ADVANCED MECHATRONICS LABORATORY

Task Automation by Interpreting User Intent

PhD Proposal

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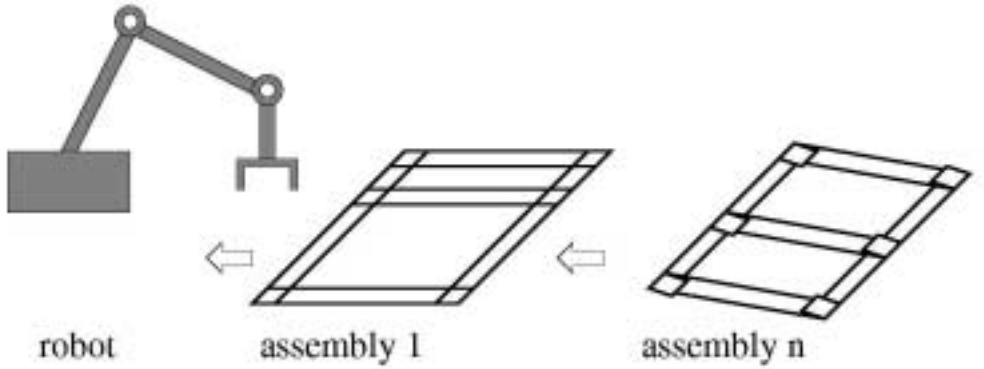
Carnegie Mellon

Introduction and Motivation



- Current development systems require traditional-programming methods.
  - Requires computer-programming and domain expertise.

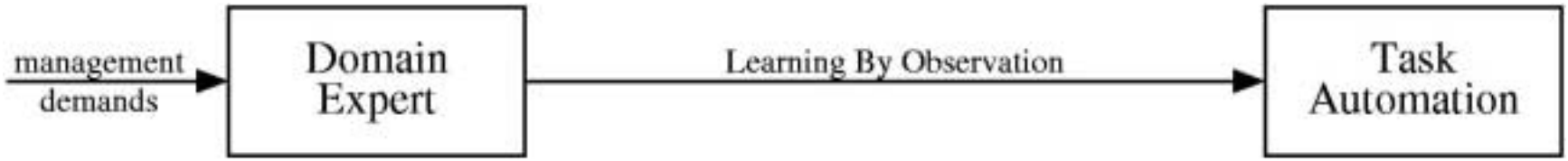
Introduction and Motivation

- Most domain experts have little procedural-programming knowledge.
- Acquiring programming expertise is expensive.

- Users tend not to automate daily tasks.
- Many industrial tasks are still performed manually.

Introduction and Motivation

- Develop an improved paradigm for automating tasks.
- Increase user productivity by creating a more natural programming process.



- Remove computer programmers from the design loop.

Approach

- Allow users to “program” automation tasks by demonstration.

- Called “Learning by Observation” or “Programming by Demonstration”

Goals of Research

- Address uncertainty in sensing.
- Interpret intent of user demonstrations.

- Insensitive to changes in the environment.

- Incorporate multiple demonstrations to improve performance.

- Integrate the user into the design loop.

Presentation Overview

- Learning by observation overview.
- Related work.
- System design.
- Sample implementation.
- Proposed work.
- Evaluation of research.
- Expected contributions.

Learning by Observation: Inherent Problems

- Must contend with usual sensor-based uncertainty.
- Environment is dynamic.
- Many demonstrations may be required to achieve generality.
  - But available data will be sparse.

Learning by Observation: Interpreting User Intent

- In many tasks, repeating the actions of the user verbatim is not desirable.
- Humans tend to be imprecise and make unintended actions.
- The LBO system must interpret the *intent* of the user.

Learning by Observation: Definitions

- **Task:** sequence of actions designed to achieve an overall goal.
- **Subgoals:** set of states sufficient to complete the task.
- **Environment Description:** information conveying anything that could affect the task.

Learning by Observation: Related Work

- Most previous systems segment fit observations to predefined symbols called *primitives*:
  - **HMMs:** Yang, Xu, and Chen [1994]
  - **TDNNs:** Friedrich *et al.* [1996]
  - **DTW:** Ikeuchi *et al*. [1994], Matarić [2000]
  - ***Ad Hoc*:** Bentivegna and Atkeson [1999]
- Primitives are used to reconstruct the demonstration.

- Most do not incorporate multiple demonstrations.

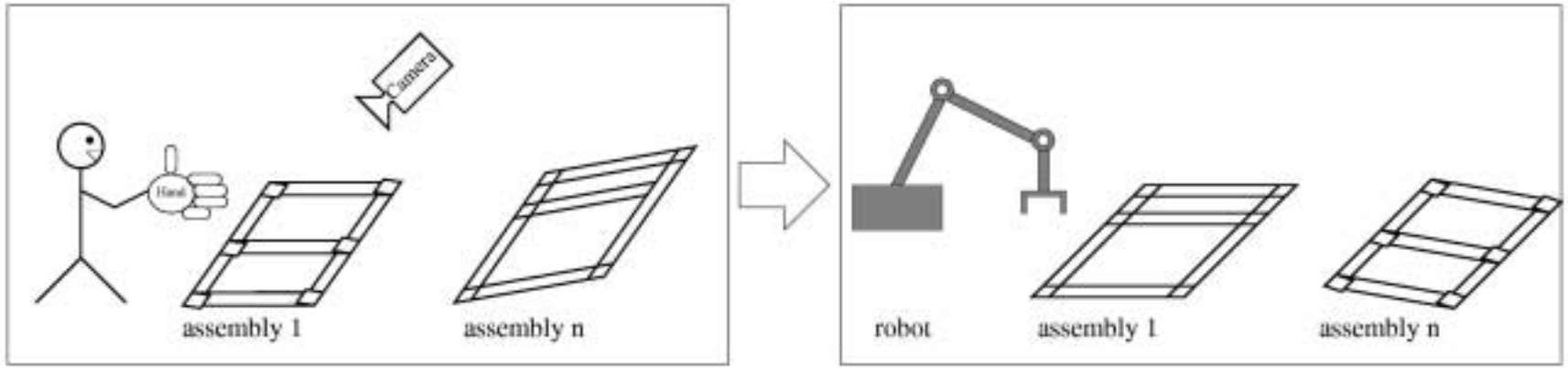
Learning by Observation: Related Work

- Manually associating subgoals in the environment: Morrow and Khosla [1995].
  - Assembly tasks.

