1 Overview of assignment

This assignment extends the lecture example of a simple lift controller, that you can extract from an archive (see 2.2). The archive contains:

- **Lift**\_\_ctx: the basic lift context;
- **BasicLift**: the machine that models all the basic lift movements;
- **Doors**\_\_ctx: the context for lift and floor doors;
- **LiftPlusDoors**: BasicLift extended with lift doors;
- **Buttons**\_\_ctx: context for lift and floor buttons;
- **LiftButtons**: LiftPlusDoors extended by buttons in lifts;

### 1.1 Requirements

**Req 1**: There is a finite non-empty set of lifts.

**Req 2**: There is a finite non-empty set of floors.

**Req 3**: All lifts operate over the full set of floors.

**Req 4**: Lifts may be one of *moving, stopped, idle*. An idle lift is inactive and must be activated before it can move.

**Req 5**: A moving lift may be moving *UP* or *DOWN*.

**Req 5a**: A lift at level 0 (lowest level) must be moving *UP*

**Req 5b**: A lift at the maximum level must be moving *DOWN*

**Req 6**: A *stopped* lift may change the direction of movement; a *moving* lift may not change direction, it must stop in order to change direction.

**Req 7**: Each lift has a door.
Req 8: On each floor there is a door for each lift.

Req 9: The lift door of a moving lift must be closed.

Req 10: If a lift is moving then all floor doors for that lift must be closed.

Req 11: If a lift is stopped then the lift door for that lift may be open.

Req 12: If a lift is stopped and the lift door for that lift is open, then the floor door for that lift may be open.

Req 13: The lift door opens before the corresponding floor door, and the floor door closes before the corresponding lift door.

Req 14: After the floor door opens there should be a delay before the floor door closes.

Req 15: Both the lift and floor doors are closed for an idle lift.

Req 16: Each lift is equipped with a set of lift-buttons corresponding to all floors for the building.

Req 17: Each lift button is either on or off.

Req 18: If a lift button is on then the lift must stop at the floor corresponding to that button.

Req 19: When the lift stops at a floor then the lift button corresponding to that floor must be off.

Req 20: Each lift should be associated with a lift schedule that contains all the floors at which the lift must stop.

Req 21:

a) After stopping a lift must continue on its current direction of travel if there are floors in that direction that are in the lift schedule. This strategy is intended to ensure that all lift passengers—that is passengers in a lift—experience the smallest possible number of lift stops before the lift stops at the floor requested by the lift buttons.

b) After stopping, a lift must change direction if the lift schedule is not empty but does not contain floors in the direction of travel.

Req 22: When a lift stops at a requested stop, then the doors must open, and remain open for an interval to allow passengers to leave the lift.

1.2 The Current State

BasicLift, LiftPlusDoors contain basic lift movement and safety constraints. These machines concentrate on establishing the rules for lift and door movements consistent with the above requirements, so that any further refinements will be constrained by those rules. All activities are currently nondeterministic and don’t describe a useful lift system. For example: there is no reliable way of entering a lift, and once in a lift there is no assurance you will be able to get out of the lift again, let alone get out at the desired floor.
1.3 Adding Lift Buttons

Lift buttons are added to each lift, providing a capability for lift passengers to request for the lift to stop at particular floors. The modelling of the servicing of lift button requests must guarantee that all requests are serviced in the shortest possible time, as assessed across all current requests. The requirements are set out in section 1.1 where a simple lift schedule that provides for simple scheduling of lift button requests is described.

The refinement for LiftButtons shown here consists of:

**LiftButtons:** add lift buttons to each lift. These buttons select floors and are either ON or OFF.

**Lift scheduling:** at the same time as the addition of lift buttons, a lift schedule is introduced.

The lift schedule records the floors to stop assigned to each lift. The requests recorded in the lift buttons are assigned to that lift’s schedule.

1.4 Adding Floor Buttons

Each floor needs to be associated with buttons, which we will call FloorButtons that are used by people on a floor to request a lift that will take them either up or down. Floor buttons are not associated with a lift, only a floor. Excepting the top and bottom floors, each floor will have two buttons, associated respectively with **UP** and **DOWN**. Each button will be either **ON** or **OFF**. For uniformity sake the extreme floors can also be associated with two buttons, one of which is always **OFF**.

LiftButtons and FloorButtons should enforce what might be described as “passenger satisfaction policies”. For LiftButtons, that policy is an expression of the idea that when passengers in a lift select floors –by pressing lift buttons— the lift will deliver all of those passengers to the chosen floors in the shortest journeys, subject to the context of the lift when the buttons were pressed.

1.5 Requirements for floor buttons

**Req 23:** Each floor is equipped with buttons for requesting a lift travelling either up or down. Obviously the bottom and top floors do not need a button for requesting a lift travelling down or up, respectively. Note that floor buttons are associated with a floor. There is no association with any particular lift.

**Req 24:** Every activated floor request must be scheduled. That is, at least one lift must eventually be scheduled to service each floor request. Of course, there may be more than one lift that is able to service a particular floor request.

**Req 25:** Scheduling must ensure that every floor request will be serviced, eventually; not necessarily optimally.

**Req 26:** Scheduling of floor requests must not compromise the scheduling strategy for lift button requests described in **Req 21**.

1.6 Rules for Lift System

The following rules are required to model a lift system that provides an acceptable level of service.

**Buttons remain ON until the request is serviced:** a button, whether a lift button or a floor button remains ON until the request implied by that button is serviced. In the case of a lift button this means the lift stops at the selected floor, and in the case of a floor button it means a lift travelling in the required direction stops at the floor.
Lifts continue as long as possible in the same direction: having stopped at a floor a lift should continue in the same direction it was travelling, if there are scheduled requests in that direction. If there are no such requests, but there are scheduled requests in the other direction then the lift will change direction and proceed using this same rule.

Lifts without scheduled requests should become IDLE: having stopped, if a lift has no scheduled requests remaining then the lift should close its doors and enter the IDLE state.

Floor requests are given to the nearest lift: as far as possible requests for a lift initiated by a floor request are assigned to the nearest lift, see below.

1.7 Scheduling floor buttons

Scheduling floor buttons is more difficult than scheduling lift buttons.

