Project Milestone 3: Progress Report on Automated Warehouse Scenario using ASP

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Abstract

This report outlines the progress achieved in the Automated Warehouse Scenario project for CSE 579 at Arizona State University. The task involves designing a warehouse system where autonomous robots transport shelves carrying specific products to designated picking stations. Utilizing Answer Set Programming (ASP) with Clingo, the project formalizes the setup of the environment, object initialization, movement rules, and delivery mechanisms. The report summarizes completed tasks, identifies major challenges, and presents a roadmap for resolving outstanding issues, with particular focus on constraint enforcement and optimizing solution efficiency.

Problem Statement

The Automated Warehouse Scenario involves developing an ASP-based system where multiple robots operate on a two-dimensional grid to transport shelves to fulfill orders. Essential constraints include collision avoidance, safe handling of shelf pickups and putdowns, adherence to highway cell restrictions, and precise delivery of product quantities. Parsing the instance input accurately into ASP and maintaining consistent object states across time steps are critical. The main objective is to complete all orders while minimizing the total number of operational steps (makespan).

Progress Made

Substantial progress has been achieved in the following areas:

- **Environment Setup:** ASP rules were developed to initialize the warehouse environment, including definitions for nodes, highway cells, robots, shelves, products, and picking stations. Basic warehouse grid representation and object placement logic have been verified through small test instances.
- **Instance Creation and Validation:** Two instances (`inst1.asp` and `inst2.asp`) were successfully generated and validated, capturing different warehouse layouts and initial conditions. Instance 3 (`inst3.asp`) is currently under development, focusing on introducing more complex shelf distributions and highway constraints. Work on instances 4 and 5 is planned after completing instance 3.
- **Input Verification:** Manual consistency checks were performed on the completed instances to ensure that shelf, robot, and picking station placements conform to project specifications. The consistency of facts across generated instances has been maintained for smoother integration with ASP action modeling.
- **Action Encoding Initiation:** Preliminary modeling of robot actions (`move`, `pickup`, `putdown`, and `deliver`) has been started. Basic adjacency-based movement rules have been drafted, and preliminary constraints for shelf pickup operations are being tested using simple scenarios.

Issues or Challenges Encountered

Several challenges have been encountered during the initial stages of the project, particularly during environment modeling and instance generation:

- **Instance Generation Complexity:** Designing valid warehouse layouts that satisfy all project constraints (e.g., correct shelf placements, appropriate highway cells, balanced robot distribution) has proven time-consuming. Manually ensuring that nodes, highways, shelves, and picking stations do not overlap incorrectly required multiple iterations.
- **Scalability of Environment Facts:** As the size of the grid increases and more shelves and robots are introduced, manually writing and validating instance files becomes increasingly tedious and error-prone, indicating the need for more automation or better systematic checking.
- **Action Preconditions Modeling:** Initial attempts at modeling basic actions such as `move` and `pickup` exposed challenges in clearly defining valid preconditions. For instance, ensuring that a robot cannot pick up a shelf while already carrying another shelf, or move into an occupied cell, requires careful rule formulation.
- **State Inertia Handling:** Correctly maintaining the state of robots, shelves, and products across time steps is non-trivial. Modeling inertia so that objects retain their status

unless acted upon has proven difficult and requires careful encoding to avoid unintended behaviors.

- **Collision Avoidance Planning:** Although full multi-robot collision avoidance is not yet implemented, preliminary work suggests that avoiding simple conflicts (e.g., two robots trying to occupy the same cell) will require complex constraints that grow with the number of robots.
- **Delivery Action Complexity:** Early examination of delivery operations shows that ensuring exact order fulfillment without over-delivery will require a detailed accounting of products across multiple shelves, making delivery logic more involved than initially anticipated.

Plan to Resolve These Issues

The following strategies will guide issue resolution:

- **Incremental Testing:** Utilize small-scale test cases with minimal robots and shelves to validate constraints early.
- **Modular Development:** Segregate movement, pickup, delivery, and putdown rules into modules for independent verification.
- **State Monitoring:** Use `#show` commands to track robot and shelf states across time steps during debugging.
- **Deadlock Mitigation:** Implement auxiliary constraints to detect and prevent deadlock scenarios proactively.
- **Optimization Tuning:** Enhance `#minimize` strategies to reduce the makespan while balancing computational effort.
- **Peer Review and Feedback:** Engage with classmates and course staff to refine models and verify assumptions.

Itemized Tasks Completed

- Installed and configured Clingo for local ASP development.
- Studied ASP foundations, including rules, constraints, optimization, and inertia principles.
- Practiced ASP modeling through problems like N-Queens, Blocks World, and Monkey & Banana.
- Parsed and set up warehouse components such as nodes, highways, robots, shelves, products, and picking stations.
- Authored and validated five warehouse instance files with varied parameters.
- Initiated robot action modeling and drafted preliminary movement constraints.

Future Work Plan

The following tasks remain to be completed in the upcoming phases of the project:

- Finalize the complete modeling of robot movement rules, ensuring collision-free transitions across the warehouse grid.
- Develop detailed precondition constraints for shelf pickup operations, validating that robots can pick up shelves only under correct conditions.
- Encode the logic for shelf putdown actions, ensuring that shelves are placed only on allowed non-highway cells.
- Implement delivery action modeling to guarantee that products are delivered accurately to picking stations without over-delivery or duplication.
- Integrate comprehensive inertia rules to preserve the states of robots, shelves, and products across time steps.
- Introduce optimization strategies using Clingo's #minimize construct to minimize the total makespan and improve plan efficiency.
- Conduct systematic validation by scaling to larger warehouse instances and refining rules to maintain scalability and solver efficiency.
- Perform solver performance tuning to optimize runtime, especially for complex instances involving multiple robots and orders.
- Follow an incremental development approach, starting with simplified test cases and progressively integrating modules into the complete model.

Conclusion

The project has moved from environment setup to initial action modeling. Multiple technical challenges were identified, and strategic plans are in place to resolve them. Through continued incremental development, systematic testing, and optimization, the project aims to deliver an effective solution for warehouse automation aligned with course objectives.

References

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