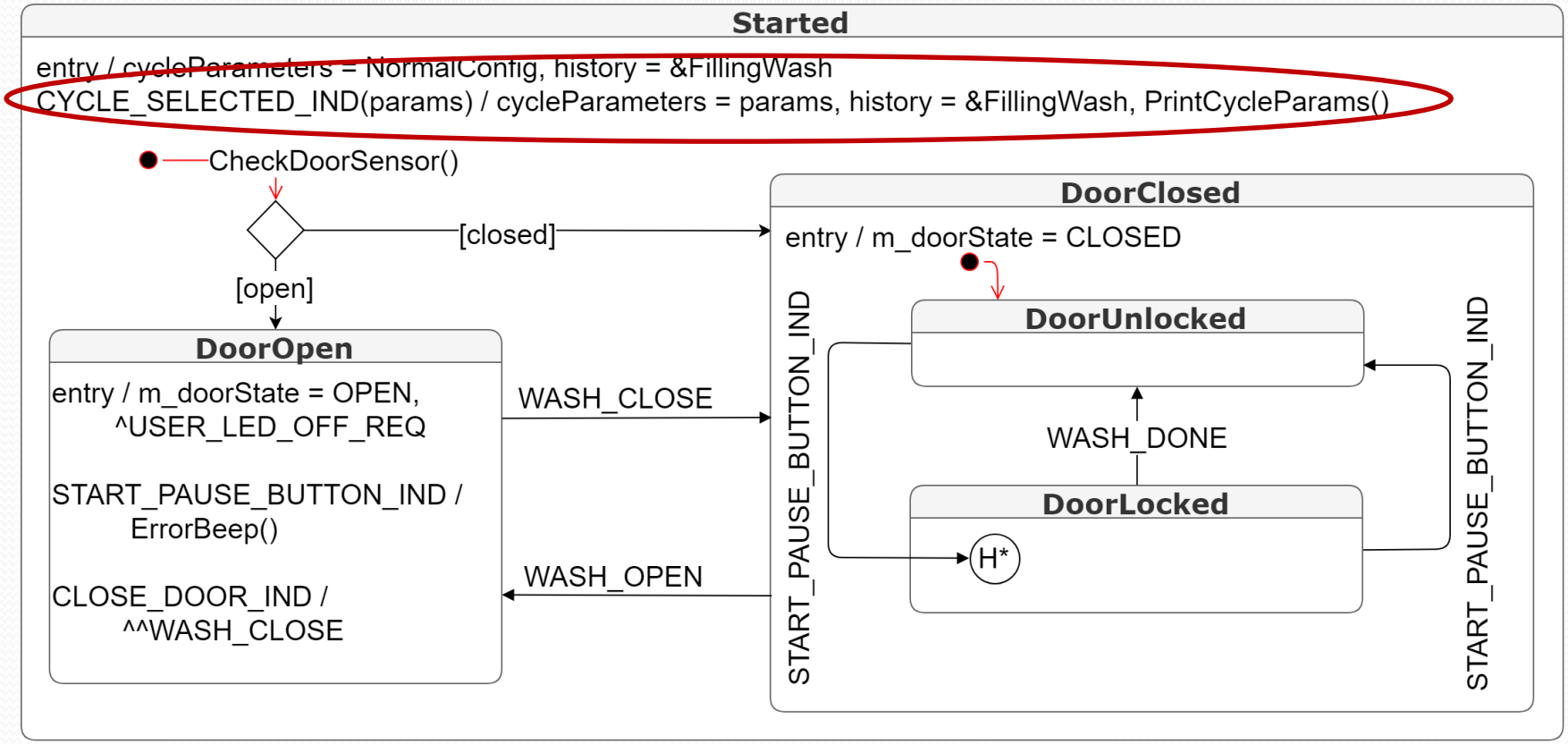
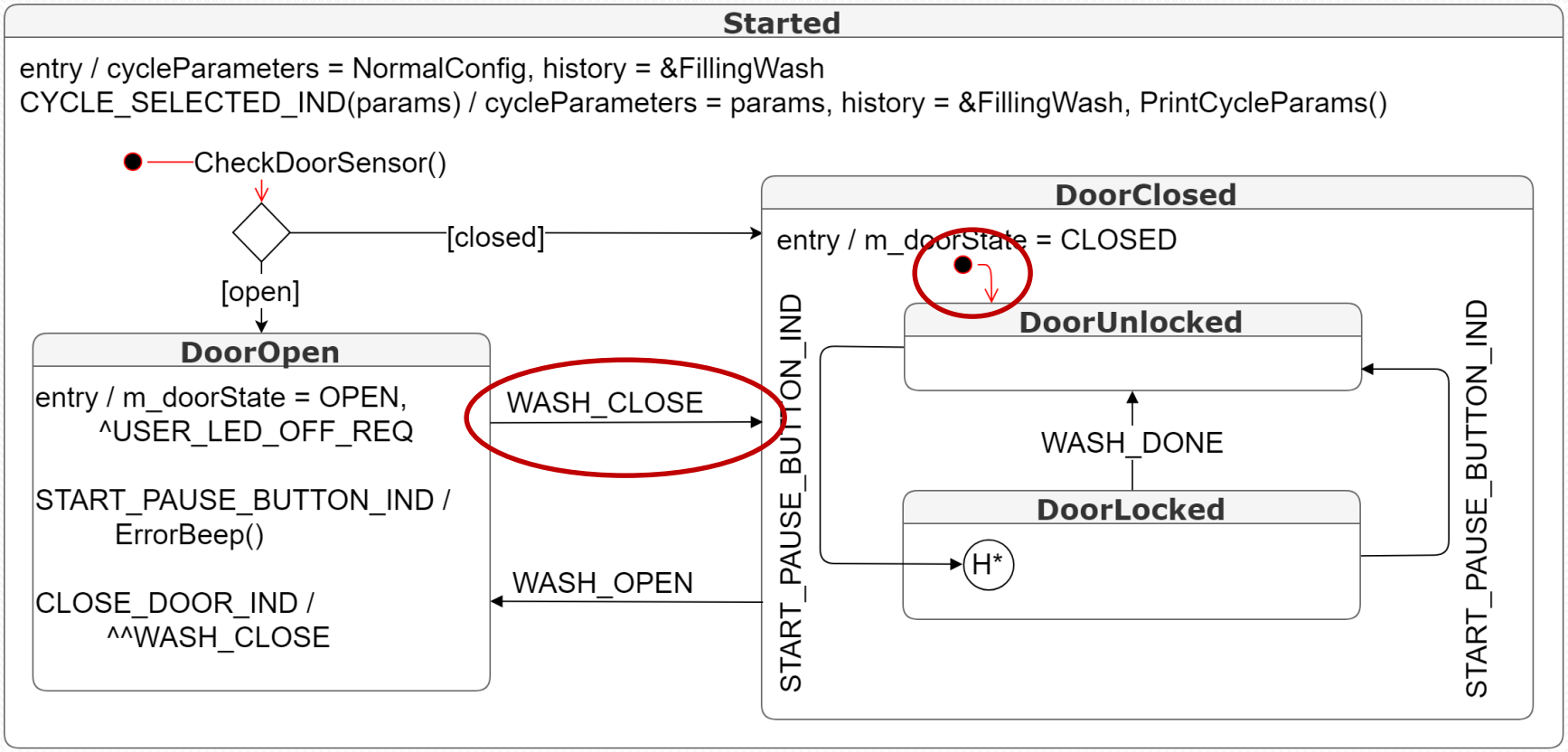


Enhanced AOWashingMachine



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