Planning for Human-Robot Collaboration

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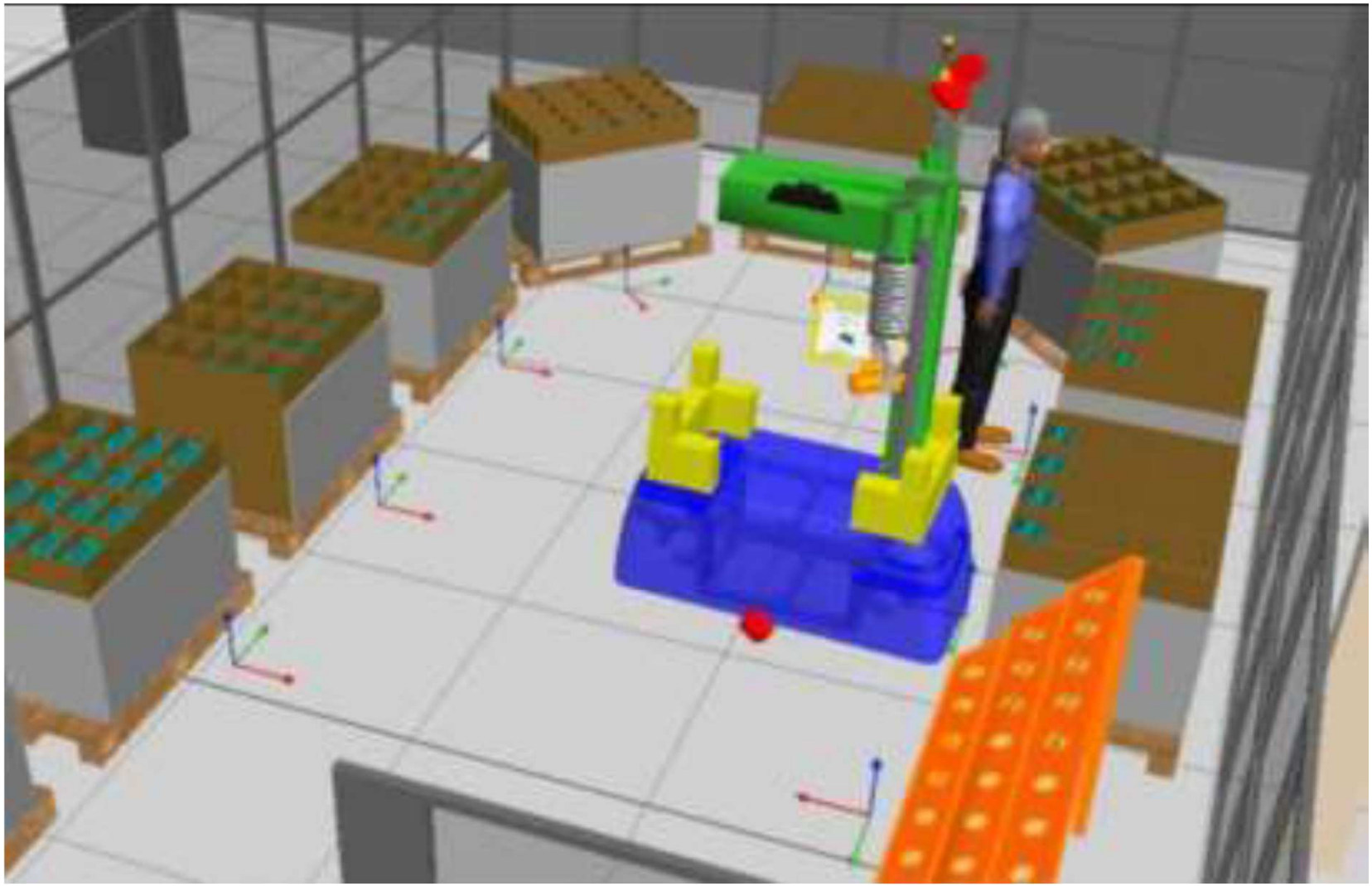
(Audi AG)

