ABSTRACT

DUDANI, AJAY B. User Interface Softbots. (Under the direction of Dr. Robert St. Amant).

A user interface softbot is a software agent that controls an interactive system through its graphical user interface, relying on visual information of the system rather than an application programming interfaces or access to source code. We have developed a prototype system that facilitates the use and extension of interface softbots, reforming the programming process and making it easier for new developers. We present the JSegMan substrate that facilitates the representation and identification of the conventional graphical user interface. The JSegMan substrate consists of sensors, effectors and framework for an agent that can control the user interface environment. Using image processing the sensor builds a representation of the desktop's visual interface. The effector module generates mouse and keyboard gestures to control the desktop environment. The sensor and effector modules work as eyes and hands of a controller application that can be tailored for a given application domain. We also present three applications - MSN Chatbots, the classical Blocks World problem solver and a GUI testing tool that use the JSegMan substrate and demonstrates applicability of JSegMan in use with off-the shelf applications, PDDL based planners and in testing environment respectively.

USER INTERFACE SOFTBOTS

by

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To my parents and family,

for their guidance, support,

love and enthusiasm.

Biography

Ajay Dudani was born on February 27, 1980 in Ahmedabad, India. He graduated with a Bachelor of Engineering degree in Information Technology from Nirma Institute of Technology, Gujarat University, India in June 2001. He worked as an Engineering Trainee with Motorola India Electronics Limited, Bangalore, India as part of his final semester project. He then joined the Masters program in Computer Science at North Carolina State University. While working towards the Masters degree, he also worked as an intern with Allied Telesyn Networks, Raleigh, NC and IBM, Cambridge, MA.

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Chapter 1

Introduction

Over the period of last two decades, researchers have shown keen interest in the area of software agents. Agents are commonly conceptualized as kinds of adaptive, self-contained and intelligently executing software processes that encapsulate some state information and can communicate with each other by exchanging messages. However, many different projects use the term "agents" for somewhat different entities, ranging from simple shell programs to systems incorporating real time planning and other sophisticated planning.

The original sense of the word "agent" is of one person acting on behalf of someone else. Agents can be as simple as subroutines, but typically they are larger entities with some sort of persistent control. Although the traditional notion of an intelligent agent in AI is that of a rational agent that has explicit representations of its goals and of its beliefs about the world, the definitions of agent commonly used tend to depend on the background of the researchers. Huhns and Singh [1] define agents as follows: "Agents are active, persistent (software) components that perceive, reason, act and communicate."

The following scenarios exemplify some typical uses of agents: such examples have motivated the use and development of software agents, even if the current technology does not enable the provision of all such facilities to an appropriate standard [3]. A user wants to locate a published article, but knows only the title and author of the paper. The user directs the Personal Assistant (PA) agent to find the article. The PA knows how to find publications on the local network, but when unsuccessful it knows other useful ftp sites and other intermediate agents. By contacting other agents, which in turn can contact more agents and ftp sites, the PA will hopefully find an ftp site with a copy of the requested article. It then arranges for transferring the article from the ftp site to the local computer without any user intervention. Other routine processes can be automated in a similar manner.

A user is occupied with some task on their computer, when their PA requests their attention: an email message has arrived that contains submission results about a paper they sent to an important conference, and the PA reasoned that the user might want to see it as soon as possible. Since the paper has been accepted, the PA begins to look into travel arrangements by contacting a number of databases and other networked information sources and agents. A short time later, the PA presents the user with a summary of cheapest and most convenient travel options.

Huhns and Singh [1] have identified the following as key characteristics of agents:

Intrinsic properties: Intrinsic properties of agents are the ones that are related to the agent itself.

Table 1: Intrinsic properties of agents

Property	*Range of Values*
Lifespan	Transient to Long-lived
Level of Cognition	Reactive to Deliberative
Construction	Declarative to Procedural
Mobility	Stationary to Itinerant
Adaptability	Fixed to Teachable to Autodidactic
Modeling	Of environment, themselves or other agents

Extrinsic properties: Extrinsic properties of an agent are defined in context of other agents.