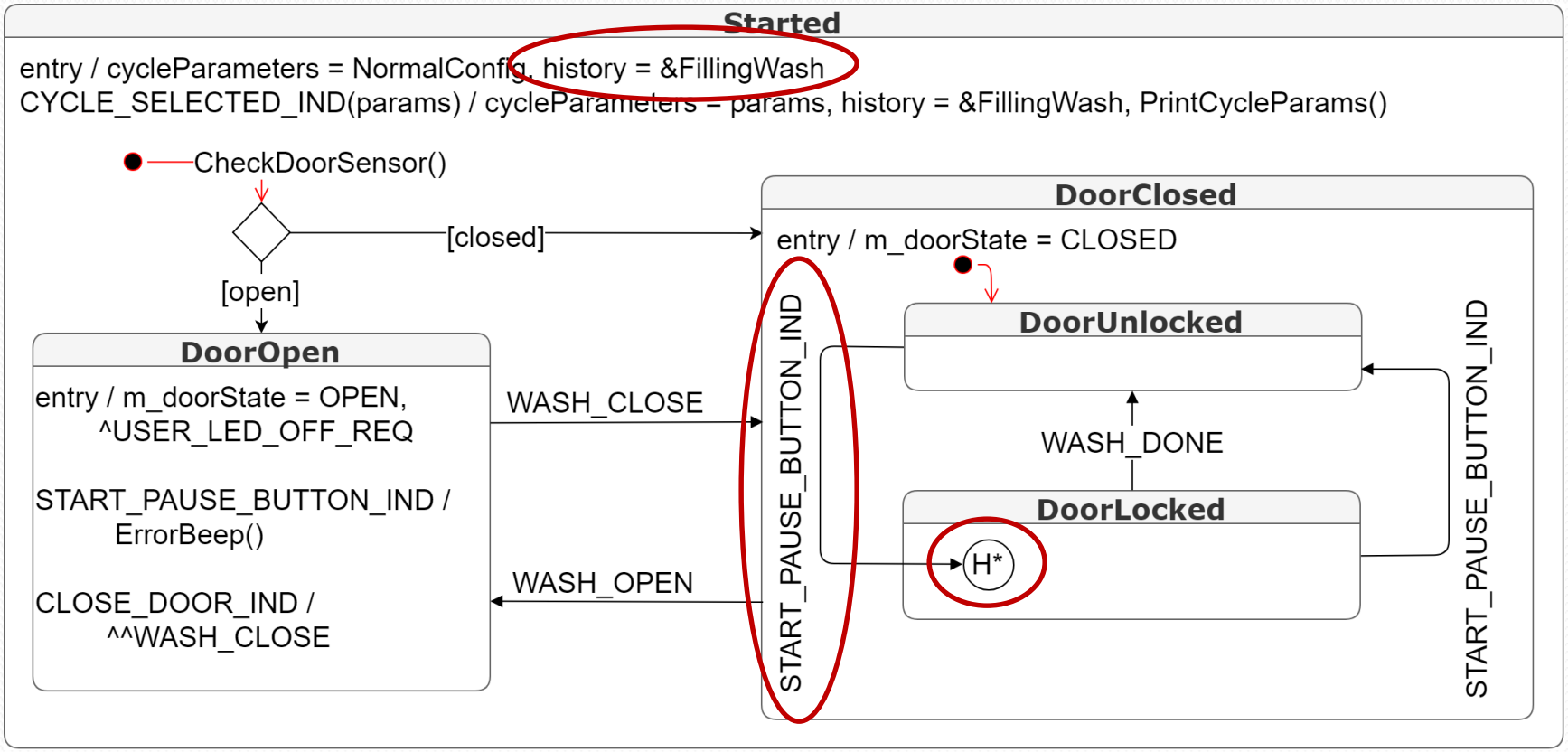

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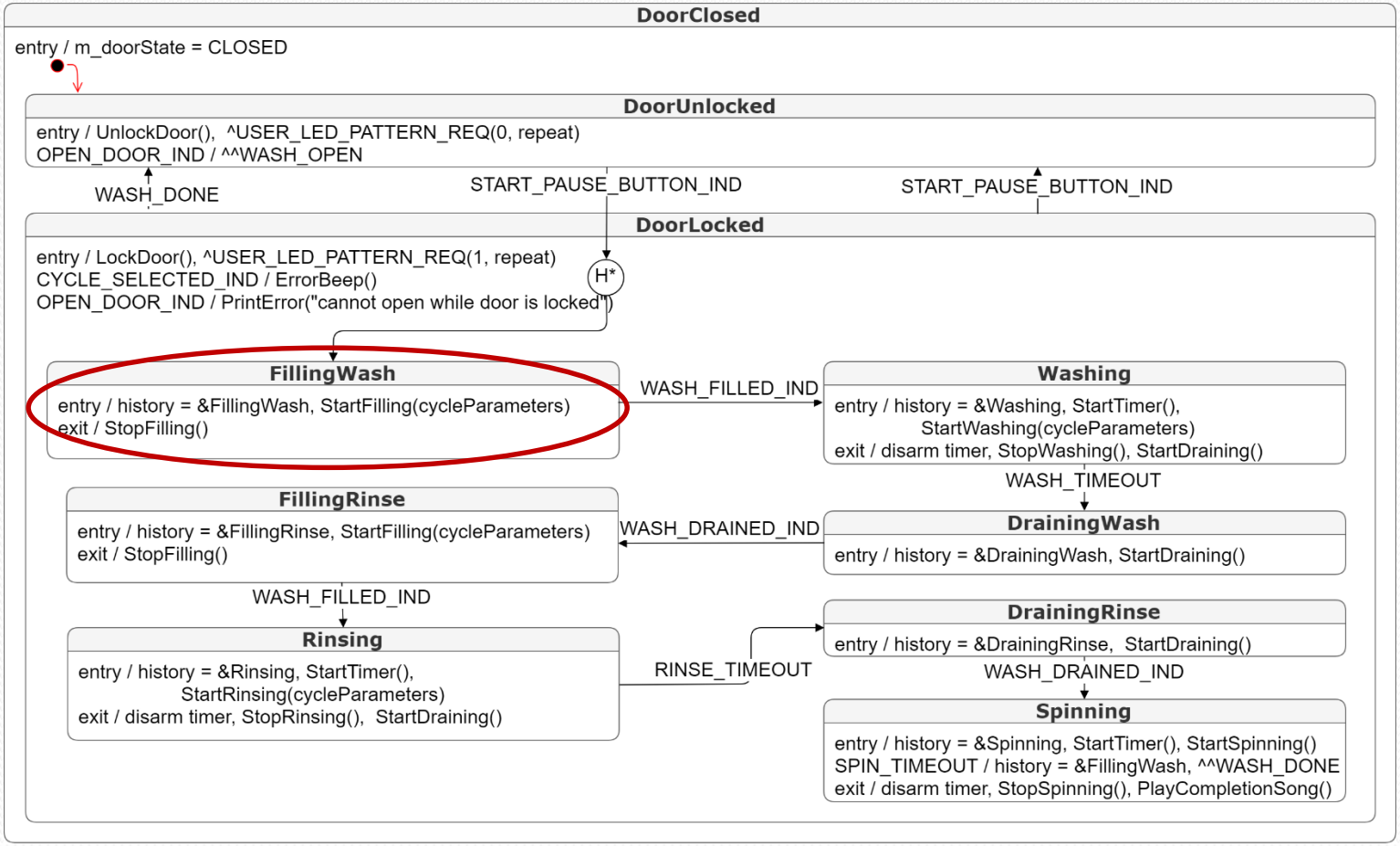