Human-Robot Collaboration



What's Involved

- The goal is to allow efficient Human-Robot Collaboration (HRC) in industrial settings
- Create a system that allows the robot to support the human during task execution as a human co-worker would
- Means scheduling the right action at the right time for the robot
- Requires interpretation of the human behaviour and reasoning about spatio-temporal consequences of actions
- A further critical aspect is the reactivity of the system
  - In order to allow realistic HRC the robot has to react within a few seconds
  - Time intensive online reasoning is thus not an option

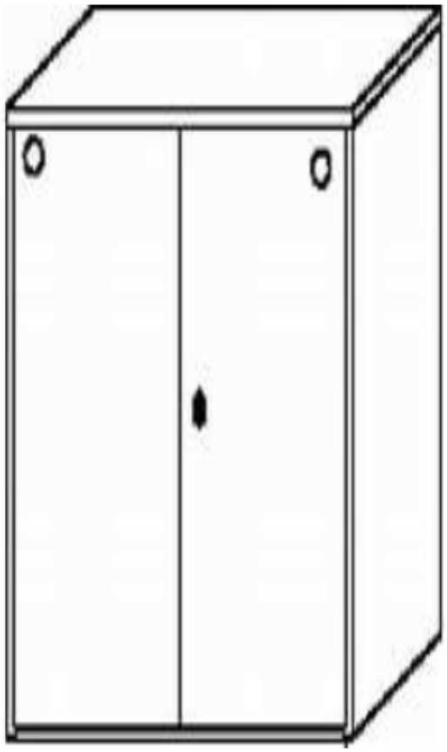
Approach

1. Construct all possible task execution strategies for the HRC-team for a given task description and a given set of available actions
2. Verify these strategies:
    a. Spatially by applying a motion planning module for dynamic environments
    b. Temporally by applying a temporal reasoning framework
3. Start the task execution with the set of HRC schedules
4. During task execution:
    a. Monitor the human and determine their current action
    b. Update the set of valid HRC schedules using the current time and the current human action
    c. Select the HRC schedules leading to the fastest task execution
    d. Dispatch the next robot action according to the selected schedules
    e. End when the task is completed or no valid HRC schedules remain