- when stopping at a floor to service a floor request the lift must not only be at the floor on which the request was made, but must be travelling in the required direction;
- of course, any lift stopping at a floor may service a floor request and this may render redundant the earlier scheduling of a lift to service the request, and in some circumstances the floor may be safely removed from the schedule;
- it would appear that a floor request should be assigned to the “nearest lift”, but that concept is quite difficult to measure, and, given the dynamic nature of the system, is likely to be less effective than expected. Remember that the extent of a lift’s travel in a particular direction is not deterministic. A lift could travel to the topmost floor or to the bottommost floor, or it may exhaust schedule requests before that happens;
- floor requests could be assigned randomly to lifts;

1.8 Policy for Floor requests

While we can construct a reasonable policy for lift requests that is capable of being implemented reasonably simply, it is more difficult for floor requests. The minimum policy is:

floor requests are scheduled in finite time and the scheduling must guarantee that the request is serviced.

The scheduling should allow for the possibility that the request could be serviced by a lift other than the intended lift.

Another possibility is that servicing of a request may be assigned to multiple lifts, with only one lift actually carrying out the task. Scheduling for requests that are no longer required can be removed.

2 What you should do

1. First, download LiftController.zip from the class archive. A link will be found on the class webpage.

2. Create a refinement of LiftButtons using the Event-B explorer. Name it Floorbuttons.

3. Add the following to the refinement:

   New variable floorbuttons
Invariant
floorbuttons ∈ FLOOR → (DIRECTION → BUTTON)
floorbuttons(0)(DOWN) = OFF
floorbuttons(MAXFLOOR)(UP) = OFF

4. Next, read the given parts of the model, especially the LiftButtons machine, and understand how the model achieves the requirements. Special attention should be paid to understanding the role of the invariants and guards.

5. Devise a scheme to schedule the floor requests and develop a model based on that scheme.

6. Special attention should be paid to developing invariants that will assist in assuring that the model is behaving as you expect it to.

7. Read and consider carefully the following item on data refinement.

8. Animate: you will almost certainly find it useful to animate in order to get an appreciation of whether your scheduling is following the type of discipline you require. Remember that animation can’t be used to verify your model. Animation will not be assessed.

9. Discharge as many POs as you can.

2.1 Data refinement of liftschedule

It is almost certain that the best refinement will be achieved by data refinement. The reason is that while the current scheduling, using liftschedule as it stands, will not be able to be used to schedule the floor button requests, because it is not sensitive to direction, the fact is that you do have a scheduling strategy. What is required is to be able to extend the direction insensitive liftschedule to incorporate the direction sensitive requirements.

That is data refinement.

If you can do that then the current framework only needs to be adapted to incorporate the data refinement.

2.2 Initiating the data refinement

Data refinement requires the following steps:

Delete liftschedule the variable liftschedule must be deleted. Simply delete the variable from the variables.

Do not make any other changes at the moment.

Decide how you are going to use the liftschedule strategy this involves creating new variables that you can use to schedule both liftbutton and floorbutton requests, and

Decide how you can extract the value of liftschedule this forms the refinement relation that relates the new set of variables to the deleted liftschedule.

The above exercise involves determining how you can use information from the floor requests that can be used at the appropriate time to drive the same scheduling model.

Since liftschedule has been deleted most of the places where you will need to do something will be highlighted with error diagnostics. What is required at these points is a description of how the current state relates to the deleted liftschedule. That is the verification of the refinement relation.
The above shows one of the big advantages of using data refinement: the structure of the floorbuttons machine remains significantly the same as the structure of liftbuttons. To a significant degree you only have to supply the information that allows the refinement relation to be verified.

Of course, there will be new cases that apply specifically to the function of the floor buttons.
CONTEXT Lift_ctx
SETS
  DIRECTION
  STATUS
  LIFT
CONSTANTS
  MAXFLOOR
  FLOOR
  UP
  DOWN
  IDLE
  STOPPED
  MOVING
  CHANGE
AXIOMS
  axm1 : MAXFLOOR ∈ N₁
  axm2 : MAXFLOOR ≥ 2
  axm3 : FLOOR = 0 .. MAXFLOOR
  axm4 : finite(LIFT)
  axm5 : partition(DIRECTION, {UP}, {DOWN})
  axm6 : partition(STATUS, {IDLE}, {STOPPED}, {MOVING})
  axm7 : CHANGE ∈ DIRECTION ↷ DIRECTION
  axm8 : CHANGE = {UP ↦ DOWN, DOWN ↦ UP}
thm1 : FLOOR ≠ ∅
thm2 : finite(FLOOR)
thm3 : finite(STATUS)
thm4 : finite(DIRECTION)
thm5 : finite(CHANGE)
END
MACHINE BasicLift
This machine models the basic lift movements, and establishes the basic lift constraints.
The behaviour is non-deterministic:
there is no attempt to express any sort of lift control or scheduling.
A discipline of lift direction is established:
* level 0: direction is UP
* level MAXFLOOR: direction is DOWN
* other floors: either direction is valid
A lift at any time has one of the following statuses:
IDLE: not currently an active lift
STOPPED: not moving
MOVING: moving between floors
The status of a lift must be STOPPED before it becomes IDLE;
and must be STOPPED before it becomes MOVING
There are no doors.

SEES Lift_ctx
VARIABLES
liftposition
liftstatus
liftdirection

INvariants
inv1 : liftposition ∈ LIFT → FLOOR
thm1 : finite(liftposition)
inv2 : liftstatus ∈ LIFT → STATUS
thm2 : finite(liftstatus)
inv3 : liftdirection ∈ LIFT → DIRECTION
thm3 : finite(liftdirection)
inv4 : ∀l ∈ LIFT ∧ liftposition(l) = 0 ⇒ liftdirection(l) = UP
inv5 : ∀l ∈ LIFT ∧ liftposition(l) = MAXFLOOR ⇒ liftdirection(l) = DOWN
thm4 : ∀l ∈ LIFT ∧ liftdirection(l) = DOWN ⇒ liftposition(l) ≠ 0
thm5 : ∀l ∈ LIFT ∧ liftdirection(l) = UP ⇒ liftposition(l) ≠ MAXFLOOR
thm6 : ∀l ∈ LIFT ∧ liftdirection(l) = UP ⇒ liftposition(l) + 1 ≤ MAXFLOOR