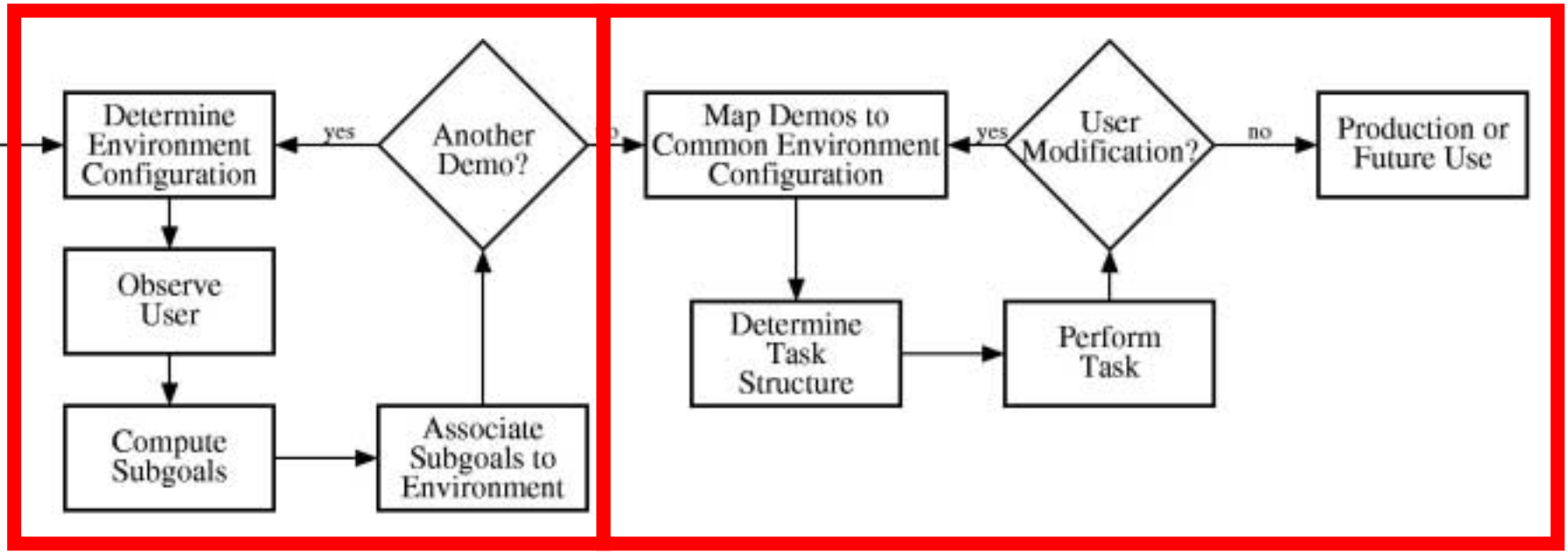
- Allowing user to modify LBO output: Friedrich *et al.* [1996].
  - Editing predicate-calculus statements.

Problem Description

- **Input:** Observations from repeated user task demonstrations and environment information.
- **Output:** Generative model (production program, controller, etc.)

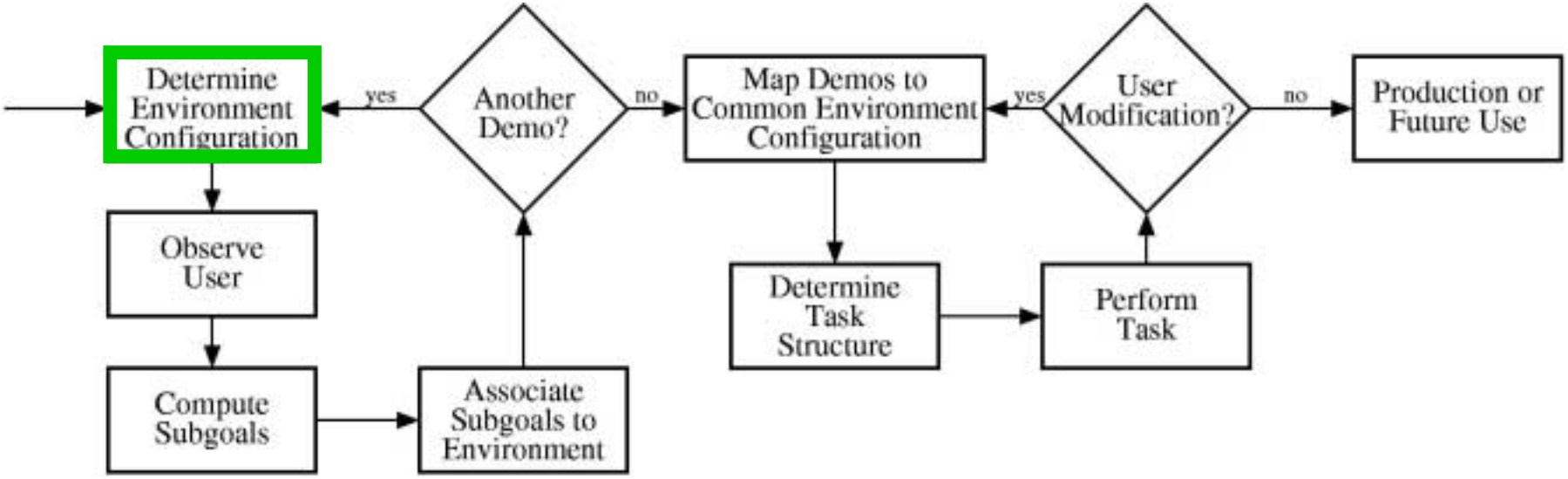


System Design



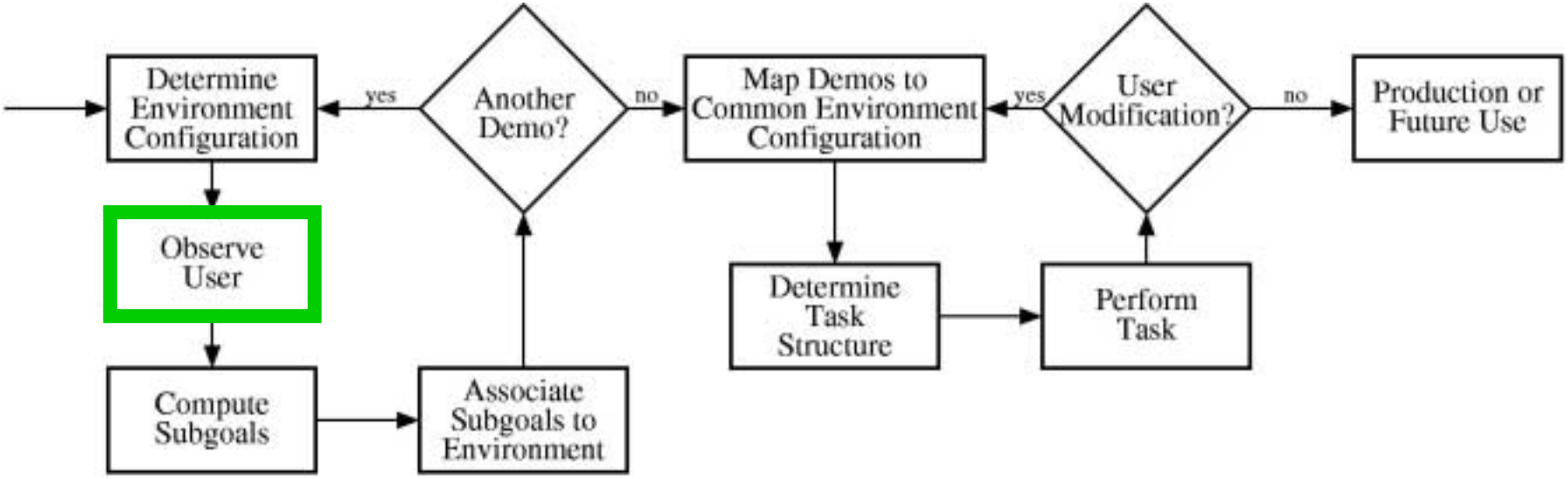
- System is broken up into two main phases.
- Data collection.
- Analysis, synthesis, and production.

System Design:
Determine Environment Configuration



- Description of all objects that could affect the task.