Table 2 : Extrinsic properties of agents

Property	*Range of Values*
Locality	Local to Remote
Social Autonomy	Independent to Controlled
Sociability	Autistic, Aware, Responsible, Team Player
Friendliness	Cooperative to Competitive to Agnostic
Interactions	Logistics: direct or via facilitators, mediators, or non-agents. Style/Quality/Nature: with agents/world Semantic Level: declarative or procedural communications

Direct manipulation of graphical user interfaces allows users to interact with modern systems. Usually, in such systems, each action to be performed by the user corresponds to one step action to be performed on the direct manipulation interface. Lieberman [5] defines *interface agent* to be a program that can also affect the objects in direct-manipulation interface, but without explicit instructions from the user. In this way, the interface agent is considered to be a robot whose sensors and effectors are input and output capabilities of the interface. In this sense, such a robot is also referred to as "softbots" [6]. Sometimes the interface agent may be anthropomorphically represented as a face or animated character on screen, such as Clippy in the MS Office Suite.

Lieberman's work [5] led to development of Letizia, an autonomous interface agent for Web browsing. Letizia is an autonomous agent that treats search through the Web space as continuous and cooperative venture between the user and the agent. Letizia records the URL surfed by the user and creates a complete profile of the user's interests. Letizia is always active, searching the web space "near" the user's current position.

Work done by St. Amant et al [7] is based on the belief that "If you can see it, you should be able to program it". It presents a radical approach to describe the user's intentions - using the visual properties of the interaction elements themselves. Only recently has the speed of image processing made feasible real-time analysis of screen images by ‘Programming by Example’ system. The foremost advantage of a Programming by Example (PBE) system is that they can work from the visual appearance of the application, and do not need to rely on the API's provided by applications. Thus a visual PBE system, independent of the source code and API can work with off the shelf applications, could potentially reach an unlimited audience.

Choosing an environment in which the agent will execute is an important decision for agent developers [8]. In practical planing research, realistic environments create a problem due to their dynamic nature. Realism of an environment can be a measure of how close the environment is to the real environment or by seeing if the problems that arise under controlled conditions are similar to those that an intelligent agent or a human user may be able to solve in the real world. As opposed to realism is the problem of tractability. It is not desirable to provide a highly realistic environment that is way too difficult for the agent - to the extent that it hinders the agent.

In the ideal environment, researchers can pose realistic but tractable problems to an agent, measure and evaluate its performance, and iteratively rework the environment to explore more ambitious questions, all at a reasonable cost, time and effort [8].

Goals

This thesis focuses on the concept of ibots, interface agents that interact with software applications through the graphical user interface, in the same way that human users do. As a part of this work, we intend to develop a system that supports the control of an application through its graphical user interface, bypassing its API. At first glance, it may seem to be a waste of processing power, but visual manipulation has potential advantages as well. For various reasons, some applications lack API and others allow only limited control through API. In some cases like online applications, API cannot substitute for direct access to events and appearance of the interface. This thesis will contribute to the development of systems for programming by demonstration, agent based systems and other opportunities to extend off-the-shelf interactive applications that one cannot modify directly as a developer.

Interface softbots usually act on the basis of their current and previous sensor readings. Inspite of detailed image processing, a softbot's information about its environment may be largely incomplete. This may be due to several reasons like imperfect sensors or the agent not being aware of its initial state. We intend to extend our system to be able to watch the users and learn from user actions. Such an adaptive learning agent will be able to scale up to be able to work efficiently with many more applications and perform tasks in the desktop environment.

Direct observation of user activities also leads to close collaboration. Once the agent and user both know and intend that the other party observe their actions, collaboration between both parties is possible. As a part of this work, we intend to extend JSegMan to be able to help users based on its knowledge of desktop environment and by observing user actions.

Outline

Chapter 2 gives a background on agents, planners and GUI testing in general. It also presents a case of using planners for interface agents and presents an example of a planning agent.

Chapter 3 briefly discusses the SegMan architectures and the moves on to a detailed description of the JSegMan system. It includes the architecture, classes and API's provided by the JSegMan substrate. It goes on to describe JSegMan as a programming environment and representation of desktop environment in planning domain and interaction between JSegMan and planning systems.