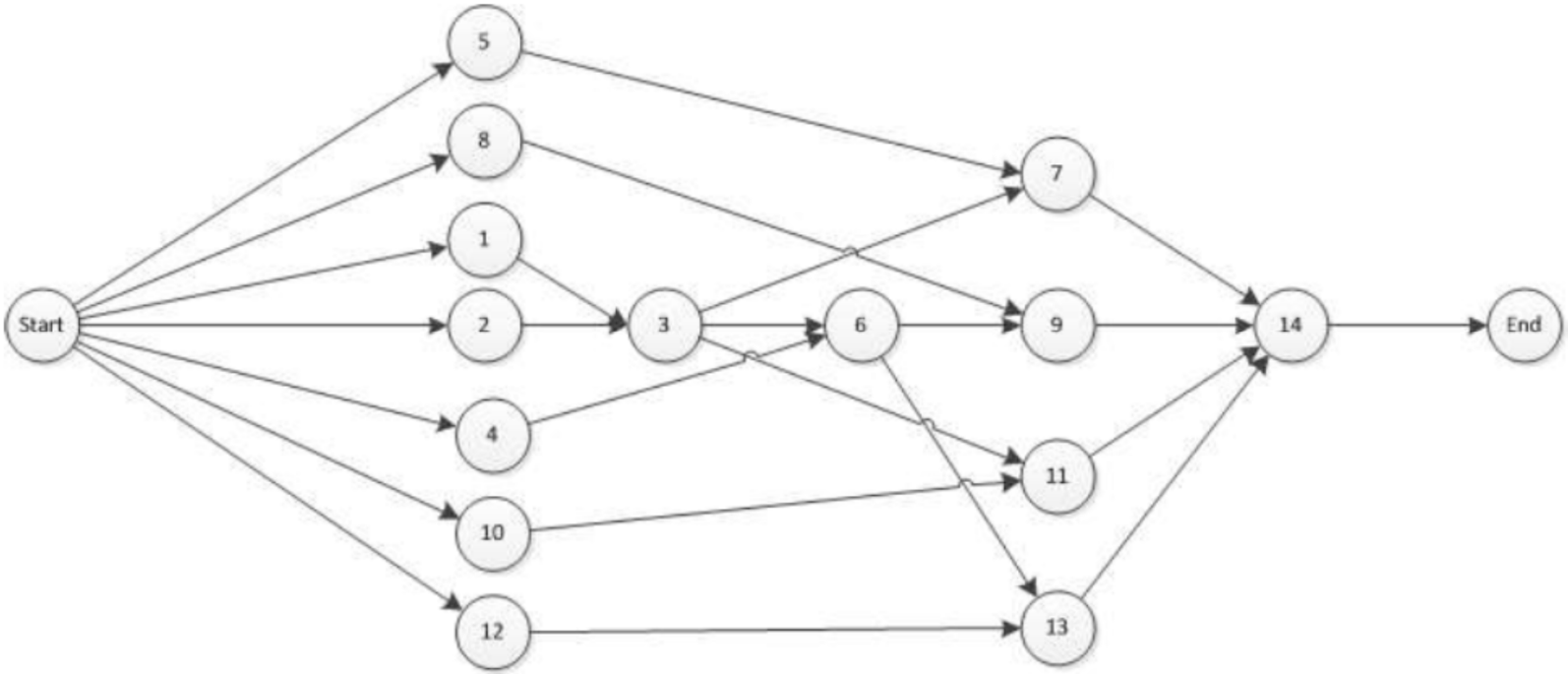
Example – Assembling a Cupboard

HRC-Recipe for assembly: list of related actions

ID	Description	Predecessor	Duration Robot	Duration Human
1	Bring closet bottom to assembly area	0	5	3
2	Bring first side wall to assembly area	0	5	3
3	Mount first side wall to bottom	1, 2	5	3
4	Bring second side wall to assembly area	0	5	3
5	Bring back board to assembly area	0	5	3
6	Mount second side wall	3, 4	5	3
7	Mount back board	3, 5	5	3
8	Bring closet top to assembly area	0	5	3
9	Mount closet top	6, 8	5	3
10	Bring first closet door to assembly area	0	5	3
11	Mount first closet door	3, 10	5	3
12	Bring second closet door to assembly area	0	5	3
13	Mount second closet door	6, 12	5	3
14	Carry closet to transport area	7, 9, 11, 13	8	8