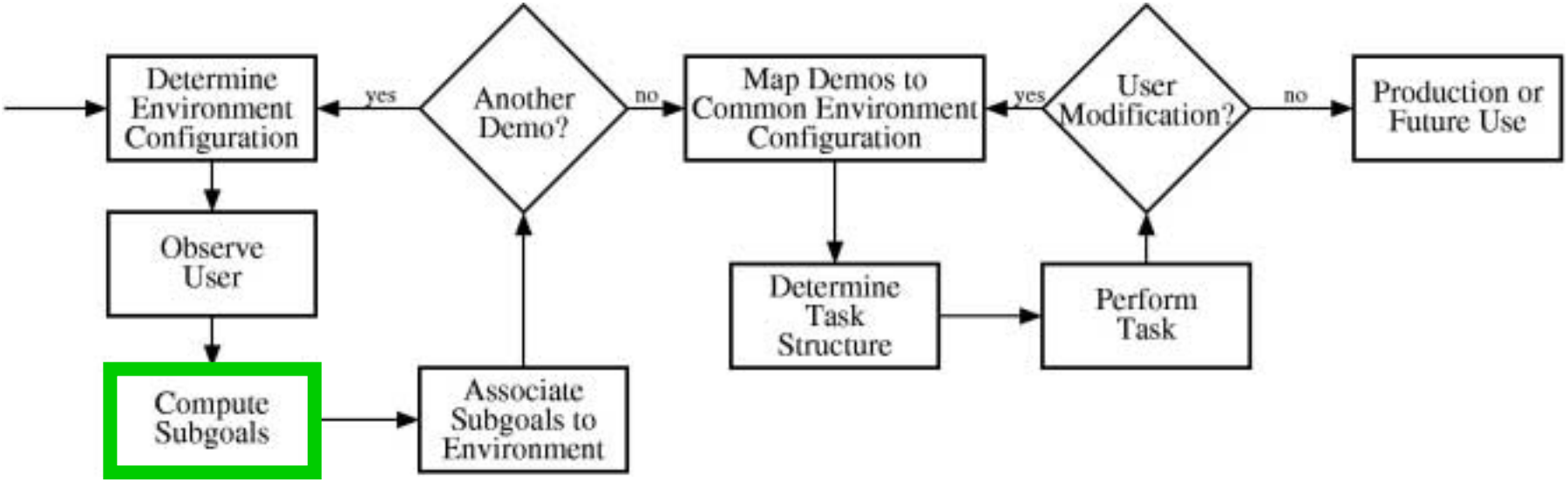
System Design:
Observe User



- We plan to use cameras to observe users performing tasks.
- Other modal inputs may be considered.
  - We want to instrument users in an unobtrusive fashion.

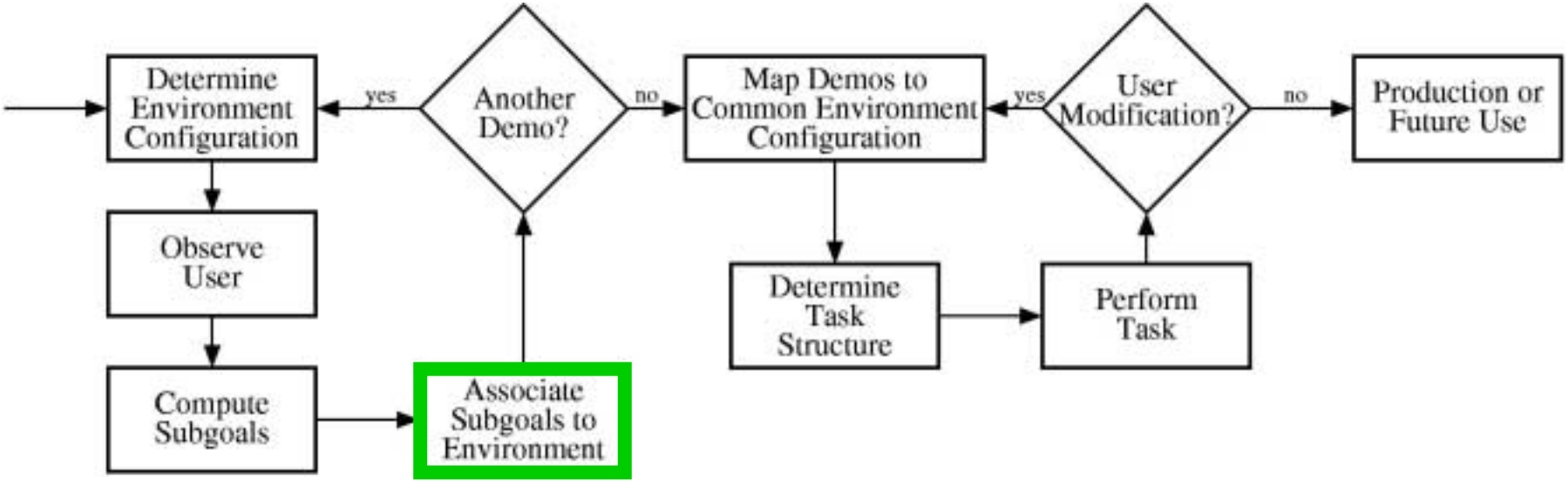
- Assume the state of the user is observable through sensors.

System Design:
Compute Subgoals



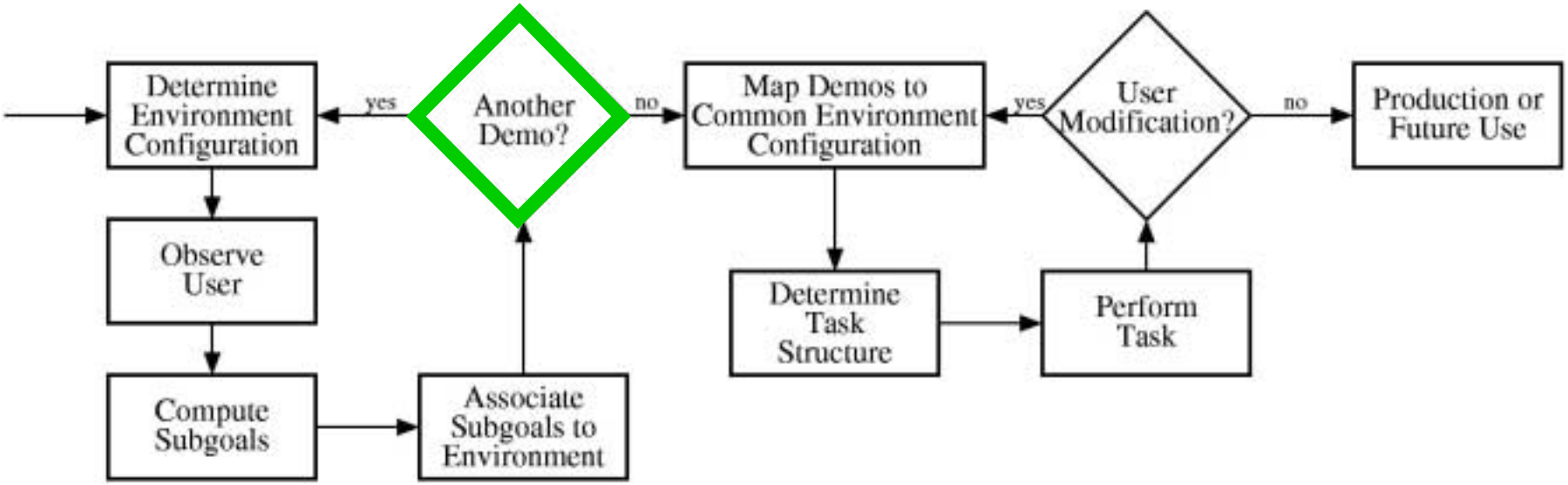
- Repeating raw observations verbatim can lead to several problems.
- Segmenting observations into symbols ignores uncertainty.
- Use likelihood of predictive model to determine subgoals.