Chapter 4 evaluates the work presented in this thesis in terms of the link between user interface and agents. It also evaluates the system developed in terms of its performance and brings to light the limitations of the system. Later, it describes the applications built based on JSegMan substrate.

Finally *Chapter 5* concludes with a summary of contributions made as a part of this thesis, limitations of the work and some pointers for future work.

Chapter 2

Related Work

Agents

An agent is any program that acts on behalf of the user in an assisting role rather than tool in the manner of a conventional direct-manipulation interface. An agent should have some level of intelligence, creativity, autonomy and initiative associated with it, in order for the human to delegate responsibility of performing a task on an agent rather than instruct it at every step. This property differentiates an agent from a tool [16]. This view of an agent is controversial since different users may view a software interface either as an agent or as a tool depending on their own view of how the software is acting. Another aspect of agents is its autonomous behavior, as opposed to having a sequence of interactions with the user.

Direct manipulation interfaces allow its users to directly manipulate the objects on the screen. Each action of the user maps directly to change in state of an object on screen. An interface agent can be defined as a program that can manipulate the direct manipulation interface just like a human would. The interface agent reads the objects and information presented by the direct manipulation interface, interprets it and acts on it based on its knowledge of the task to be performed. In this sense, the interface agent is a robot whose sensors and effectors are written in software, hence such agents are often known as "softbots".

An agent can be considered having both characteristics of interface and autonomous agent when there are some parts of the direct manipulation interface that the agent can act on in an autonomous fashion. As a result, the end user would see the objects in direct manipulation interface moving on their own, and the agent shall be able to identify the changes in the interface on its own rather than being told by the end user.

Wooldrige and Jennings [17] divide agent related issues into three areas. *Agent theory* is concerned with issues of what an agent and its formal mathematical representation and reasoning. *Agent architecture* is related to software architectures of agents, and is concerned with the problem of designing software implementation of agents that satisfies agent theories. Finally, *agent languages* are related to software systems for programming and experimenting with these agents. This thesis touches upon aspects of agent architecture and agent languages.

Etzioni and Weld [18], at the University of Washington developed an AI agent that uses the UNIX shell to interact with the World Wide Web. The agent's sensors included UNIX utilities like netfind, gopher and archie and effectors included utilities like ftp, telnet and mail. This softbot's planning environment included concepts of sub-goaling and accepting incomplete specification of goals by searching for missing information within its search space.

Over the last few years a lot of research has been done in agents related to Internet activities like search agents and email agents to prevent spam. However interface agents that directly manipulate an interactive environment using the interface have not been exploited. Some similar work has been done in area of GUI testing, as discussed in sections below, but the perspective of work done there has been done specifically keeping GUI testing in mind instead of creating a generic system for a programmable interface agent environment

Planners

The following section gives a brief introduction to planning and the different planning techniques.

Automated plan generation techniques have been widely investigated and used in the field of artificial intelligence. Planning systems require a starting state, a goal state and a set of operations along with pre-conditions and post-conditions to those operations. The planner then, by using various different algorithms, generates plans to move from initial state to goal state [19].

Formally, a planning problem P(A, D, I , G) is a 4-tuple, where A is the set of operators, D is the finite set of objects, I is the initial state of the system and G is the goal state of the system. The solution to the planning problem is a plan: a tuple <S, O, L, B> where S are the steps, O are ordering constrains on the elements of S, L are causal links representing the causal structure of the plan, and B are binding constraints on the variables in S. Causal links are triples <Si, e, Sj>, where Si and Sj are parts of S. c is a result of Si and also a pre-condition for Sj. Typically, the ordering constrains only induce a partial ordering, so the set of solutions are all linearization of S consistent with O.