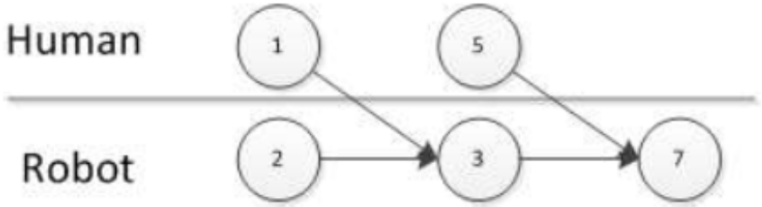


Task Graph

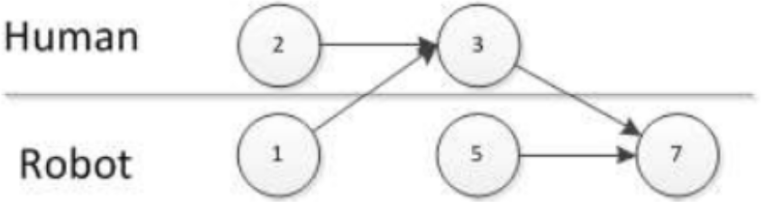


Collaborative Execution Plans

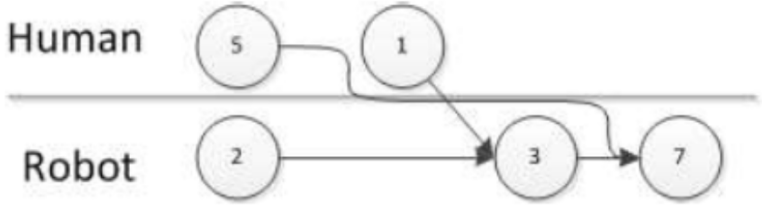