System Design:
Associate Subgoals to Environment



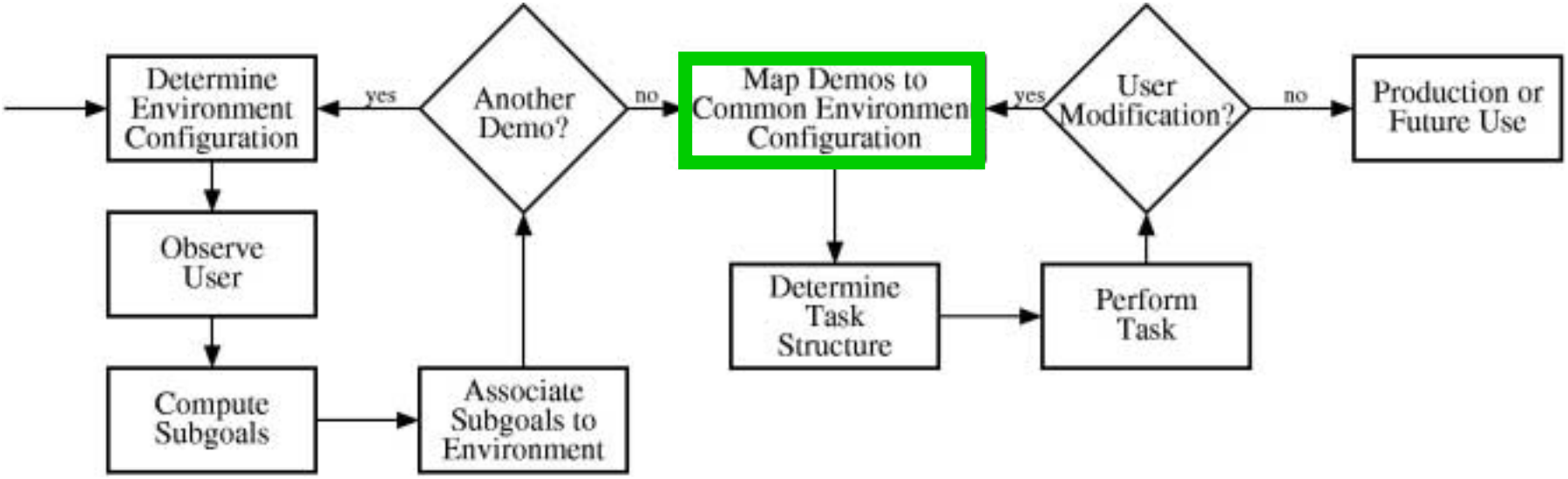
- Most tasks are defined with respect to objects in the environment.
- Associate subgoals automatically with objects in the environment.
- Potential problems: object occlusion, incorrect associations.

System Design:
Another Demo?



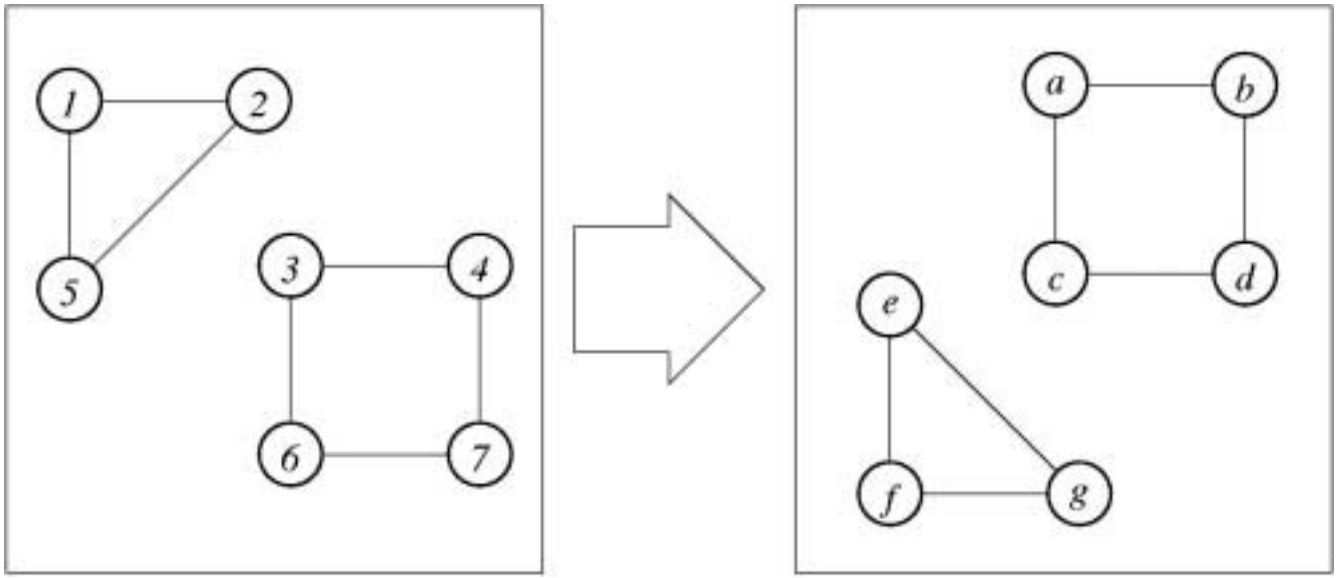
- The user can demonstrate the task as many times as desired.