EVENTS
Initialisation begin
  act1 : liftposition := LIFT × {0}
  act2 : liftdirection := LIFT × {UP}
  act3 : liftstatus := LIFT × {IDLE}
end
Event IdleLift ⇐
  Idle lifts cannot move
any
  lift
where
  grd1 : liftstatus(lift) = STOPPED
then
  act1 : liftstatus(lift) := IDLE
end

Event ActivateLift ≡
  Ready an Idle lift to enable moving
any
  lift
where
  grd1 : liftstatus(lift) = IDLE
then
  act1 : liftstatus(lift) := STOPPED
end

Event StartLift ≡
  Models the starting of a STOPPED lift, maintaining previous direction
any
  lift
where
  grd1 : liftstatus(lift) = STOPPED
then
  act1 : liftstatus(lift) := MOVING
end

Event ChangeDir ≡
  Models the changing of direction of a STOPPED lift
any
  lift
where
  grd1 : liftstatus(lift) = STOPPED
  grd2 : liftposition(lift) ≠ 0
  grd3 : liftposition(lift) ≠ MAXFLOOR
then
  act1 : liftdirection(lift) := CHANGE(liftdirection(lift))
end

Event MoveUp ≡
  Models a lift moving up to the next floor
  where its status is either MOVING or STOPPED
any
  lift
where
grd1 : liftstatus(lift) = MOVING  
grd2 : liftdirection(lift) = UP  

then

act1 : liftposition(lift) := liftposition(lift) + 1

act2 : liftdirection : |liftdirection' ∈ LIFT → DIRECTION  
\∧ (liftposition(lift) + 1 = MAXFLOOR  
⇒ liftdirection' = liftdirection \& \{lift \mapsto DOWN\})  
\∧ (liftposition(lift) + 1 \neq MAXFLOOR  
⇒ liftdirection' = liftdirection)  

act3 : liftstatus : |liftstatus' ∈ LIFT → STATUS  
((liftdirection' = liftstatus \& \{lift \mapsto MOVING\})  
\lor (liftdirection' = liftstatus \& \{lift \mapsto STOPPED\}))  

end

Event MoveDown ≜  
Models a lift moving down to the next floor  
where its status is either MOVING or STOPPED

any

lift

where

grd1 : liftstatus(lift) = MOVING  
grd2 : liftdirection(lift) = DOWN  

then

act1 : liftposition(lift) := liftposition(lift) - 1

act2 : liftdirection : |liftdirection' ∈ LIFT → DIRECTION  
\∧ (liftposition(lift) = 1  
⇒ liftdirection' = liftdirection \& \{lift \mapsto UP\})  
\∧ (liftposition(lift) \neq 1  
⇒ liftdirection' = liftdirection)  

act3 : liftstatus : |liftstatus' ∈ LIFT → STATUS  
((liftdirection' = liftstatus \& \{lift \mapsto MOVING\})  
\lor (liftdirection' = liftstatus \& \{lift \mapsto STOPPED\}))  

end

END
CONTEXT  Doors_ctx
SETS
    DOORS
CONSTANTS
    OPEN
    CLOSED
AXIOMS

    axm1 : partition(DOORS, {OPEN}, {CLOSED})
END
MACHINE LiftPlusDoors

Add doors to the floors and also the lifts.

Floor doors requirements:
When a lift stops at a floor the status of the doors moves through the sequence:

CLOSED OPEN, CLOSED.

1) the lift door may be opened only if the lift status is STOPPED, and the liftdoorstatus is CLOSED
2) the floor door may be opened only if the lift status is STOPPED, the liftdoorstatus is OPEN and the floordoorstatus is CLOSED
3) the floor door may be closed only if the lift status is STOPPED, the liftdoorstatus and floordoorstatus are both OPEN
4) the lift door may be closed only if the lift status is STOPPED, the floordoorstatus is CLOSED and liftdoorstatus is OPEN
5) the lift floordoor may be OPEN only on the floor on which the lift is stopped

6) it is clear that the above door opening/closing sequence can cycle; this will be prevented by scheduling

Lift doors requirements:
1) a Lift door may be open only if
   a) the lift is STOPPED, and
   b) the floor door is OPEN
   The lift door opens AFTER the floor door and closes AFTER the floor door.
   A new event OpenDoors is introduced.
   This event can only be activated when the lift status is STOPPED and will initiate a cycle through the door opening sequence.

REFINES BasicLift
SEES Lift_ctx, Door_ctx

VARIABLES

liftposition
liftstatus
liftdirection
floordoorstatus
liftdoorstatus
waiting

INVARIANTS

inv1 : floordoorstatus ∈ LIFT → (FLOOR → DOOR)
inv2 : liftdoorstatus ∈ LIFT → DOOR
inv3 : ∀l, f ∈ FLOOR ∧ f ≠ liftposition(l)
    ⇒ floordoorstatus(l)(f) = CLOSED
Floor doors may be OPEN only on the floor that is the current position of the lift
inv4 : ∀l liftdoorstatus(l) ∈ {MOVING, IDLE}
    ⇒ liftdoorstatus(l) = CLOSED
\( \forall l, f \cdot \text{liftstatus}(l) \in \{\text{MOVING, IDLE}\} \land f \in \text{FLOOR} \Rightarrow \text{floordoorstatus}(l)(f) = \text{CLOSED} \)

If a lift is MOVING or IDLE then the lift door and all floor doors are CLOSED

\( \forall l, f : f = \text{liftposition}(l) \land \text{floordoorstatus}(l)(f) = \text{OPEN} \Rightarrow \text{liftdoorstatus}(l) = \text{OPEN} \)

Floor door may be OPEN only if the lift door is OPEN

\( \forall l, f : f \in \text{FLOOR} \land \text{floordoorstatus}(l)(f) = \text{OPEN} \Rightarrow f = \text{liftposition}(l) \)

\( \forall l : \text{liftdoorstatus}(l) = \text{OPEN} \Rightarrow \text{liftstatus}(l) = \text{STOPPED} \)

\( \forall l : \text{floordoorstatus}(l)(\text{liftposition}(l)) = \text{OPEN} \Rightarrow \text{liftstatus}(l) = \text{STOPPED} \land \text{liftdoorstatus}(l) = \text{OPEN} \)