Option 1



Option 2



Option 3



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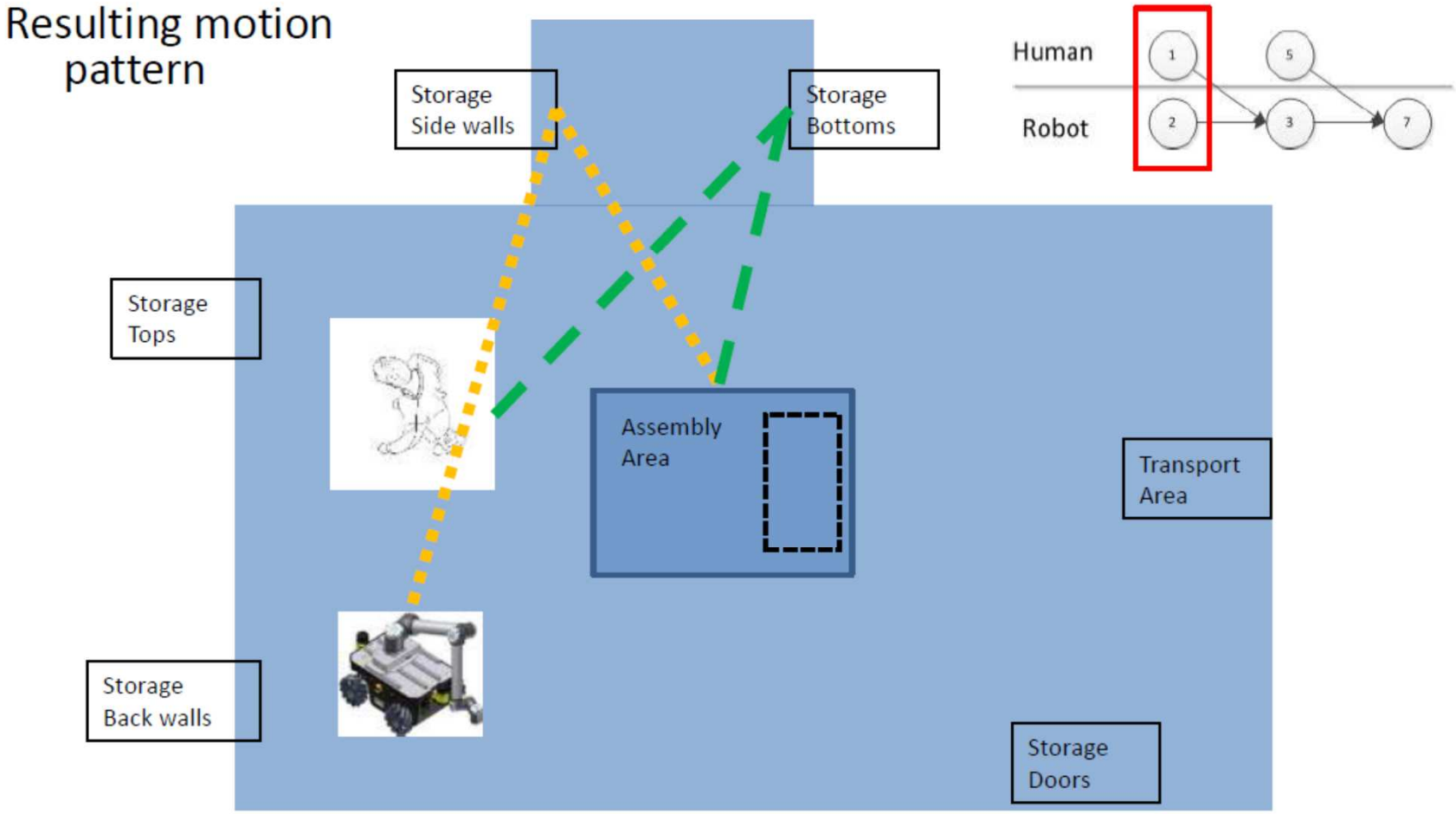
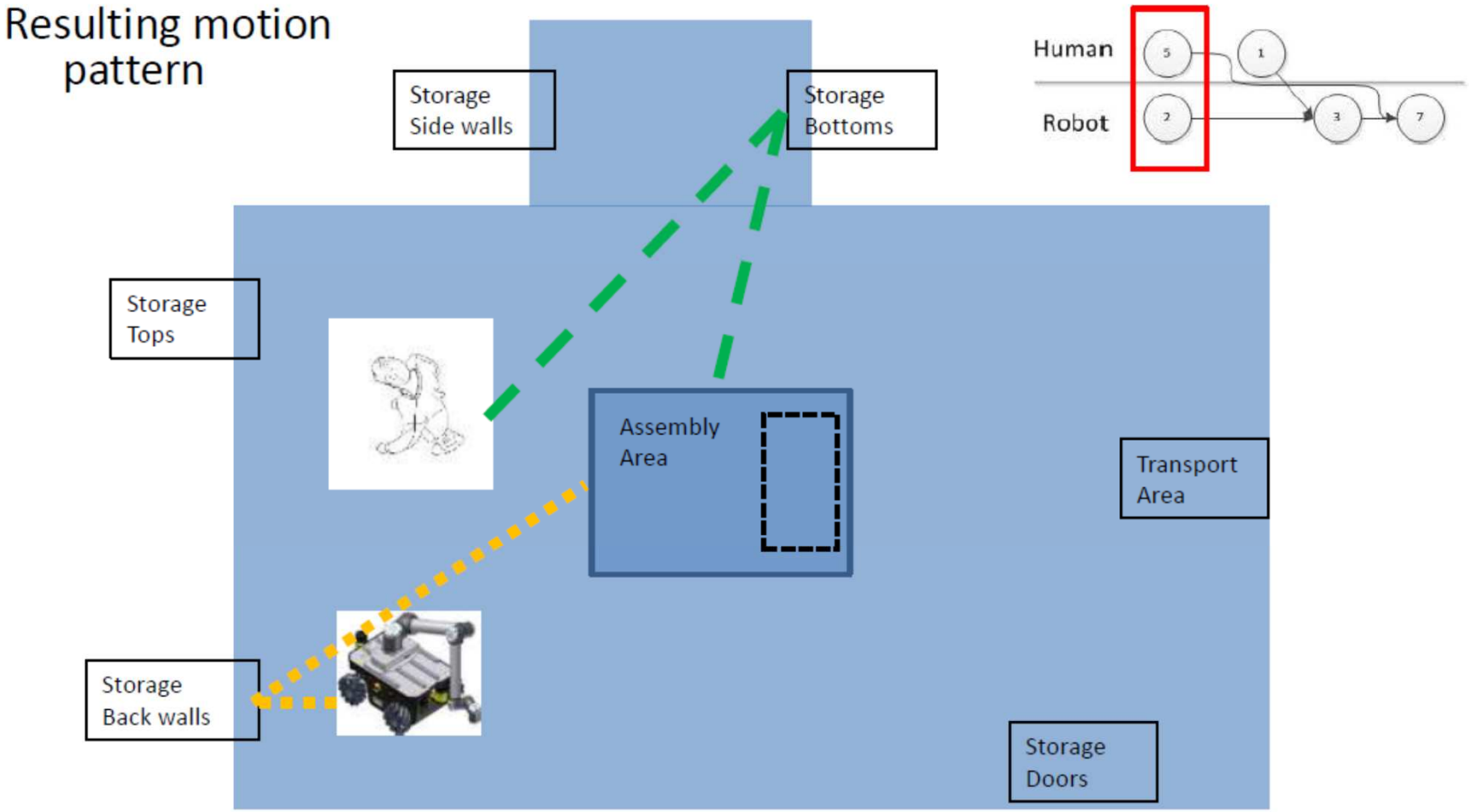