System Design:
Map Demos to Common Environment



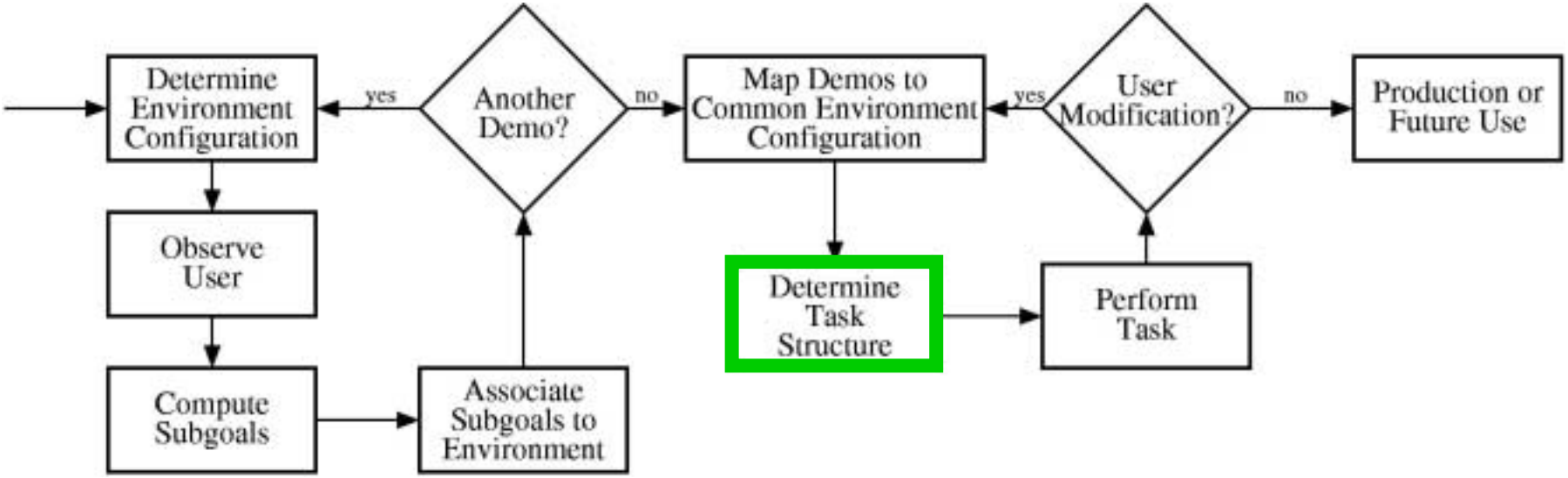
- Environment configuration may be different for each demonstration and cannot use object tracking.
- Map demonstrations to a “canonical” environment to minimize configuration-specific user behavior.

System Design:
Map Demos to Common Environment



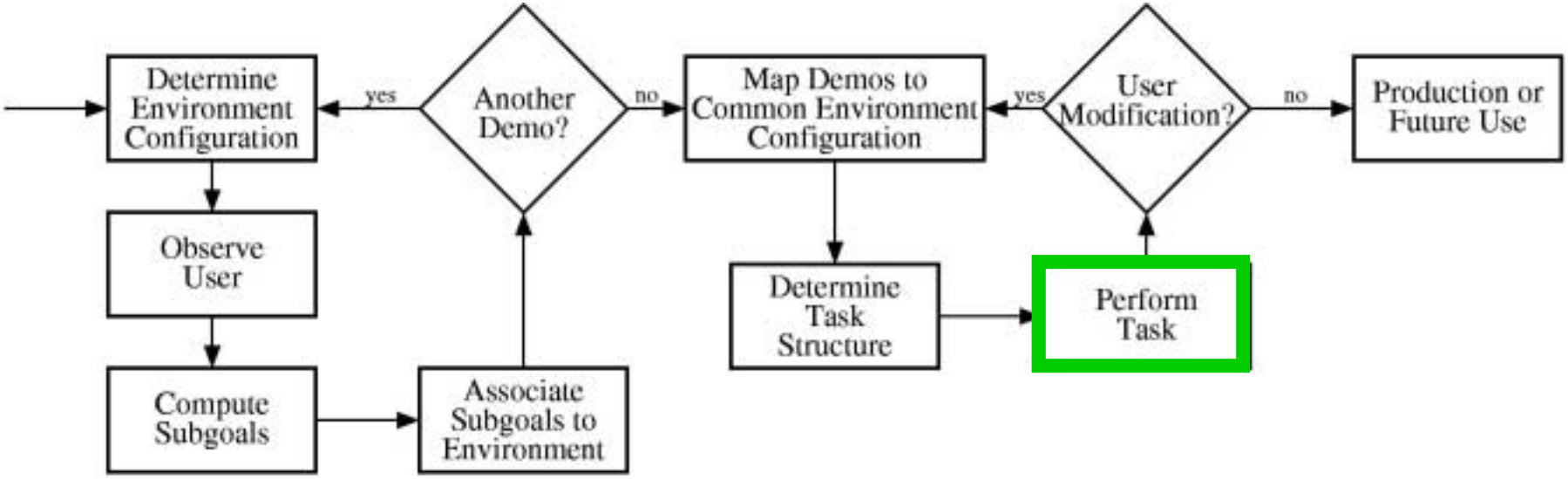
- Determining the mapping is an optimization problem, solutions depend on the objective function used.
- Implicit assumptions about likely perturbations are built into the objective function.
- Must be able to map environments with extraneous and occluded objects.

System Design:
Determine Task Structure



- Combine observations from all demonstrations to determine the *intent* of the user, captured by an FSA.
- FSA output should be necessary set of subgoals to complete the task, including branching.

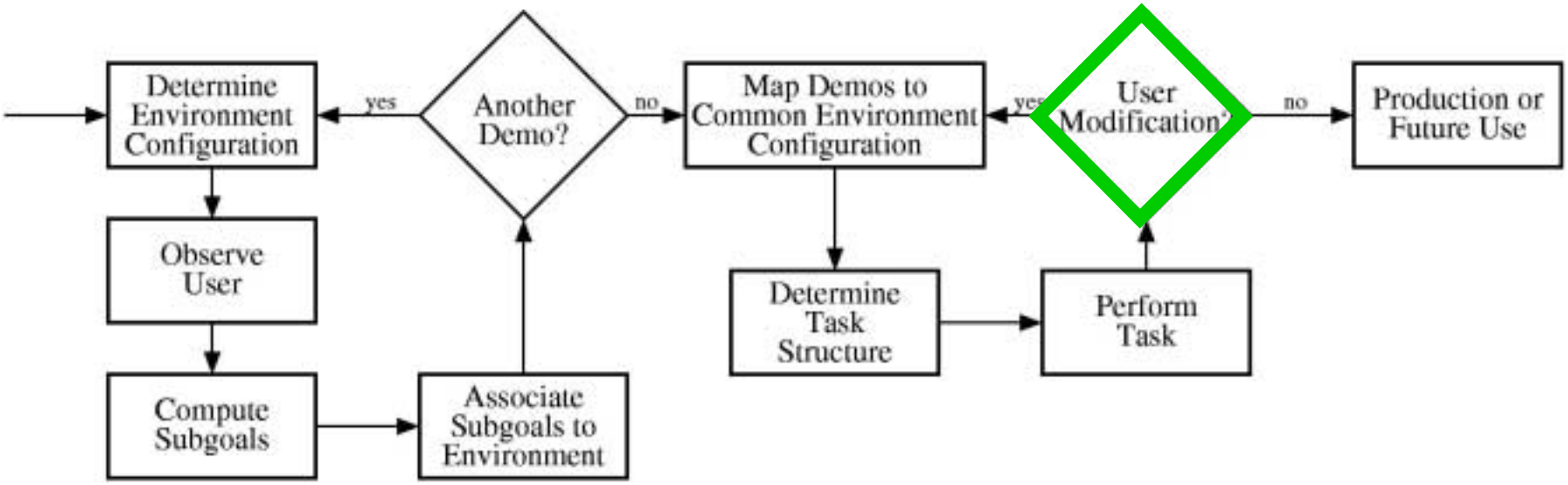
System Design:
Perform Task



- Map canonical environment to current environment.
  - Mapping must work in both directions.