The actions that are results of planner executions have certain constrain on the relationship among them. An action is an instance of operations with its variables bound to values. STRIPS (Strategic Information and Planning System) is one such well-known action representation language which specifies operators in terms of parameterized pre-conditions and post-conditions. STRIPS, however was developed over twenty years ago and has limited expressive power. For example, no additional conditional or universally quantified effects are allowed. Although, in theory, sets of STRIPS operators can be combined together to encode various complex conditional effects, the number of operators used to represent such effects increase exponentially very fast. A more powerful representation is ADL [20], which allows conditional and universally quantified effects in operators. This facility allows for defining operators in a more intuitive manner. A more recent domain representation language is Planning Domain Definition Language (PDDL), first used in AIPS'98 planning competition. The goals of designing the PDDL language were to encourage empirical evaluation of planner performance, the development of standard set of planning problems.

Recent developments in planning technology based on propositionalization of the search space have greatly increased the efficiency of plan generation algorithms. A well-known planner based on this technology is the Fast Forward Planner (FF) [21], a system that extends the ideas of the Graphplan system [23]. Graphplan introduced the idea of plan generation by converting the representation of a planning problem into a propositional encoding. Plans are then found by a means of search through a leveled graph, in which even levels (0, 2, …, i) represent actions that might be performed at stage i of the plan, and odd levels (1, 3, … i+1) represent actions that might be performed at time i+1. The planners in Graphplan family, including FF, have shown increases in planning speeds of several orders of magnitude on a wide range of problems as compared to earlier planning systems [25].

Planning at one level of abstraction may be impractical for complex systems, which consists of a large number of objects and operators. Techniques have been developed to generate plans at multiple levels of abstraction; this is typically called Hierarchical Task Network (HTN) planning [26] in which domain actions are modeled at different levels of abstraction, and for each operator at level n, one specifies more "methods" at level n-1. A method is a single-level partial plan and an action is said to "decompose" into its methods. HTN planning focuses on resolving conflicts among alternative methods of decompositions at each level.

PDDL is intended to express the "physics" of a domain i.e. what predicates there are, what actions are possible, what the structure of compound action is, and what the effects of actions are. The language supports the following syntactic features:

- Basic STRIPS-style actions
- Conditional effects

- Universal quantification over dynamic universes
- Domain action over stratified theories
- Specification of safety constraints
- Specifications of goals and sub-goals, thus providing hierarchical goals support.

The domain specific knowledge is specified using predicates. Various actions to be performed on domain are specified with actions. Usually a PDDL based planner takes two files as input, one being the domain definition file consisting of domain predicates and possible actions along with their pre conditions and post conditions. The second file is the problem file, which consists of initial state of domain and final goal state of the domain. The following is the syntax of domain definition file in PDDL:

```
(define (domain DOMAIN_NAME)
 (:requirements [:strips][:equality][:typing][:adl])
 (:types TYPE_1 TYPE_2 … TYPE_N)
 (:predicates (PREDICATE_1 [?A1 ?A2 … ?AN])
              (PREDICATE_1 [?A1 ?A2 … ?AN])
                      . . .)

 (:action  ACTION_1
  [:parameters (?P1 ?P2 …?PN) ]
  [:precondition PRECOND_FORMULA]
  [:effect EFFECT_FORMULA] )
 (:action  ACTION_2
         . . .)
```

Listing 1: Syntax of domain definition file in PDDL

The *requirements* keyword specifies the packages to be included for this planning problem. *Types* specifies user defined domain specific types. *Predicates* are a set of truth statements that govern the domain. *Actions* are operators available in the domain. The actions have a *precondition* that specifies the predicates, which must be true, before this operator is applied. The *effect* specifies the predicates that become true after this operator is applied.

The syntax of a problem definition file is as under:

```
define (problem PROBLEM_NAME)
(:domain DOMAIN_NAME)
(:objects OBJ_1 OBJ_2 ... OBJ_N)
(:init ATOM_1 ATOM_2 ... ATOM_N)
(:goal CONDITION_FORMULA)
)
```

Listing 2: Syntax of problem definition file in PDDL

The problem definition file describes the problem to be solved. The *init* specifies the predicates that are true at the beginning of the problem. The *goal* state specifies the predicates that need to be true at the end of the problem.