Waiting is used to provide a simple model of a pause before closing doors

**EVENTS**

**Initialisation**

```
begin
  act1 : \text{liftposition} := \text{LIFT} \times \{0\}
  act2 : \text{liftdirection} := \text{LIFT} \times \{\text{UP}\}
  act3 : \text{liftstatus} := \text{LIFT} \times \{\text{IDLE}\}
  act4 : \text{floordoorstatus} := \text{LIFT} \times \{\text{FLOOR} \times \{\text{CLOSED}\}\}
  act5 : \text{liftdoorstatus} := \text{LIFT} \times \{\text{CLOSED}\}
  act6 : \text{waiting} := \emptyset
end
```

**Event OpenFloorDoor**

```
any
lift
  where
    grd1 : \text{liftstatus}(lift) = \text{STOPPED}
    grd2 : \text{floordoorstatus}(lift)(\text{liftposition}(lift)) = \text{CLOSED}
    grd3 : \text{liftdoorstatus}(lift) = \text{OPEN}
  then
    act1 : \text{floordoorstatus}(lift) := \text{floordoorstatus}(lift) \ominus \{\text{liftposition}(lift) \mapsto \text{OPEN}\}
    act2 : \text{waiting} := \text{waiting} \cup \{\text{lift}\}
end
```

**Event OpenLiftDoor**

```
any
```
\begin{itemize}
\item \textit{lift}
\item where
\item \texttt{grd1 : liftstatus(lift) = STOPPED}
\item \texttt{grd2 : floordoorsstatus(lift)(liftposition(lift)) = OPEN}
\item \texttt{grd3 : liftdoorstatus(lift) = CLOSED}
\item then
\item \texttt{act1 : liftdoorstatus(lift) := OPEN}
\item end
\item \textbf{Event} \textit{CloseFloorDoor} \equiv
\item any
\item \textit{lift}
\item where
\item \texttt{grd1 : liftstatus(lift) = STOPPED}
\item \texttt{grd2 : floordoorsstatus(lift)(liftposition(lift)) = OPEN}
\item \texttt{grd3 : liftdoorstatus(lift) = OPEN}
\item \texttt{grd4 : lift \notin waiting}
\item then
\item \texttt{act1 : floordoorsstatus(lift) := floordoorsstatus(lift) \cup \{liftposition(lift) \mapsto CLOSED\}}
\item end
\item \textbf{Event} \textit{CloseLiftdoor} \equiv
\item any
\item \textit{lift}
\item where
\item \texttt{grd1 : liftstatus(lift) = STOPPED}
\item \texttt{grd2 : floordoorsstatus(lift)(liftposition(lift)) = CLOSED}
\item \texttt{grd3 : liftdoorstatus(lift) = OPEN}
\item then
\item \texttt{act1 : liftdoorstatus(lift) := CLOSED}
\item end
\item \textbf{Event} \textit{Release} \equiv
\item Models pausing between opening and closing lift doors
\item any
\item \textit{lift}
\item where
\item \texttt{grd1 : lift \in waiting}
\item then
\item \texttt{act1 : waiting := waiting \setminus \{lift\}}
\item end
\item \textbf{Event} \textit{MoveUp} \equiv
\item refines \textit{MoveUp}
\item Models a lift moving up to the next floor and continuing to move
\item any
\item \textit{lift}
\end{itemize}
where

\[ \text{grd1: } \text{liftstatus}(\text{lift}) = \text{MOVING} \]
\[ \text{grd2: } \text{liftdirection}(\text{lift}) = \text{UP} \]

then

\[ \text{act1: } \text{liftposition}(\text{lift}) := \text{liftposition}(\text{lift}) + 1 \]
\[ \text{act2: } \text{liftdirection}(\text{lift})' \in \text{LIFT} \rightarrow \text{DIRECTION} \]
\[ \land (\text{liftposition}(\text{lift}) + 1 = \text{MAXFLOOR}) \]
\[ \Rightarrow \]
\[ \text{liftdirection}' = \text{liftdirection} \land \{\text{lift} \mapsto \text{DOWN}\} \]
\[ \land (\text{liftposition}(\text{lift}) + 1 \neq \text{MAXFLOOR}) \]
\[ \Rightarrow \]
\[ \text{liftdirection}' = \text{liftdirection} \]
\[ \text{act3: } \text{liftstatus}(\text{lift}) := \text{STOPPED} \]

end

Event \ MoveUpAndStop \overset{\text{Def}}{=} \\
\text{Models a lift moving up to the next floor and stopping }

refines \ MoveUp \\
any \\
lift \\
where

\[ \text{grd1: } \text{liftstatus}(\text{lift}) = \text{MOVING} \]
\[ \text{grd2: } \text{liftdirection}(\text{lift}) = \text{UP} \]

then

\[ \text{act1: } \text{liftposition}(\text{lift}) := \text{liftposition}(\text{lift}) + 1 \]
\[ \text{act2: } \text{liftdirection}(\text{lift})' \in \text{LIFT} \rightarrow \text{DIRECTION} \]
\[ \land (\text{liftposition}(\text{lift}) + 1 = \text{MAXFLOOR}) \]
\[ \Rightarrow \]
\[ \text{liftdirection}' = \text{liftdirection} \land \{\text{lift} \mapsto \text{DOWN}\} \]
\[ \land (\text{liftposition}(\text{lift}) + 1 \neq \text{MAXFLOOR}) \]
\[ \Rightarrow \]
\[ \text{liftdirection}' = \text{liftdirection} \]
\[ \text{act3: } \text{liftstatus}(\text{lift}) := \text{STOPPED} \]

end

Event \ MoveDown \overset{\text{Def}}{=} \\
\text{Models a lift moving down to the next floor and continuing to move }

refines \ MoveDown \\
any \\
lift \\
where

\[ \text{grd1: } \text{liftstatus}(\text{lift}) = \text{MOVING} \]
\[ \text{grd2: } \text{liftdirection}(\text{lift}) = \text{DOWN} \]