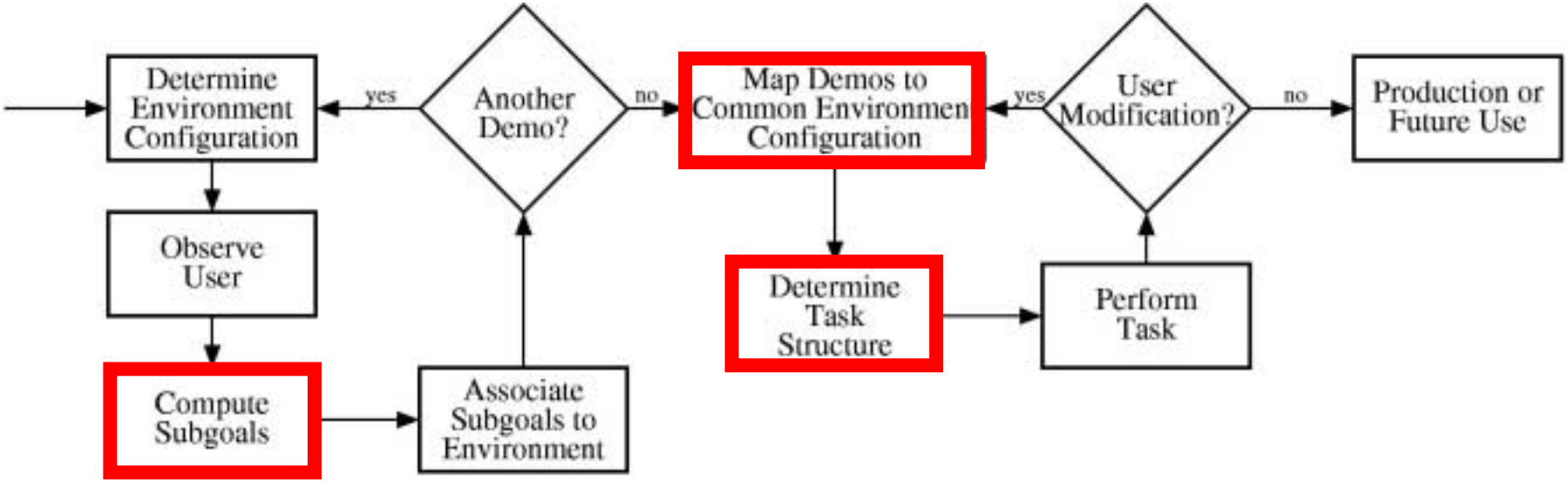
- Used necessary subgoals from FSA to perform the task.

System Design:
User Modification?



- Integrate the user into the design loop to improve LBO system performance.
- Modifications should alter the way that the task structure is determined.

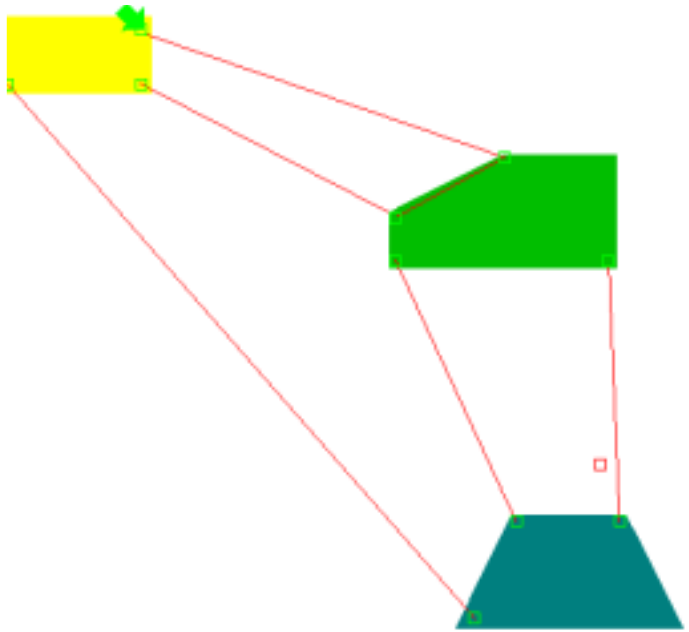
System Design:
Sample Implementation



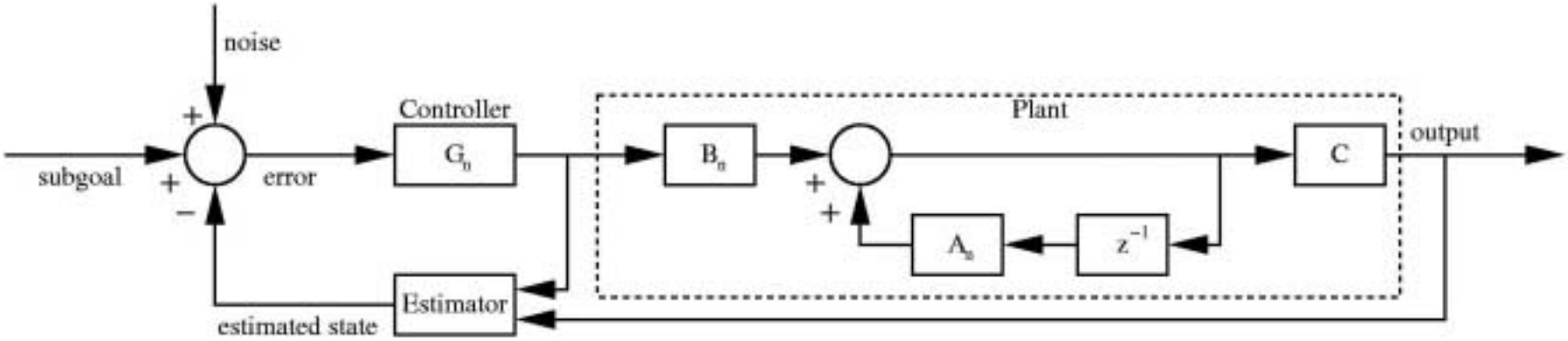
- Simulator description.
- Computing subgoals.
- Map demonstrations to common environment configuration.
- Determine Task Structure
- Performance Metric

Sample Implementation: Simulator

- Tasks consist of click-and-drag operations with the mouse
  - Mouse state is given directly by simulator.
- Environment is comprised of planar polygons.
  - Configuration consists of corner locations, found by vision algorithms.

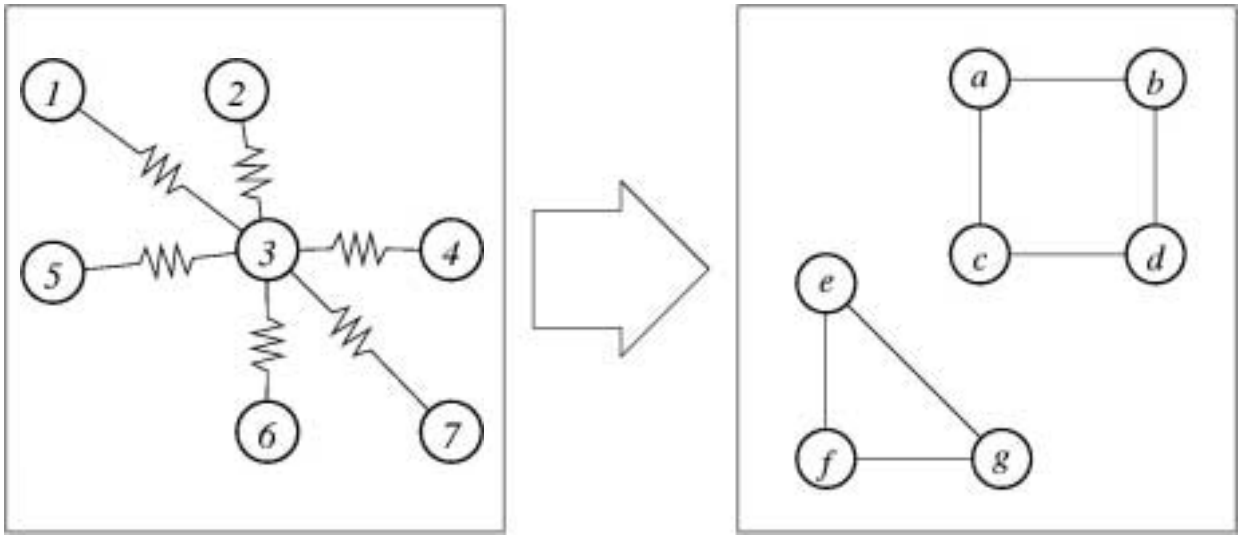


Determining Subgoals



- Assume user follows smooth trajectories between subgoals.
- Estimate the parameters of a time-varying linear system using a moving average.
- When likelihood of predicting next state drops dramatically, mark previous state as subgoal.