Here is a listing of air cargo problem, to transfer cargo from one airport to another using a plane. The domain definition file and problem files are listed below.

```
(define  ( domain AirCargo )
  (:requirements  :typing  :adl )
  (:types    Airport - Location
            PlaneType - Object
             CargoType - Object )
  (:predicates
          (In ?c - CargoType ?p - PlaneType)
         (At ?obj - Object ?loc - Airport) )
  (:action Load
    :parameters
     (?c - CargoType ?p - PlaneType ?a - Airport)
     :precondition ( and (At ?c ?a)
                         (At ?p ?a))
     :effect (and (not At(?c ?a))
                         (In ?c ?p) ) )
  (:action Unload
    :parameters    (?c - CargoType ?p - PlaneType ?a - Airport)
    :precondition (and (In ?c ?p)
                       (At ?p ?a))
    :effect (and  (At ?c ?a )
                  (not (In ?c ?p) ) ) )

  (:action Fly
    :parameters  (?p - PlaneType ?from - Airport ?to - Airport)
    :precondition  (At ?p ?from)
    :effect (and (not (At ?p ?from))
                     (At ?p ?to) ) )
```

Listing 3: Representation of Cargo problem's domain definition in PDDL

In the cargo problem domain definition, we first define three types of entities Airport, PlaneType and CargoType with user defined types. Once we define the predicates for them, all the possible actions in the domain are listed. The planner, to solve problems defined by various problem files then uses these actions.

Consider the actions 'Fly'. It first describes the parameters involved in the action - a plane along with originating and destination airports. The precondition of the action specifies that the plane has to be at the originating airport before the action can be performed. The effect specifies that once this action has been performed, the plane is no longer at the originating airport and is now stationed at the destination airport.

The following is listing of a problem file for moving cargo from RDU to LAX airport.

```
(define (problem Transport1)
(:domain AirCargo)
(:objects   C1, C2 - CargoType
            P1, P2 - PlaneType
            RDU, LAX - Airport )
(:init
     (At C1 RDU)
     (At P1 RDU)
     (At C2 LAX)
     (At C2 LAX))
(:goal (and
     (At C1 LAX)
     (At C2 RDU))))
```

Listing 4: Representation of Cargo problem's problem definition file in PDDL

The Transport1 problem is defined in the Cargo domain, which means that the planner can use the actions defined in Cargo domain definition file to solve this problem. The problem file first describes the objects involved in the problem, in this case, two cargo items, two planes and two airports. This is followed by initial state of the objects, which states that cargo C1 and plane P1 are at RDU airport and cargo C2 and plane P2 are at

LAX airport. The goal state specifies the final state of these objects. The planner works its way from initial state to goal state using actions specified in the domain definition file.

Planning agents for interface agents

Artificial intelligence and human-computer interaction have close historical ties, going back to Newell and Simon's work on human problem solving [9], and farther. User interface issues have given AI developers challenging problems in realistic environments, leading to results in automatic interface adaptation, multi-modal interaction, interface generation, and agent interaction, among a wide range of other areas [10]. HCI borrows the notion of human as a rational problem-solving agent from AI. In this sense, both AI and HCI are concerned with facilitating the interaction of agents with their environment.

Interface agents help the goal of improved interaction between agent and its environment to a great extent. By building interface agents, one can predict some aspects of usability of an interface based on engineering models. Such an agent must face all the hurdles of interacting with a complex environment. This involves taking the pixel level input from the screen and identifying objects on the screen to understanding the meaning of different controls on screen. This idea is quite exciting from an agent's perspective as it leads to development of agents that can use interactive applications just like a human user. Compared to robotic agents that deal with real world - interface agents are at par with human counterparts in terms of using software interfaces since they have access to the same environmental information without any degradation of quality or quantity. Thus the user interface is a level-playing field for comparison between agents' and humans' performance on real world problems.

Memon's work [19] is an example of planning agent. In his work, Memon proposes a GUI testing framework based on a planning agent. He presents a classification of GUI widgets in a hierarchical manner with an event flow graph that identifies the different events and their interactions. A regression test performed by GUITAR, the GUI test agent, uses a test oracle to verify if the GUI passed or failed the test. The desktop environment is represented using the Planning Domain Definition Language (PDDL). In PDDL, the initial state and final expected state of the desktop environment is presented to a PDDL based planner like FF, Blackbox, STAN or IPP. Once the planner determines the appropriate path to achieve the final state, it informs the interface agent, which in turn uses Windows API's to perform the appropriate mouse or keyboard actions.