Resulting motion pattern
Storage Side walls
Storage Bottoms
Storage Tops
Assembly Area
Transport Area
Storage Back walls
Storage Doors
Human
Robot
1
2
3
5
7

Option 3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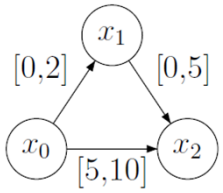
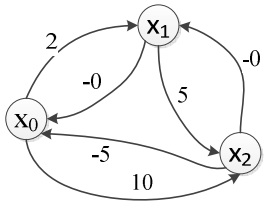
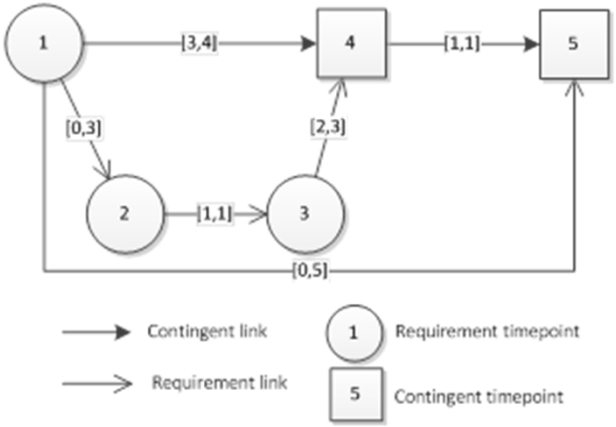
Event Timing

- Simple Temporal Network (STN)
  - [x,y] specifies min and max time difference between linked events
- Distance Graph (DG)
  - STN is consistent if no negative cycles in the corresponding DG