then

\[ \text{act1: } \text{liftposition}(\text{lift}) := \text{liftposition}(\text{lift}) - 1 \]
act2 : liftdirection : \( \text{liftdirection}' \in \text{LIFT} \rightarrow \text{DIRECTION} \)
\( \land (\text{liftposition}(\text{lift}) = 1) \)
\( \Rightarrow \)
\( \text{liftdirection}' = \text{liftdirection} \Leftrightarrow \{\text{lift} \mapsto \text{UP}\} \)
\( \land (\text{liftposition}(\text{lift}) \neq 1) \)
\( \Rightarrow \)
\( \text{liftdirection}' = \text{liftdirection} \)

act3 : liftstatus : \( \text{liftstatus}' \in \text{LIFT} \rightarrow \text{STATUS} \)
\( \land (\text{liftstatus}' = \text{liftstatus} \Leftrightarrow \{\text{lift} \mapsto \text{MOVING}\}) \)

end

Event MoveDownAndStop $\hat{=}$$
Models a lift moving down to the next floor and stopping

refines MoveDown

any

\( \text{lift} \)

where

\( \text{grd1} : \text{liftstatus}(\text{lift}) = \text{MOVING} \)
\( \text{grd2} : \text{liftdirection}(\text{lift}) = \text{DOWN} \)

then

act1 : \( \text{liftposition}(\text{lift}) := \text{liftposition}(\text{lift}) - 1 \)
act2 : liftdirection : \( \text{liftdirection}' \in \text{LIFT} \rightarrow \text{DIRECTION} \)
\( \land (\text{liftposition}(\text{lift}) = 1) \)
\( \Rightarrow \)
\( \text{liftdirection}' = \text{liftdirection} \Leftrightarrow \{\text{lift} \mapsto \text{UP}\} \)
\( \land (\text{liftposition}(\text{lift}) \neq 1) \)
\( \Rightarrow \)
\( \text{liftdirection}' = \text{liftdirection} \)
act3 : \( \text{liftstatus}(\text{lift}) := \text{STOPPED} \)

end

Event StartLift $\hat{=}$$
Models the starting of a STOPPED lift, maintaining of previous direction

extends StartLift

any

\( \text{lift} \)

where

\( \text{grd1} : \text{liftstatus}(\text{lift}) = \text{STOPPED} \)
\( \text{grd2} : \text{liftdoorstatus}(\text{lift}) = \text{CLOSED} \)
\( \text{grd3} : \text{floordoortstatus}(\text{lift})(\text{liftposition}(\text{lift})) = \text{CLOSED} \)

then

act1 : \( \text{liftstatus}(\text{lift}) := \text{MOVING} \)

end

Event ChangeDir $\hat{=}$$
Models the changing of direction of a STOPPED lift

extends ChangeDir

any

\( \text{lift} \)

16
where
\begin{align*}
\text{grd1} & : \text{liftstatus}(\text{lift}) = \text{STOPPED} \\
\text{grd2} & : \text{liftposition}(\text{lift}) \neq 0 \\
\text{grd3} & : \text{liftposition}(\text{lift}) \neq \text{MAXFLOOR}
\end{align*}
then
\begin{align*}
\text{act1} & : \text{liftdirection}(\text{lift}) := \text{CHANGE}(\text{liftdirection}(\text{lift}))
\end{align*}
end
Event \text{IdleLift} := \text{Idle lifts cannot move}
extends \text{IdleLift}
any
\begin{align*}
\text{lift}
\end{align*}
where
\begin{align*}
\text{grd1} & : \text{liftstatus}(\text{lift}) = \text{STOPPED} \\
\text{grd2} & : \text{floordoorstatus}(\text{lift})(\text{liftposition}(\text{lift})) = \text{CLOSED} \\
\text{grd3} & : \text{liftdoorstatus}(\text{lift}) = \text{CLOSED}
\end{align*}
then
\begin{align*}
\text{act1} & : \text{liftstatus}(\text{lift}) := \text{IDLE}
\end{align*}
end
Event \text{ActivateLift} := \text{Ready an Idle lift to enable moving}
extends \text{ActivateLift}
any
\begin{align*}
\text{lift}
\end{align*}
where
\begin{align*}
\text{grd1} & : \text{liftstatus}(\text{lift}) = \text{IDLE}
\end{align*}
then
\begin{align*}
\text{act1} & : \text{liftstatus}(\text{lift}) := \text{STOPPED}
\end{align*}
end
END
This machine completes the modelling of doors for a lift by introducing floor doors.

**MACHINE** LiftPlusFloorDoors

**REFINES** LiftPlusDoors

**SEES** Lift_ctx, Doors_ctx

**VARIABLES**
- liftposition
- liftstatus
- liftdirection
- liftdoorstatus
- floordoorstatus

**INVARIANTS**

```plaintext
inv1 : floordoorstatus ∈ LIFT → (FLOOR → DOORS)
inv2 : ∀l· l ∈ LIFT ∧ liftdoorstatus(l) = CLOSED
     ⇒ floordoorstatus(l)(liftposition(l)) = CLOSED
     Req 13: The floor door opens AFTER the lift door opens

inv3 : ∀l, f· l ∈ LIFT ∧ f ∈ FLOOR \ {liftposition(l)}
     ⇒ floordoorstatus(l)(f) = CLOSED
     Req 11: Floor doors may be OPEN only on the floor where a lift is stopped

inv4 : ∀l· l ∈ LIFT ∧ floordoorstatus(l)(liftposition(l)) = OPEN
     ⇒ liftdoorstatus(l) = OPEN
     Req 13, 14: Floor door OPEN implies lift door OPEN

inv5 : ∀l· l ∈ LIFT ∧ liftdoorstatus(l) = OPEN
     ⇒ liftstatus(l) = WAITING
     Req 11 (variant): Floor door may be OPEN only in WAITING state
```

**EVENTS**

**Initialisation**

```plaintext
extended
begin
  act1 : liftposition := LIFT × {0}
  act2 : liftdirection := LIFT × {UP}
  act3 : liftstatus := LIFT × {IDLE}
  act4 : liftdoorstatus := LIFT × {CLOSED}
  act5 : floordoorstatus := LIFT × {FLOOR × {CLOSED}}
end
```

