

# Titolo esplicativo

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## 1 List of predicates

### 1.1 Whose state is known by the robot by mean of sensors

- isLocalBinEmpty
- isLocalBinFull
- isLeftArmAt( $x, y$ )
- isRightArmAt( $x, y$ )
- isJointAt( $x, y$ )
- isEndEffectorAt( $x, y$ )
- isCartAt( $x, y$ )
- isOpOnTheLeft
- isOpOnTheRight
- isOperatorAt( $x, y$ )
- isRobotResting

### 1.2 Whose state is controlled by the robot

- isCartMoving
- isCartStill
- isCartMovingFast
- isCartMovingSlow
- isJointMoving
- isCartMovingLeft
- isCartMovingRight

## 2 Specification of the system

### 2.1 Specification of the model

1. It is impossible that the local bin is empty and full at the same time.

$$\neg(\text{isLocalBinEmpty} \wedge \text{isLocalBinFull})$$

### 2.1.1 Specification of the arm

1. The joint can be in only one position at a time.
2. The joint has to be close to the cart.

$$\begin{aligned} \text{isCartAt}(x, y) \rightarrow & \text{isJointAt}(x, y) \vee \text{isJointAt}(x+1, y) \vee \text{isJointAt}(x, y+1) \\ & \vee \text{isJointAt}(x+1, y+1) \vee \text{isJointAt}(x-1, y) \vee \text{isJointAt}(x, y-1) \\ & \vee \text{isJointAt}(x-1, y-1) \vee \text{isJointAt}(x+1, y-1) \vee \text{isJointAt}(x-1, y+1) \end{aligned}$$

3. The end effector can be in only one position at a time.
4. The end effector has to be close to the joint.

$$\begin{aligned} \text{isJointAt}(x, y) \rightarrow & \text{isEndEffectorAt}(x, y) \vee \text{isEndEffectorAt}(x+1, y) \vee \text{isEndEffectorAt}(x, y+1) \\ & \vee \text{isEndEffectorAt}(x+1, y+1) \vee \text{isEndEffectorAt}(x-1, y) \\ & \vee \text{isEndEffectorAt}(x, y-1) \vee \text{isEndEffectorAt}(x-1, y-1) \\ & \vee \text{isEndEffectorAt}(x+1, y-1) \vee \text{isEndEffectorAt}(x-1, y+1) \end{aligned}$$

5. The joint can move close to its position.

$$\begin{aligned} \text{isJointMoving} \wedge \text{isJointAt}(x, y) \rightarrow & \text{Dist}(\text{isJointAt}(x+1, y) \vee \text{isJointAt}(x, y+1) \\ & \vee \text{isJointAt}(x+1, y+1) \vee \text{isJointAt}(x-1, y) \\ & \vee \text{isJointAt}(x, y-1) \vee \text{isJointAt}(x-1, y-1) \\ & \vee \text{isJointAt}(x+1, y-1) \vee \text{isJointAt}(x-1, y+1), 1) \end{aligned}$$

6. The end effector can move close to its position.

$$\begin{aligned} \text{isEndEffectorMoving} \wedge \text{isEndEffectorAt}(x, y) \rightarrow & \text{Dist}(\text{isEndEffectorAt}(x+1, y) \vee \text{isEndEffectorAt}(x, y+1) \\ & \vee \text{isEndEffectorAt}(x+1, y+1) \vee \text{isEndEffectorAt}(x-1, y) \\ & \vee \text{isEndEffectorAt}(x, y-1) \vee \text{isEndEffectorAt}(x-1, y-1) \\ & \vee \text{isEndEffectorAt}(x+1, y-1) \vee \text{isEndEffectorAt}(x-1, y+1), 1) \end{aligned}$$

7. The operator is on the left of the cart if its in the adjacent cell to the left.

$$\text{isOpOnTheLeft} \longleftrightarrow \text{isCartAt}(x, y) \wedge \bigvee_{x-3 \leq h \leq x+2, y-2 \leq k \leq y+2} \text{isOperatorAt}(h, k)$$