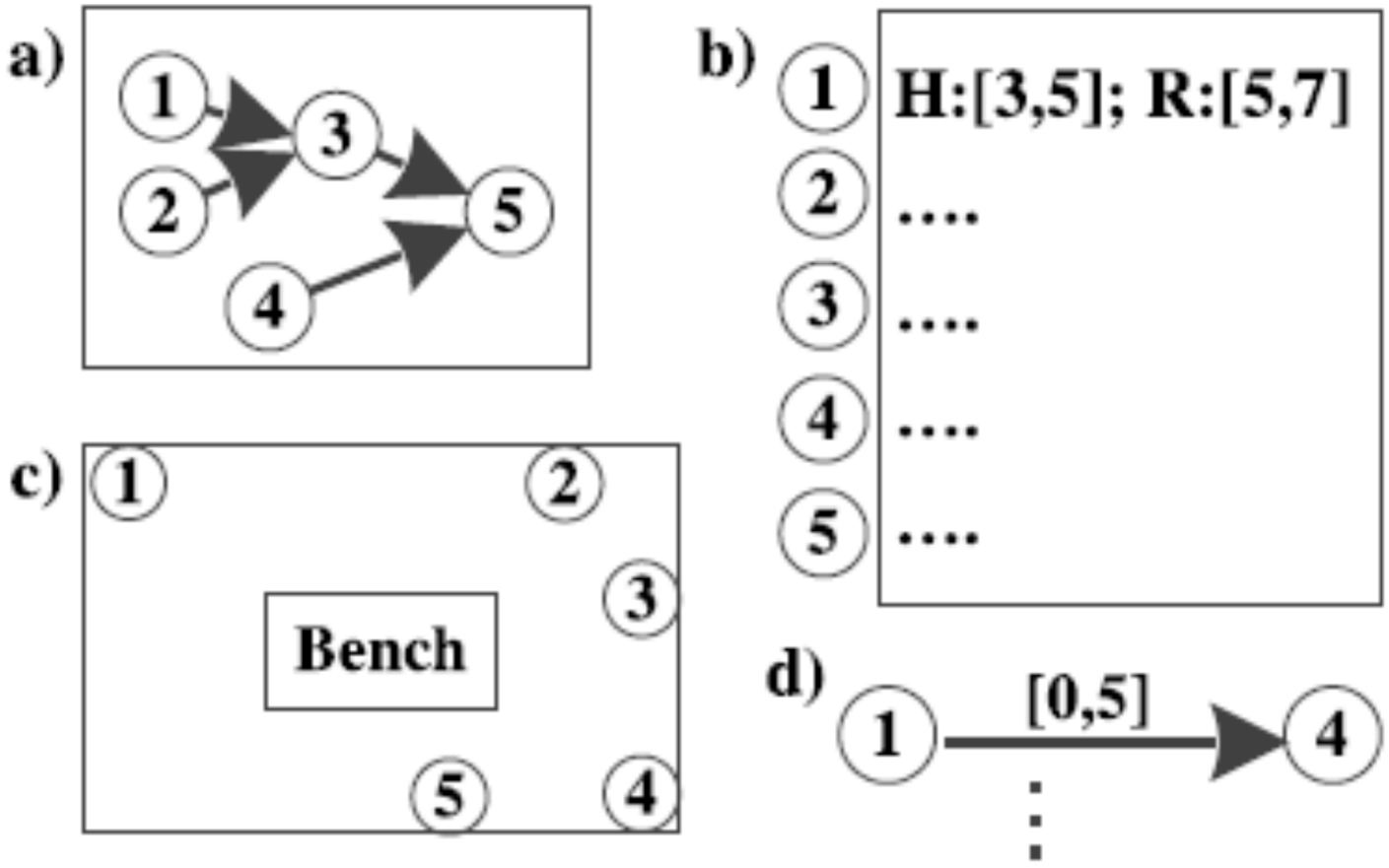




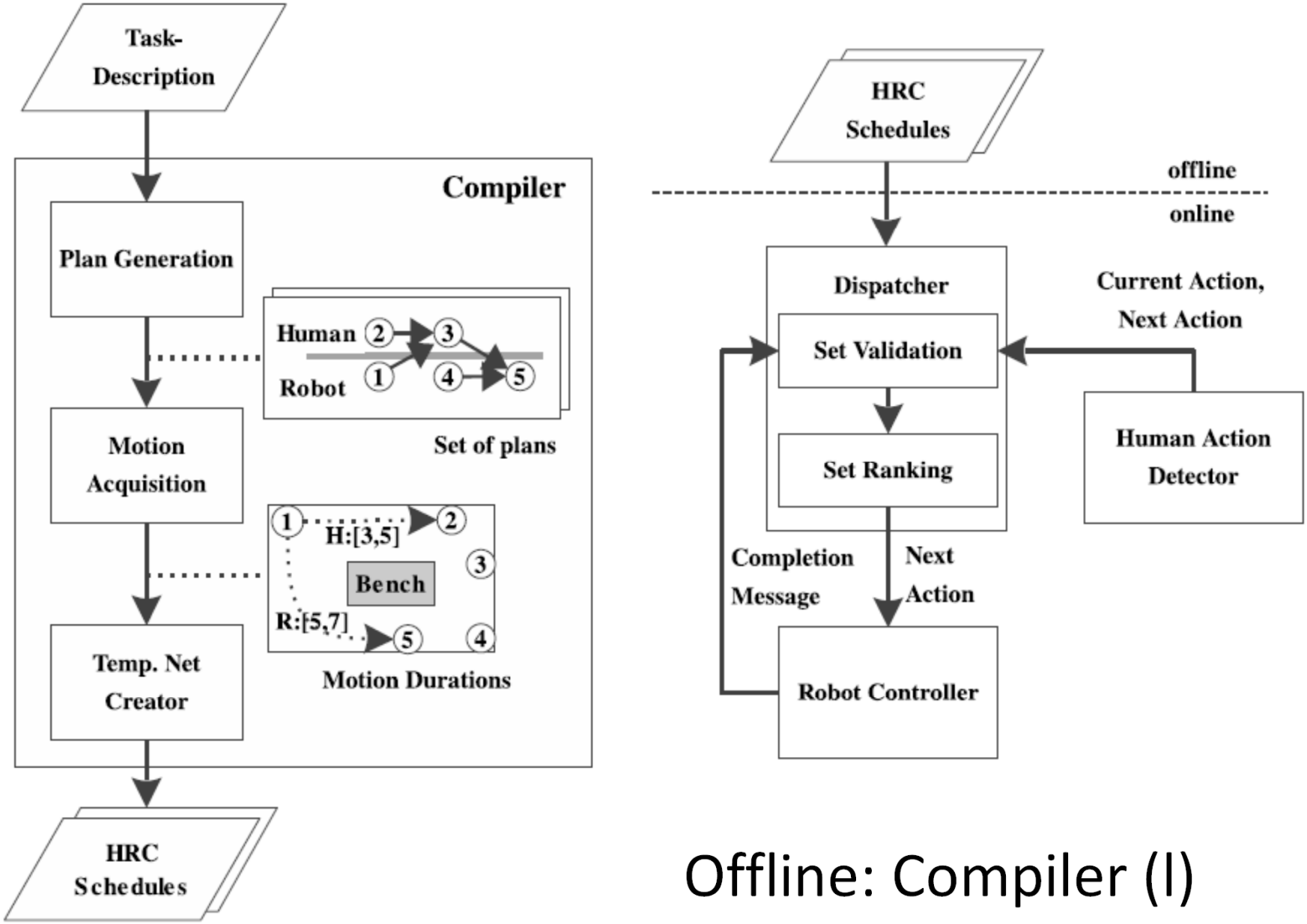
- Simple Temporal Network with Uncertainty (STNU)
  - Requirement links as per STN
  - Contingent links introduce dependence on external events of uncertain durations