GUI Testing

Graphical User Interfaces have become ubiquitous means of interacting with software systems. A GUI is the front end of the software system that the end user interacts with. The GUI interacts with the underlying functional code using function calls and messages.

Verifying the correct operation of GUI is a problem. The traditional way to testing involves creating a test oracle and having a human user execute all the test cases in the oracle. Finally comparing the actual output with the expected output as documented in the oracle determines the passing or failing of the test case. Most of the times, this can also be automated with a script. However GUI testing the scenario becomes different as there can be multiple events occurring simultaneously. Regression testing is an accepted way for testing GUI correctness. If such regression testing is performed manually, then it could lead to high expenditure in manpower and costs. Also the correctness of these tests is highly dependent on the abilities and experience of the tester. In spite of these issues such a method is prevalent with some use of automated scripts or tools written for specific GUI's since there is a lack of a generic GUI scripting environment that can be tailored or programmed to specific needs of GUI testing.

There is a gamut of GUI test drivers available for GUI testing. Most of them, however, are tied down to the Windows operating system GUI environment, since they use Windows API's to query the widgets of a particular application. Some others have been written in cross-platform languages like Java and provide for functions for moving the mouse and pressing keystrokes, but offer no information about the widgets available on screen.

Chapter 3

System Design and Implementation

SegMan provides a set of functions developed by Riedl and St. Amant [2] that facilitates a direct interaction between cognitive models and GUI of Windows 98/2000 operating system. SegMan has the ability to take screenshots of the desktop and perform image processing to identify the various buttons, windows and other widgets on the desktop.

The architecture of the system is shown in Figure 1. Currently SegMan only supports the Microsoft Windows interface as it has been configured to process and recognize widgets specific to the Windows environment.

Segman.dll is a dynamic-link library of code written in C++. It provides functionality for capturing the Windows screen and breaking it into groups of like-colored pixels, known as pixel-groups.