**Event** OpenFloorDoor ≡ Req 11: The floor door opens when the status of the lift is WAITING
any

\[
\begin{align*}
\text{lift} & \\
\text{floor} & \\
\text{where} & \\
\text{grd1} : & \text{floor} = \text{liftposition(lift)} \\
\text{grd2} : & \text{liftdoorstatus(lift)} = \text{OPEN} \\
\text{grd3} : & \text{floordoorsstatus(lift)(floor)} = \text{CLOSED} \\
\text{grd4} : & \text{lifstatus(lift)} = \text{WAITING} \\
\text{then} & \\
\text{act1} : & \text{floordoorsstatus(lift)} := \text{floordoorsstatus(lift)} \triangleq \{\text{floor} \mapsto \text{OPEN}\} \\
\text{end} & \\
\text{Event} & \text{CloseFloorDoor} \cong \text{Req 14} \\
\text{refines} & \text{ChangeStatus} \\
\text{any} & \\
\text{lift} & \\
\text{where} & \\
\text{grd1} : & (\text{floordoorsstatus(lift)})(\text{liftposition(lift)}) = \text{OPEN} \\
\text{grd2} : & \text{lifstatus(lift)} = \text{WAITING} \\
\text{then} & \\
\text{act1} : & \text{floordoorsstatus(lift)} := \text{floordoorsstatus(lift)} \triangleq \{\text{liftposition(lift)} \mapsto \text{CLOSED}\} \\
\text{act2} : & \text{lifstatus(lift)} := \text{STOPPED} \\
\text{end} & \\
\text{Event} & \text{OpenLiftDoor} \cong \text{extends} \text{OpenLiftDoor} \\
\text{any} & \\
\text{lift} & \\
\text{where} & \\
\text{grd1} : & \text{lifstatus(lift)} = \text{WAITING} \\
\text{grd2} : & \text{lifdoorsstatus(lift)} = \text{CLOSED} \\
\text{then} & \\
\text{act1} : & \text{lifdoorsstatus(lift)} := \text{OPEN} \\
\text{end} & \\
\text{Event} & \text{CloseLiftdoor} \cong \text{extends} \text{CloseLiftdoor} \\
\text{any} & \\
\text{lift} & \\
\text{where} & \\
\text{grd1} : & \text{lifdoorsstatus(lift)} = \text{OPEN} \\
\text{grd2} : & (\text{floordoorsstatus(lift)})(\text{liftposition(lift)}) = \text{CLOSED} \\
\text{then} & \\
\text{act1} : & \text{lifdoorsstatus(lift)} := \text{CLOSED} \\
\text{act2} : & \text{lifstatus(lift)} := \text{STOPPED} \\
\text{end} & \\
\text{Event} & \text{StartLift} \cong \text{Models the starting of a STOPPED lift, maintaining of previous direction}
extends StartLift
    any
    lift
where
    grd1 : liftstatus(lift) = STOPPED
    grd2 : liftdoorstatus(lift) = CLOSED
    Req 9
then
    act1 : liftstatus(lift) := MOVING
end

Event ChangeDir \equiv Models the changing of direction of a STOPPED lift
extends ChangeDir
    any
    lift
where
    grd1 : liftstatus(lift) = STOPPED
    grd2 : liftposition(lift) \neq 0
    grd3 : liftposition(lift) \neq MAXFLOOR
then
    act1 : liftdirection(lift) := CHANGE(liftdirection(lift))
end

Event IdleLift \equiv Idle lifts cannot move
extends IdleLift
    any
    lift
where
    grd1 : liftstatus(lift) = STOPPED
    grd2 : liftdoorstatus(lift) = CLOSED
    Req 15
then
    act1 : liftstatus(lift) := IDLE
end

Event ActivateLift \equiv Ready an Idle lift to enable moving
extends ActivateLift
    any
    lift
where
    grd1 : liftstatus(lift) = IDLE
then
    act1 : liftstatus : liftstatus' \in LIFT \rightarrow STATUS
    \land
    ((liftstatus' = liftstatus \Leftrightarrow \{lift \mapsto STOPPED\})
    \lor
    (liftstatus' = liftstatus \Leftrightarrow \{lift \mapsto WAITING\}))
**Event** MoveUp ≡

*Models a lift moving up to the next floor*

extends MoveUp

any

\[ \text{lift} \]

where

\[
\begin{align*}
grd1 &: \text{liftstatus}(\text{lift}) = \text{MOVING} \\
\text{grd2} &: \text{liftdirection}(\text{lift}) = \text{UP}
\end{align*}
\]

then

\[
\begin{align*}
\text{act1} &: \text{liftposition}(\text{lift}) := \text{liftposition}(\text{lift}) + 1 \\
\text{act2} &: \text{liftdirection} : [\text{liftdirection}' \in LIFT \rightarrow \text{DIRECTION} \\
& \quad \land (\text{liftposition}(\text{lift}) + 1 = \text{MAXFLOOR}) \\
& \quad \Rightarrow \\
& \quad \text{liftdirection}' = \text{liftdirection} \Leftrightarrow \{\text{lift} \mapsto \text{DOWN}\} \\
& \quad \land (\text{liftposition}(\text{lift}) + 1 \neq \text{MAXFLOOR}) \\
& \quad \Rightarrow \\
& \quad \text{liftdirection}' = \text{liftdirection}
\end{align*}
\]

Req 5a and 5b

\[
\begin{align*}
\text{act3} &: \text{liftstatus} : [\text{liftstatus}' \in LIFT \rightarrow \text{STATUS} \land \\
& \quad ((\text{liftstatus}' = \text{liftstatus} \Leftrightarrow \{\text{lift} \mapsto \text{MOVING}\}) \\
& \quad \lor \\
& \quad (\text{liftstatus}' = \text{liftstatus} \Leftrightarrow \{\text{lift} \mapsto \text{WAITING}\}) \\
& \quad \lor \\
& \quad (\text{liftstatus}' = \text{liftstatus} \Leftrightarrow \{\text{lift} \mapsto \text{STOPPED}\}))
\end{align*}
\]

end

**Event** MoveDown ≡

*Models a lift moving down to the next floor*

extends MoveDown

any

\[ \text{lift} \]

where

\[
\begin{align*}
grd1 &: \text{liftstatus}(\text{lift}) = \text{MOVING} \\
\text{grd2} &: \text{liftdirection}(\text{lift}) = \text{DOWN}
\end{align*}
\]

then

\[
\begin{align*}
\text{act1} &: \text{liftposition}(\text{lift}) := \text{liftposition}(\text{lift}) - 1 \\
\text{act2} &: \text{liftdirection} : [\text{liftdirection}' \in LIFT \rightarrow \text{DIRECTION} \\
& \quad \land (\text{liftposition}(\text{lift}) = 1) \\
& \quad \Rightarrow \\
& \quad \text{liftdirection}' = \text{liftdirection} \Leftrightarrow \{\text{lift} \mapsto \text{UP}\} \\
& \quad \land (\text{liftposition}(\text{lift}) \neq 1) \\
& \quad \Rightarrow \\
& \quad \text{liftdirection}' = \text{liftdirection}
\end{align*}
\]