8. The operator is on the right of the cart if its in the adjacent cell to the right.

$$\text{isOpOnTheRight} \longleftrightarrow \text{isCartAt}(x, y) \wedge \bigvee_{x-1 \leq h \leq x+3, y-2 \leq k \leq y+2} \text{isOperatorAt}(h, k)$$

9. The robot has to set in such a way that

### 2.1.2 Specification of the cart

1. It is impossible that the cart is moving and is still at the same time.

$$\text{isCartMoving} \longleftrightarrow \neg \text{isCartStill}$$

2. The cart is moving if and only if it is moving at some speed.

$$\text{isCartMoving} \longleftrightarrow (\text{isCartMovingFast} \vee \text{isCartMovingSlow})$$

3. It is impossible that the cart is moving at different speeds at the same time.

$$\neg(\text{isCartMovingFast} \wedge \text{isCartMovingSlow})$$

4. The cart is moving if and only if is moving to the bin or to the pallet.

$$\text{isCartMoving} \longleftrightarrow (\text{isCartMovingToBin} \vee \text{isCartMovingToPallet})$$

5. It is impossible that the cart is moving to the bin and to the pallet at the same time.

$$\neg(\text{isCartMovingToBin} \wedge \text{isCartMovingToPallet})$$

6. The cart has to be in a cell.

7. The cart can't be in more than one cell.

8. Slow speed is one cell per time step.  $2 \leq x \leq 13, 1 \leq y \leq 3$

$$\begin{aligned} \text{isCartMovingSlow} \wedge \text{isCartAt}(x, y) \rightarrow & \text{Dist}(\text{isCartAt}(x+1, y) \vee \text{isCartAt}(x, y+1) \\ & \vee \text{isCartAt}(x-1, y) \vee \text{isCartAt}(x, y-1), 1) \end{aligned}$$

9. Fast speed is two cells per time step.

$$\begin{aligned} \text{isCartMovingFast} \wedge \text{isCartAt}(x, y) \rightarrow & \text{Dist}(\text{isCartAt}(x+2, y) \vee \text{isCartAt}(x, y+1) \\ & \vee \text{isCartAt}(x-2, y) \vee \text{isCartAt}(x, y-1), 1) \end{aligned}$$

10. The robot is resting if and only if both the joint and the end effector are in the same cell of the cart.

$$\text{isRobotResting} \longleftrightarrow (\text{isCartAt}(x, y) \rightarrow \text{isEndEffectorAt}(x, y) \wedge \text{isJointAt}(x, y))$$

11. The cart is moving left if it is moving on the adjacent left cell at distance one or two.

$$\begin{aligned} \text{isCartMovingLeft} \longleftrightarrow & (\text{isCartAt}(x, y) \rightarrow \text{Dist}(\text{isCartAt}(x - 1, y), 1)) \\ & \vee (\text{isCartAt}(x, y) \rightarrow \text{Dist}(\text{isCartAt}(x - 2, y), 1)) \end{aligned}$$

12. The cart is moving right if is moving on the adjacent right cell at distance one or two.

$$\begin{aligned} \text{isCartMovingRight} \longleftrightarrow & (\text{isCartAt}(x, y) \rightarrow \text{Dist}(\text{isCartAt}(x + 1, y), 1)) \\ & \vee (\text{isCartAt}(x, y) \rightarrow \text{Dist}(\text{isCartAt}(x + 2, y), 1)) \end{aligned}$$