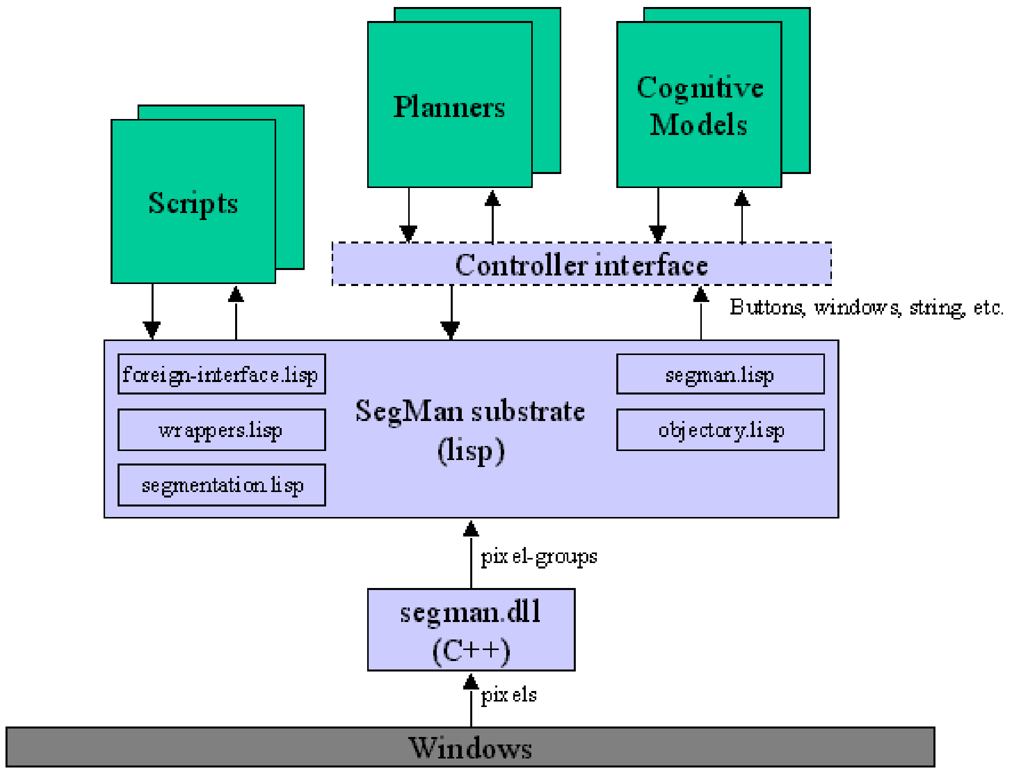


Figure 1: Architecture of SegMan

SegMan substrate is a collection of Lisp routines that use the functionality provided by the DLL. They retrieve the pixel-groups from the DLL's memory, process them and identify and classify them by subjecting them to some predicates. SegMan internally represents and determines the state of the Windows screen as a list of all pixel-groups, and symbolic references for what they might look like and what they might be used for.

On top of this substrate is a functional substrate, which comprises of programs and scripts that access the SegMan data structures and functions to solve problems.

However SegMan, as stated above, is designed specifically for desktop environments. It is even limited in terms of desktop environments, as it can only support Windows GUI. Work done as a part of this thesis extends work done my Riedl on SegMan. Although the JSegMan substrate is very similar to SegMan, there are certain differences. The most important addition by work over SegMan is that work done as a part of this thesis is platform independent and can work equally well under the XWindows environment as with the Windows GUI environment. My work involves trying to present the desktop environment as a planning domain, rather than tying the GUI directly to a planning model. By making the desktop environment available in the planning domain and making the JSegMan substrate available as a programming model, any PDDL based planner or a Java program can interact with the desktop environment as a human user would. The possibilities of use of such an environment range from adding intelligence into planner/program to do mundane desktop tasks like GUI Testing, automated chat based help desk, scripting to perform repeated tasks. Another scenario where it can find its use is user help. If the JSegMan programmable substrate is available on multiple systems; a user on one system can script a task to perform and send the script to another novice user to help him perform the task on his own system. The following figure shows the different layers including JSegMan substrate and layers above it.

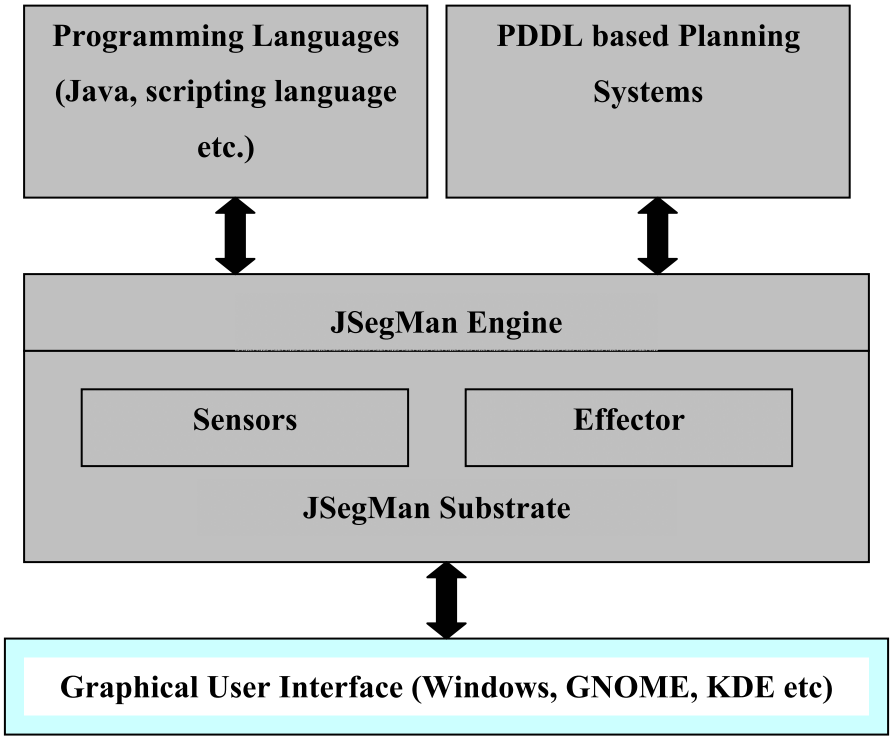

Programming Languages (Java, scripting language etc.)
PDDL based Planning Systems
JSegMan Engine
Sensors
Effector
JSegMan Substrate
Graphical User Interface (Windows, GNOME, KDE etc)