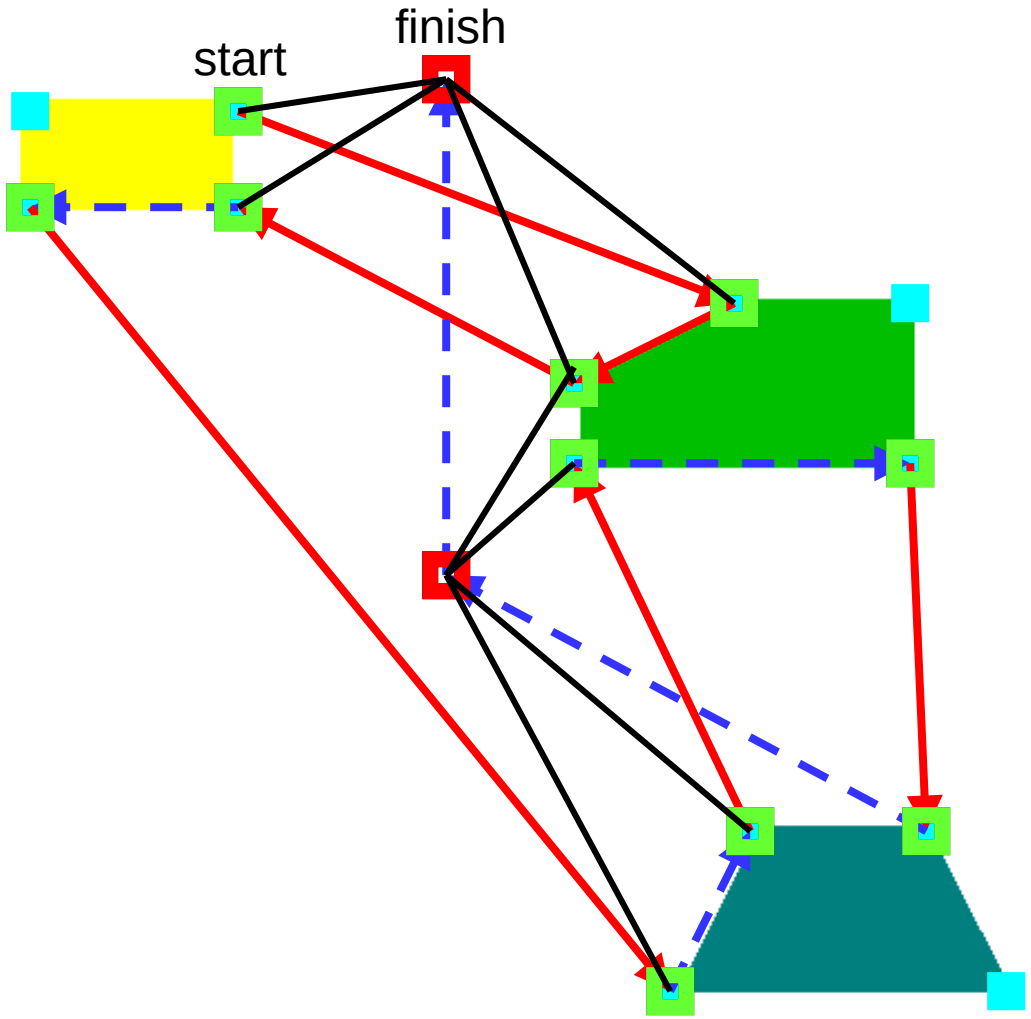
Determining Mapping



- Attach springs from each corner to all others.
- Repeat for resultant frame.
- Minimize change in force for all objects.

  Weighted bipartite graph matching: Linear Program.
- Gets confused easily…

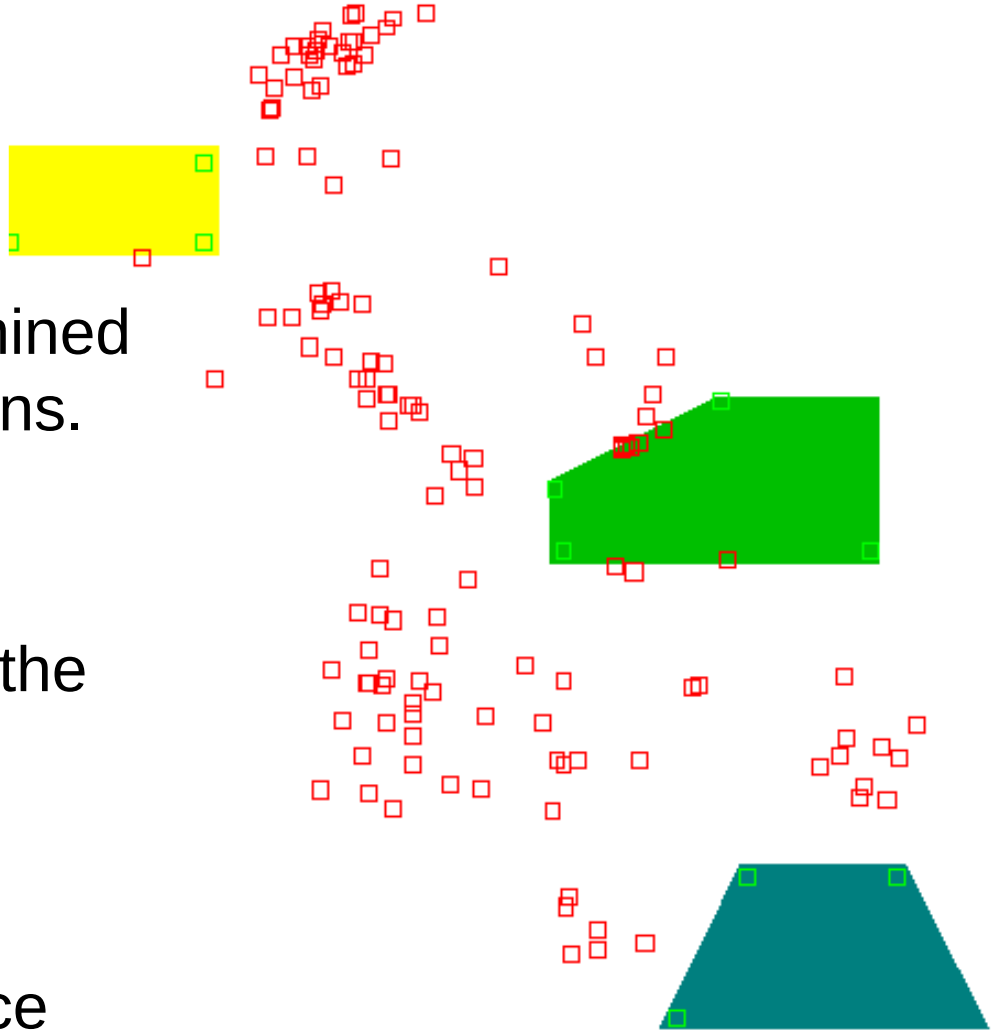
Sample Task



- First, find corners.
- Next, observe user and determine subgoals.
- Determine subgoal-environment associations.