Req 5a and 5b
\textbf{act3} : liftstatus : |liftstatus' \in LIFT \rightarrow STATUS \\
\quad \wedge ((liftstatus' = liftstatus \Leftarrow \{lift \mapsto MOVING\}) \\
\quad \vee \\
\quad (liftstatus' = liftstatus \Leftarrow \{lift \mapsto WAITING\}) \\
\quad \vee \\
\quad (liftstatus' = liftstatus \Leftarrow \{lift \mapsto STOPPED\}))

\textbf{end}

\textbf{END}
CONTEXT  Buttons_ctx
SETS
  BUTTONS
CONSTANTS
  ON
  OFF
AXIOMS

  axm1 : partition(BUTTONS, {ON}, {OFF})
    Req 17
END
MACHINE LiftButtons

This machine extends the LiftPlusDoors model to

1) add buttons within each lift by which passengers indicate the floor to which they want to travel;

2) establish a lift schedule associated with each lift.
   The lift schedule:
   * is used to determine the direction of travel of a lift and the floors at which the lift should stop
   * the lift adopts a strategy by which a lift keeps travelling in its current direction while the schedule contains floors in that direction.

This strategy ensures satisfaction of Req21 a & b

REFINES LiftPlusDoors
SEES Lift_ctx, Door_ctx, Button_ctx

VARIABLES

  liftposition
  liftstatus
  liftdirection
  liftdoorstatus
  floordoorstatus
  liftbuttons
  liftschedule
  waiting

INVARIANTS

  inv1 : liftbuttons ∈ LIFT → (FLOOR → BUTTON)
  inv2 : liftschedule ∈ LIFT → ℙ(FLOOR)
  inv3 : ∀ l, f · l ∈ LIFT ∧ f ∈ FLOOR
  ⇒
  (liftbuttons(l)(f) = ON ⇒ f ∈ liftschedule(l))

EVENTS

Initialisation
extended

begin

  act1 : liftposition := LIFT × {0}
  act2 : liftdirection := LIFT × {UP}
  act3 : liftstatus := LIFT × {IDLE}
  act4 : floordoorstatus := LIFT × {FLOOR × {CLOSED}}
  act5 : liftdoorstatus := LIFT × {CLOSED}
  act6 : waiting := ∅
  act7 : liftbuttons := LIFT × {FLOOR × {OFF}}
  act8 : liftschedule := LIFT × {∅}

end

Event SelectFloor ≡

  Select floor to stop using lift buttons; also adds floor to lift schedule
any
  lift
  floor
where
  grd1 : floor ∈ FLOOR
  grd2 : liftbuttons(lift)(floor) = OFF
  grd3 : floor ≠ liftposition(lift)
then
  act1 : liftbuttons(lift) := liftbuttons(lift) \{ floor \mapsto ON \}
  act2 : liftschedule(lift) := liftschedule(lift) \cup \{ floor \}
end
Event StartLift ≡ 
  Models the starting of a STOPPED lift, maintaining of previous direction
extends StartLift
any
  lift
where
  grd1 : liftstatus(lift) = STOPPED
  grd2 : liftdoorstatus(lift) = CLOSED
  grd3 : floordoorstatus(lift)(liftposition(lift)) = CLOSED
  grd4 : liftschedule(lift) ≠ ∅
  grd5 : liftdirection(lift) = DOWN
       ⇒ liftposition(lift) > min(liftschedule(lift))
  grd6 : liftdirection(lift) = UP
       ⇒ liftposition(lift) < max(liftschedule(lift))
  grd7 : liftposition(lift) \notin liftschedule(lift)
then
  act1 : liftstatus(lift) := MOVING
end
Event ChangeDir ≡ 
  Models the changing of direction of a STOPPED lift
extends ChangeDir
any
  lift
where
  grd1 : liftstatus(lift) = STOPPED
  grd2 : liftposition(lift) ≠ 0
  grd3 : liftposition(lift) ≠ MAXFLOOR
  grd4 : liftschedule(lift) ≠ ∅
  grd5 : (liftdirection(lift) = UP
         ⇒ liftposition(lift) > max(liftschedule(lift)))
  grd6 : (liftdirection(lift) = DOWN
         ⇒ liftposition(lift) < min(liftschedule(lift)))
then
act1 : liftdirection(lift) := CHANGE(liftdirection(lift))
end

Event IdleLift \(\cong\)
extends IdleLift
any
liftdirection(lift)

where

grd1 : liftstatus(lift) = STOPPED
grd2 : floordoorstatus(lift)(liftposition(lift)) = CLOSED
grd3 : liftdoorstatus(lift) = CLOSED
grd4 : liftschedule(lift) = \emptyset

then
act1 : liftstatus(lift) := IDLE

end

Event ActivateLift \(\cong\)
extends ActivateLift
any
liftdirection(lift)

where

grd1 : liftstatus(lift) = IDLE

then
act1 : liftstatus(lift) := STOPPED
act2 : liftschedule(lift) := liftschedule(lift) \cup \{liftposition(lift)\}

end

Event MoveUp \(\cong\)
refines MoveUp
Models a lift moving up to the next floor
Next floor is not MAXFLOOR
any
liftdirection(lift)

where

grd1 : liftstatus(lift) = MOVING
grd2 : liftdirection(lift) = UP
grd3 : liftschedule(lift) \neq \emptyset
grd4 : liftposition(lift) < max(liftschedule(lift))
grd5 : liftposition(lift) + 1 \notin liftposition(lift)

then

act1 : liftposition(lift) := liftposition(lift) + 1

act2 : liftdirection : \langle liftdirection' \in LIFT \rightarrow DIRECTION \rangle
\land (liftposition(lift) + 1 = MAXFLOOR
\Rightarrow liftdirection' = liftdirection \iff \left\{\begin{array}{l}
\text{if liftdirection = UP then liftdirection'} = \text{DOWN}\vspace{0.2cm}
\text{if liftdirection = DOWN then liftdirection'} = \text{UP}
\end{array}\right.)}
act3 : liftstatus(lift) := MOVING
end