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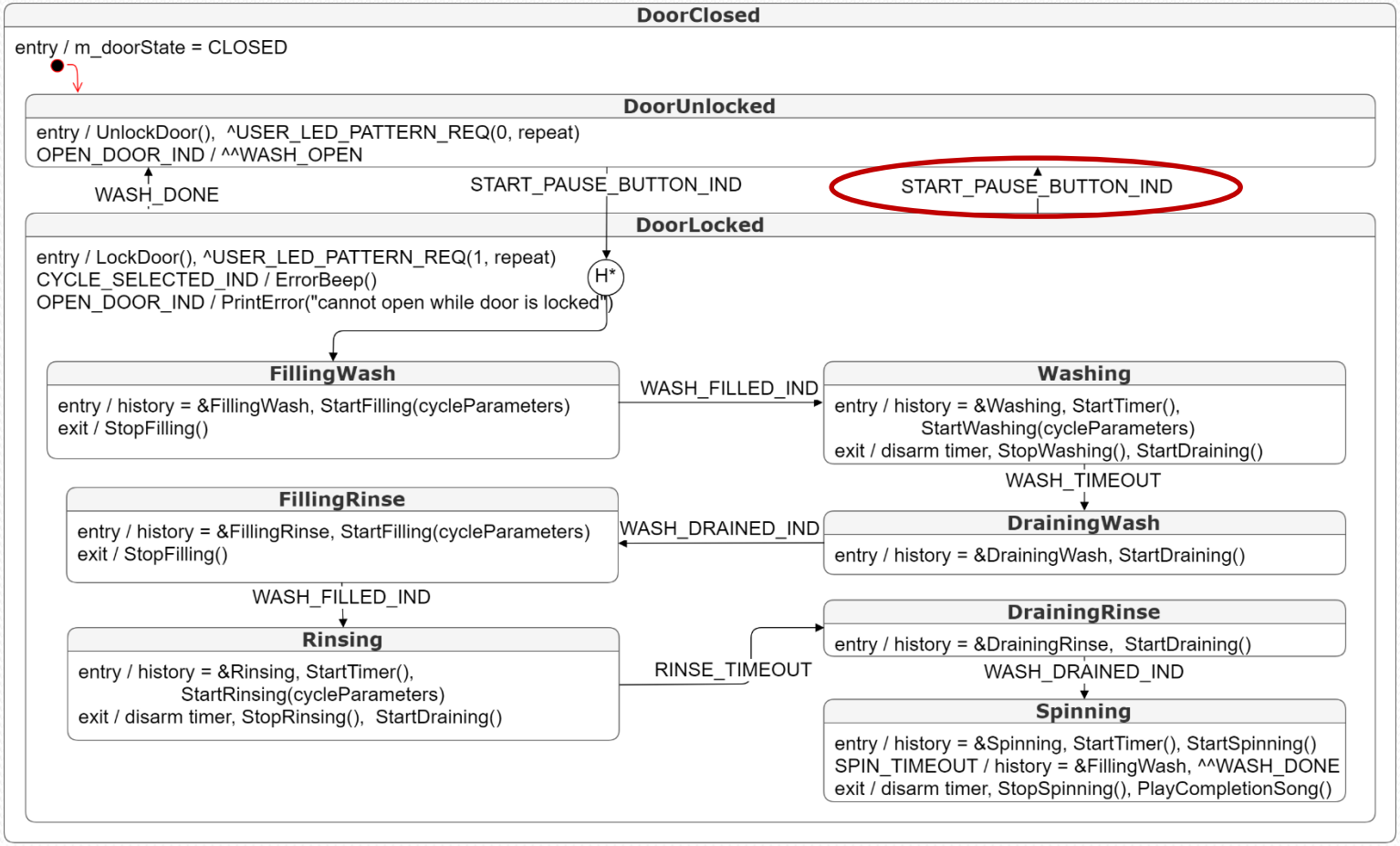

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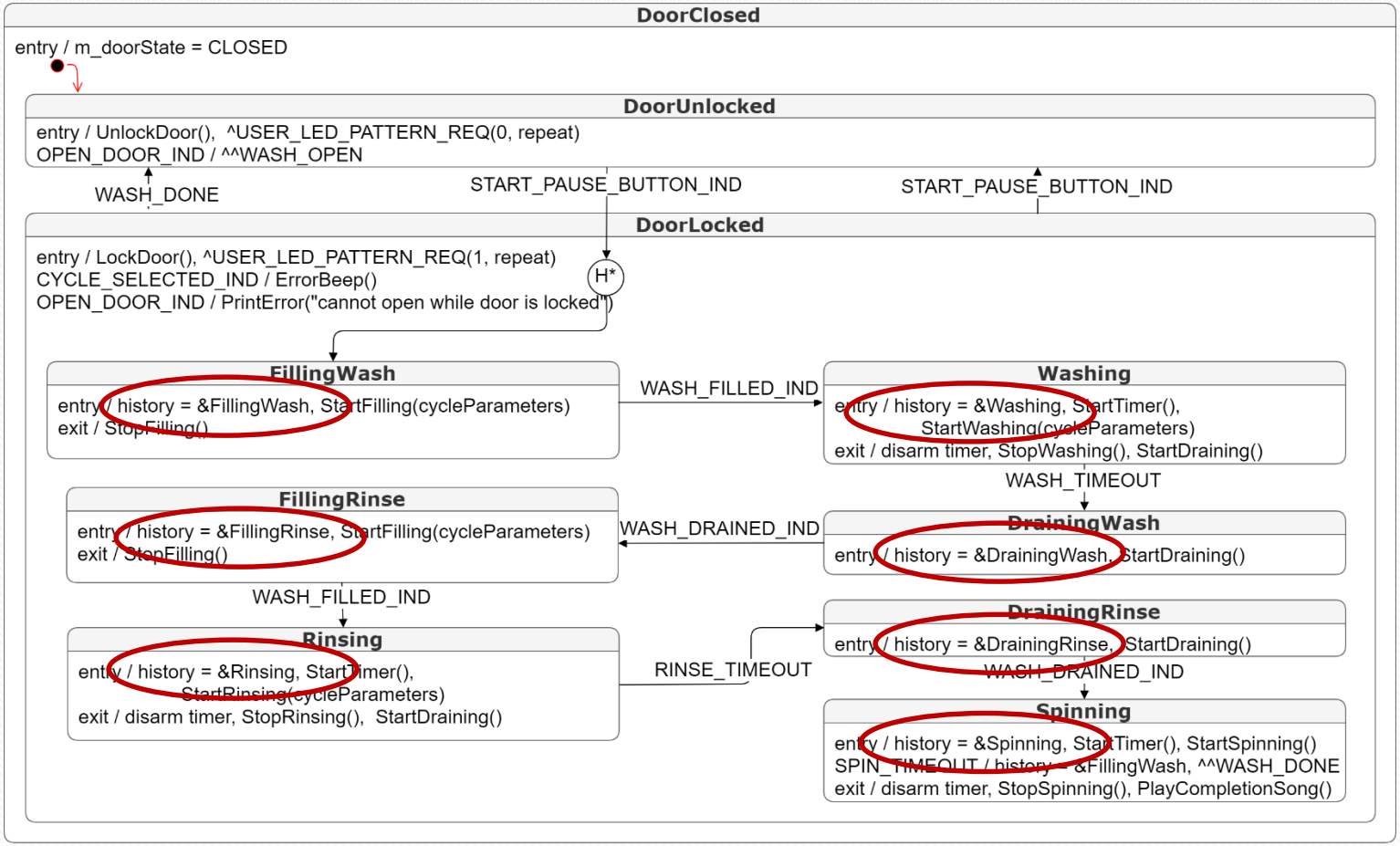