### 2.1.3 Specification of the operator

1. The operator is trapped only if it is close to the robot.

$$\text{isOperatorTrapped} \rightarrow \text{isOperatorClose}$$

2. The operator is close to the robot or away.

$$\text{isOperatorClose} \longleftrightarrow \neg \text{isOperatorAway}$$

3. The body of the operator has to be somewhere.

4. Arms of the operator have to be close to the body.

$$\begin{aligned} \text{isOperatorAt}(x, y) \rightarrow & \text{isRightArmAt}(x, y) \vee \text{isRightArmAt}(x + 1, y) \vee \text{isRightArmAt}(x, y + 1) \\ & \vee \text{isRightArmAt}(x + 1, y + 1) \vee \text{isRightArmAt}(x - 1, y) \\ & \vee \text{isRightArmAt}(x, y - 1) \vee \text{isRightArmAt}(x - 1, y - 1) \\ & \vee \text{isRightArmAt}(x + 1, y - 1) \vee \text{isRightArmAt}(x - 1, y + 1) \end{aligned}$$

$$\begin{aligned} \text{isOperatorAt}(x, y) \rightarrow & \text{isLeftArmAt}(x, y) \vee \text{isLeftArmAt}(x + 1, y) \vee \text{isLeftArmAt}(x, y + 1) \\ & \vee \text{isLeftArmAt}(x + 1, y + 1) \vee \text{isLeftArmAt}(x - 1, y) \\ & \vee \text{isLeftArmAt}(x, y - 1) \vee \text{isLeftArmAt}(x - 1, y - 1) \\ & \vee \text{isLeftArmAt}(x + 1, y - 1) \vee \text{isLeftArmAt}(x - 1, \text{jointy} + 1) \end{aligned}$$

- 5.

## 2.2 Specification of the behaviour

1. When the cart is moving, the robot (joint plus end effector) has to be still.

$$\neg(\text{isRobotResting} \wedge \text{Dist}(\text{isRobotResting}, 1)) \rightarrow \neg \text{isCartMoving}$$

2. The cart has to move to the bin when the local bin is empty.

$$\text{isLocalBinEmpty} \wedge \neg \text{isOpOnTheLeft} \wedge \text{isRobotResting} \wedge \neg \text{isCartAt}(2, 4) \rightarrow \text{isCartMovingLeft}$$

3. The cart has to move to the pallet when the local bin is full.

$$\text{isLocalBinFull} \wedge \neg \text{isOpOnTheRight} \wedge \text{isRobotResting} \wedge \neg \text{isCartAt}(13, 4) \rightarrow \text{isCartMovingRight}$$

4. The cart has to move slowly near pallet and near bin.

$$\begin{aligned} \text{isCartMoving} \wedge (\text{isCartAt}(2, 4) \vee \text{isCartAt}(3, 4) \vee \text{isCartAt}(4, 4) \vee \text{isCartAt}(11, 4) \\ \vee \text{isCartAt}(12, 4) \vee \text{isCartAt}(13, 4)) \rightarrow \text{isCartMovingSlow} \end{aligned}$$

5. The cart has to move slowly when the operator is close to it.

$$\begin{aligned} \text{isCartMovingLeft} \wedge \text{isCartAt}(x, y) \wedge (\text{isOperatorAt}(x - 4, y + 2) \vee \text{isOperatorAt}(x - 4, y + 1) \\ \vee \text{isOperatorAt}(x - 4, y) \vee \text{isOperatorAt}(x - 4, y - 1) \vee \text{isOperatorAt}(x - 4, y - 2)) \rightarrow \text{isCartMovingSlow} \end{aligned}$$

$$\begin{aligned} \text{isCartMovingRight} \wedge \text{isCartAt}(x, y) \wedge (\text{isOperatorAt}(x + 4, y + 2) \vee \text{isOperatorAt}(x + 4, y + 1) \\ \vee \text{isOperatorAt}(x + 4, y) \vee \text{isOperatorAt}(x + 4, y - 1) \vee \text{isOperatorAt}(x + 4, y - 2)) \rightarrow \text{isCartMovingSlow} \end{aligned}$$

## 3 Specification of the safety properties

- The cart and the operator cannot be in the same cell of the pallet.