- Asked four hapless grad students to demonstrate the task five times.

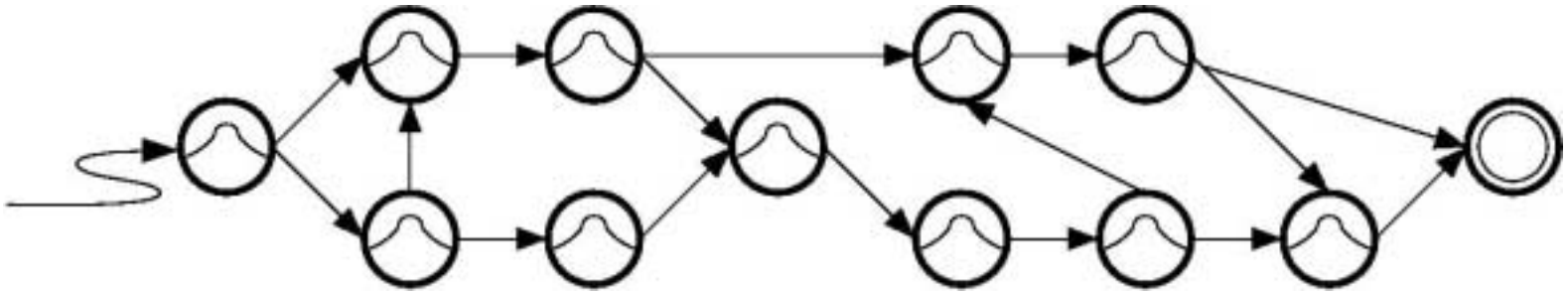
Sample Task



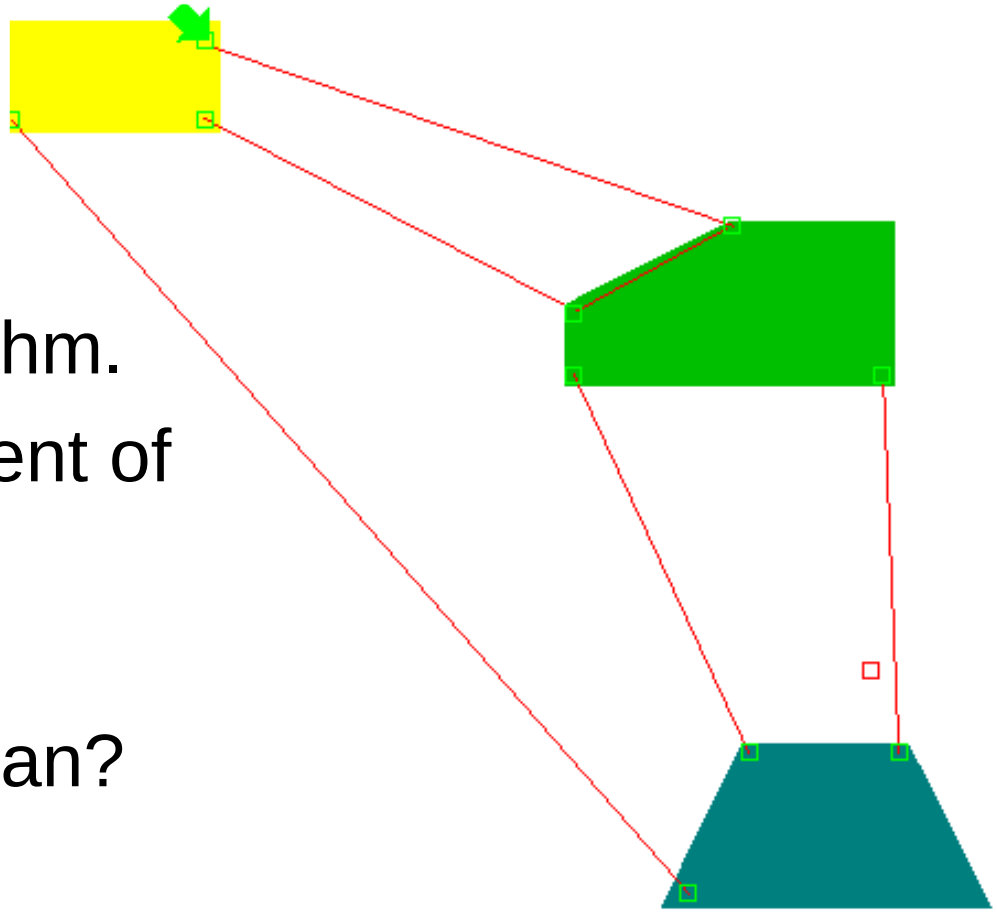
- Resulting subgoals determined from 20 user demonstrations.
- From these data, we must determine the structure of the task.
- Description of training algorithms and performance comparison.

Acyclic Probabilistic Finite Automaton Training Algorithm

- Each demonstration is an ordered set of subgoals.
- Build a DAG that is comprised of all demonstrations.
- Treat demonstrations as stochastic to combine similar subgoals.



Sample Task



- Output of APFA algorithm.
- Appears to capture intent of users well.

- But what does *well* mean?

Quantifying *Well*

- What's missing from the diagram is a way of measuring which is better.

- Preliminary answer: Normalized string edit distance.
  - Percentage of subgoals that must be added, deleted, or modified to get "correct" answer.
  - APFA algorithm: 0.11 ☺
  - HMM algorithm: 0.95 ☹
- These are scores for canonical environment, not ensemble averages.

Proposed Work

- Determine “ergodic” performance metric of LBO system.
- Incorporate robust mapping algorithm that can handle object occlusion.
- Develop theory behind APFA-training algorithm.
- Incorporate users into design loop of LBO system.
- Integration of vision algorithms.

Evaluation of Research

- Cross-validation sets will be used on hand-crafted problems to evaluate subsystems.

- Target task is arc welding.
- Feedback from domain experts will be used to evaluate viability of system.

Expected Contributions

- Demonstrate that an LBO system is a viable automation tool.
- Create an LBO system resilient to environment perturbations.
- Determining subgoals in a non-symbolic fashion.
- Incorporating multiple demonstrations to increase performance.
- Devising an algorithm to determine the structure of underlying tasks.

Preliminary Timetable

Task	Start date	End date	Duration
Verification of algorithms in simulation.	May 01	August 01	4 months
Integration of vision algorithms.	September 01	November 01	3 months
Controlled experiments on robot manipulators.	December 01	March 02	4 months
Experiments with domain experts and integrating their feedback	April 02	July 02	4 months
Write report	July 02	September 02	3 months
Total	May 01	September 02	18 months