Event MoveUpAndStop ≡
extends MoveUpAndStop
any

   lift
where

   grd1 : liftstatus(lift) = MOVING
   grd2 : liftdirection(lift) = UP
   grd3 : liftposition(lift) + 1 \in liftschedule(lift)
then

   act1 : liftposition(lift) := liftposition(lift) + 1
   act2 : liftdirection : |liftdirection' \in LIFT \rightarrow DIRECTION
       \land (liftposition(lift) + 1 = \text{MAXFLOOR})
       \Rightarrow liftdirection' = liftdirection \iff \{\text{lift} \mapsto \text{DOWN}\}
       \land (liftposition(lift) + 1 \neq \text{MAXFLOOR})
       \Rightarrow liftdirection' = liftdirection
   act3 : liftstatus(lift) := STOPPED
end

Event MoveDown ≡
refines MoveDown
any

   lift
where

   grd1 : liftstatus(lift) = MOVING
   grd2 : liftdirection(lift) = DOWN
   grd3 : liftschedule(lift) \neq \emptyset
   grd4 : liftposition(lift) > \text{min}(liftschedule(lift))
   grd5 : liftposition(lift) - 1 \notin \text{liftschedule}(lift)
then

   act1 : liftposition(lift) := liftposition(lift) - 1
   act2 : liftdirection : |liftdirection' \in LIFT \rightarrow DIRECTION
       \land (liftposition(lift) - 1 \neq 0
       \Rightarrow liftdirection' = liftdirection
       \land (liftposition(lift) - 1 = 0
       \Rightarrow liftdirection' = liftdirection \iff \{\text{lift} \mapsto \text{UP}\}
   act3 : liftstatus(lift) := MOVING
end

Event MoveDownAndStop ≡
extends MoveDownAndStop
any

   lift
where

\[ \text{grd1} : \text{liftstatus(lift)} = \text{MOVING} \]
\[ \text{grd2} : \text{liftdirection(lift)} = \text{DOWN} \]
\[ \text{grd3} : \text{liftposition(lift)} - 1 \in \text{liftschedule(lift)} \]
\[ \text{grd4} : \text{liftposition(lift)} - 1 \in \text{liftschedule(lift)} \]

then

\[ \text{act1} : \text{liftposition(lift)} := \text{liftposition(lift)} - 1 \]
\[ \text{act2} : \text{liftdirection : } \text{liftdirection}' \in \text{LIFT} \rightarrow \text{DIRECTION} \]
\[ \wedge (\text{liftposition(lift)} = 1) \]
\[ \Rightarrow \]
\[ \text{liftdirection}' = \text{liftdirection} \Leftrightarrow \{\text{lift} \mapsto \text{UP}\} \]
\[ \wedge (\text{liftposition(lift)} \neq 1) \]
\[ \Rightarrow \]
\[ \text{liftdirection}' = \text{liftdirection} \]
\[ \text{act3} : \text{liftstatus(lift)} := \text{STOPPED} \]

end

Event $\text{OpenFloorDoor} \equiv$

extends $\text{OpenFloorDoor}$

any

\[ \text{lift} \]

where

\[ \text{grd1} : \text{liftstatus(lift)} = \text{STOPPED} \]
\[ \text{grd2} : \text{floordoorstatus(lift)(liftposition(lift))} = \text{CLOSED} \]
\[ \text{grd3} : \text{liftdoorstatus(lift)} = \text{OPEN} \]
\[ \text{grd4} : \text{liftposition(lift)} \in \text{liftschedule(lift)} \]

then

\[ \text{act1} : \text{floordoorstatus(lift)} := \text{floordoorstatus(lift)} \Leftrightarrow \{\text{liftposition(lift)} \mapsto \text{OPEN}\} \]
\[ \text{act2} : \text{waiting} := \text{waiting} \cup \{\text{lift}\} \]

end

Event $\text{CloseFloorDoor} \equiv$

extends $\text{CloseFloorDoor}$

any

\[ \text{lift} \]

where

\[ \text{grd1} : \text{liftstatus(lift)} = \text{STOPPED} \]
\[ \text{grd2} : \text{floordoorstatus(lift)(liftposition(lift))} = \text{OPEN} \]
\[ \text{grd3} : \text{liftdoorstatus(lift)} = \text{OPEN} \]
\[ \text{grd4} : \text{lift} \notin \text{waiting} \]

then

\[ \text{act1} : \text{floordoorstatus(lift)} := \text{floordoorstatus(lift)} \Leftrightarrow \{\text{liftposition(lift)} \mapsto \text{CLOSED}\} \]

end

Event $\text{OpenLiftDoor} \equiv$

extends $\text{OpenLiftDoor}$

any

\[ \text{lift} \]
where

g1 : liftstatus(lift) = STOPPED

g2 : floordoorstatus(lift)(liftposition(lift)) = OPEN

g3 : liftdoorstatus(lift) = CLOSED

g4 : liftposition(lift) ∈ liftschedule(lift)

then

act1 : liftdoorstatus(lift) := OPEN

diff

Event CloseLiftdoor ≡
extends CloseLiftdoor

any

lift

where

g1 : liftstatus(lift) = STOPPED

g2 : floordoorstatus(lift)(liftposition(lift)) = CLOSED

g3 : liftdoorstatus(lift) = OPEN

g4 : liftposition(lift) ∈ liftschedule(lift)

then

act1 : liftdoorstatus(lift) := CLOSED

act2 : liftbuttons(lift) := (liftbuttons(lift) \ {liftposition(lift) ↦ OFF})

act3 : liftschedule(lift) := liftschedule(lift) \ {liftposition(lift)}

diff

Event Release ≡
extends Release

any

lift

where

g1 : lift ∈ waiting

then

act1 : waiting := waiting \ {lift}

diff

END