Task Description



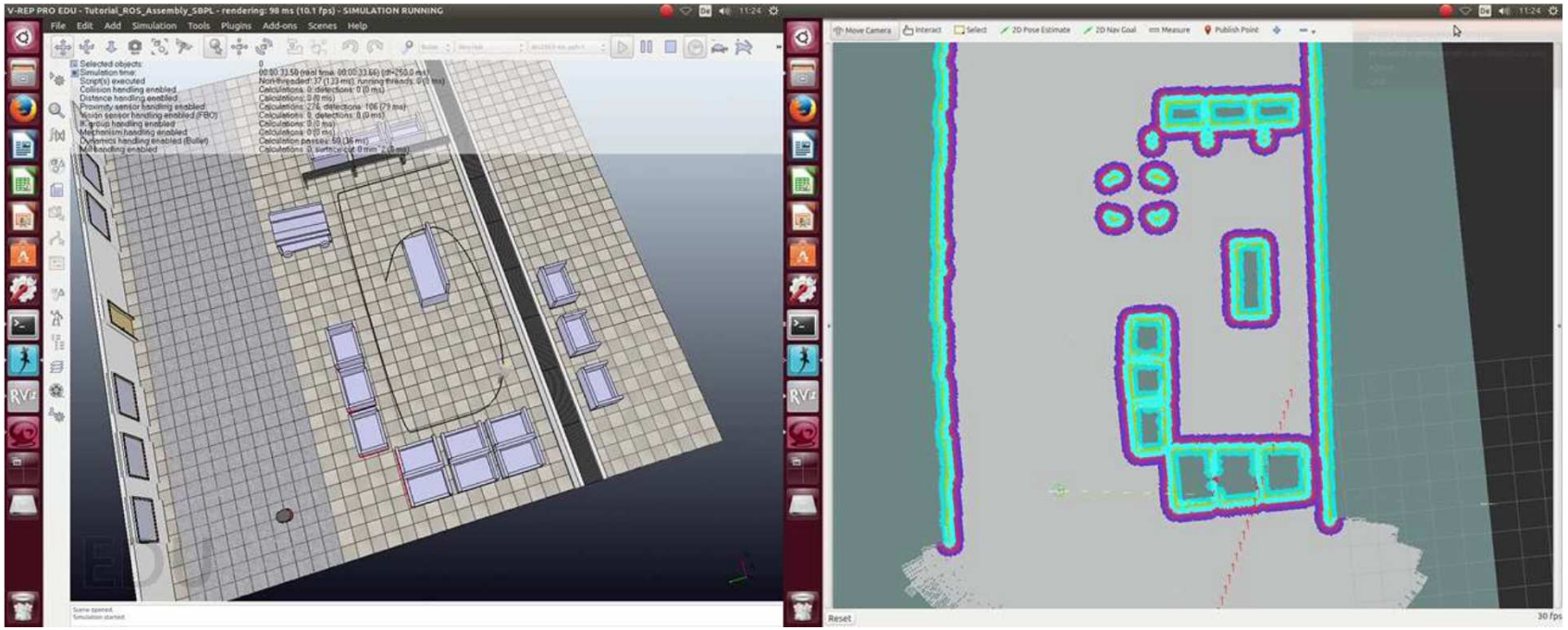
a) Task graph; b) Action descriptions; c) Workspace map; d) Temporal constraints



Offline: Compiler (l)

Online: Dispatcher (r)

Simulations



Real-world Testing