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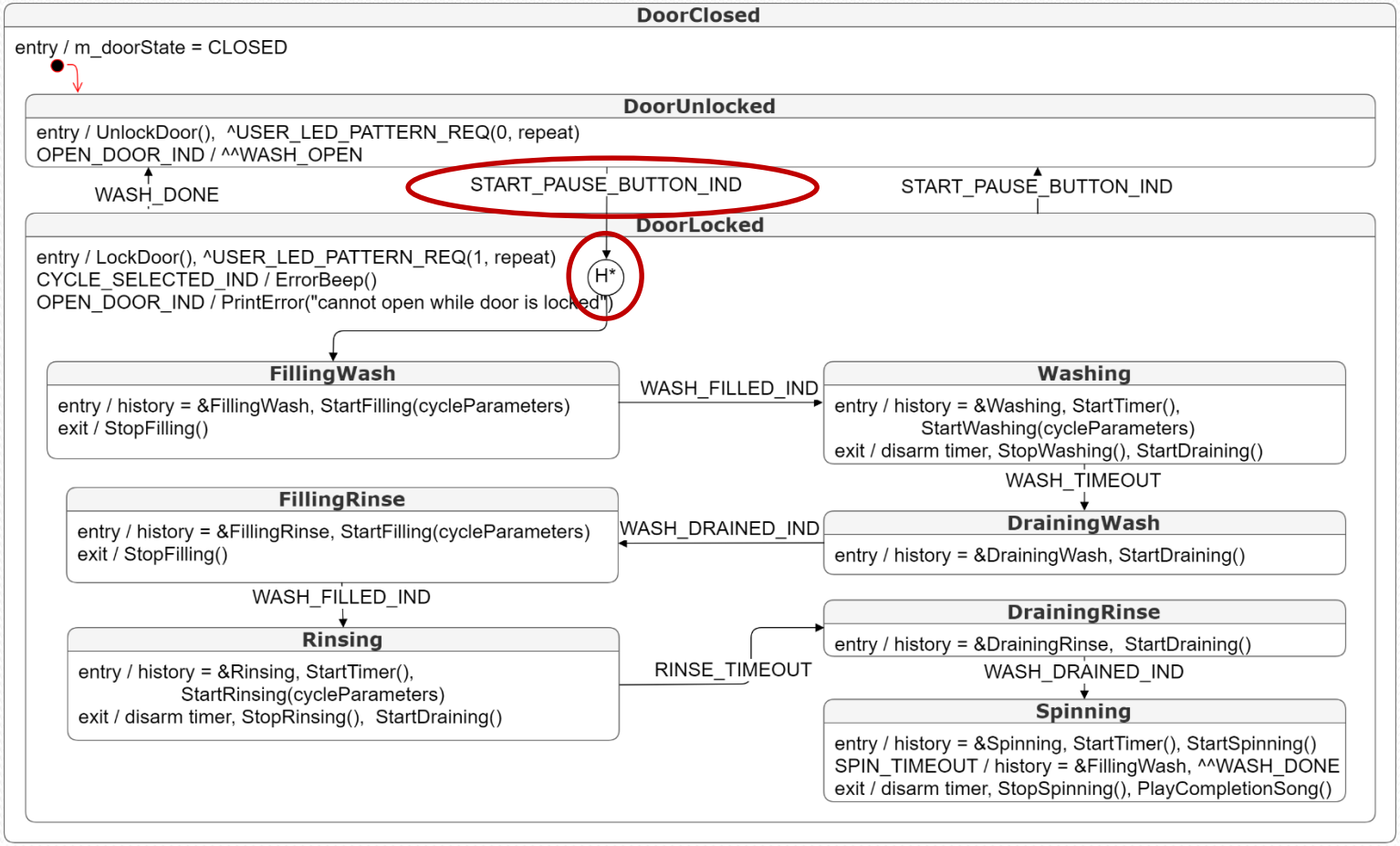

State Design Summary

- UML state machines combine elements of both Moore and Mealy machines.
- Use UML state machines for behavioral systems.
  - Hierarchically combine states with shared characteristics to allow for code reuse and simpler designs.
  - Design patterns: LSP, event deferral, extended state machines, history states
- QP provides a framework for UML state machine implementation.
  - The design of the statecharts is the hard part. Using QP, coding statecharts is easy.

References & Resources

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