Figure 2: Architecture of JSegMan

JSegMan is a perceptual substrate that uses computational vision to "see" the Microsoft Windows graphical direct-manipulation interface. JSegMan enables other programs to be able to see the graphical interface screen as a human would see it. This enables programs to interact with Microsoft Windows as if it were a user sitting at the console instead of relying on low-level APIs. With JSegMan we can create and test more realistic cognitive models of direct-manipulation interface usage, build AI agents that can reason about and use the graphical interface, and write scripts and programs that learn and perform routine tasks in the graphical interface.

JSegMan is a substrate because it is a layer of functionality that sits just above the level of the operating system and provides hook functions that other programs can use to perceive and manipulate the graphical user interface. JSegMan itself does not perform any functionality except segmenting the screen into well-understood features and widgets that other programs and scripts can utilize for their own ends.

The computational vision routines that JSegMan use are fairly rudimentary -- coming no where close to the sophistication of human vision. However, the Microsoft Windows graphical user interface is highly rectilinear and highly standardized so we can use short cuts for detecting features and widgets on the screen. This chapter goes into more detail on how JSegMan segments the screen into useful visual components.

The architecture is a layered architecture. On the bottommost level lies the operating system. For the current version of JSegMan, the only operating system completely supported is Microsoft Windows; JSegMan feature detection routines are geared specifically for recognizing screen widgets that are defined by the Microsoft Windows look-and-feel. However the substrate has been tested to work with KDE and GNOME desktop environment with a minimal support of widgets on these desktops - just enough to demonstrate JSegMan in action.

JSegMan sensor and effector subsystems

There are two main sub systems that make up the JSegMan system. These are the sensor subsystem and the effector subsystem.

The effector subsystem of the JSegMan system manages all interaction with the computer as a human would. It allows for various mouse operations like moving mouse pointer, single click, double click and pressing of specific keys on the keyboard. This sub system of JSegMan also allows for saving all the events being executed on the system to a text file and later plays all the events from a text file. The implementation of effector subsystem is quite simple compared to the sensor subsystem, since basic functionality of moving mouse and typing key-strokes is available through Java API's. The effector subsystem builds on top of these basic Java API's providing incremental movement of mouse pointer and typing of sentences instead of single characters.

The sensor subsystem of JSegMan deals with low-level details of the screen processing. It allows for image captures of the screen, identifying color attributes of screen pixels at the screen level for image processing. This subsystem also does all the identification of objects on the screen including windows, buttons and text among others. On completing the processing of the screen once, JSegMan systems stores information about the widgets and text identified on the screen in its internal database, which can be queried by any other system using JSegMan as a library to query the widgets and fonts available on the screen. This information is stored as a part of JSegMan engine.

Object recognition and optical character recognition is a complex subject that has received attention over the past 30 years. In spite of many years of research, tools that can satisfactorily identify objects or characters are rare. The reason for this difficulty is associated with the ambiguity in distinction of objects and recognition of similar looking objects in a variety of contexts.

The task of object recognition can be broadly separated into two categories: the recognition of machine related data which are uniform in size, shape and include computer fonts, windows and buttons among other widgets. In contrast, real world objects or hand written characters are non-uniform; they can be perceived from a variety of different angles and can be produced in different shapes, yet be identifiable by the human eye.

The JSegMan sensor subsystem uses simple vision computation algorithms to identify the screen pixels and aggregate the information of each pixel to recognize the text and widgets on the screen. The sensor subsystem of JSegMan processes the pixel level details from the screen captured image and creates pixel groups [30]. These pixel groups are then identified for specific properties that various shapes related to a desktop environment have. On establishing relations between these pixel groups, we have high level vision of the desktop environment in terms of text and widgets available on the screen.

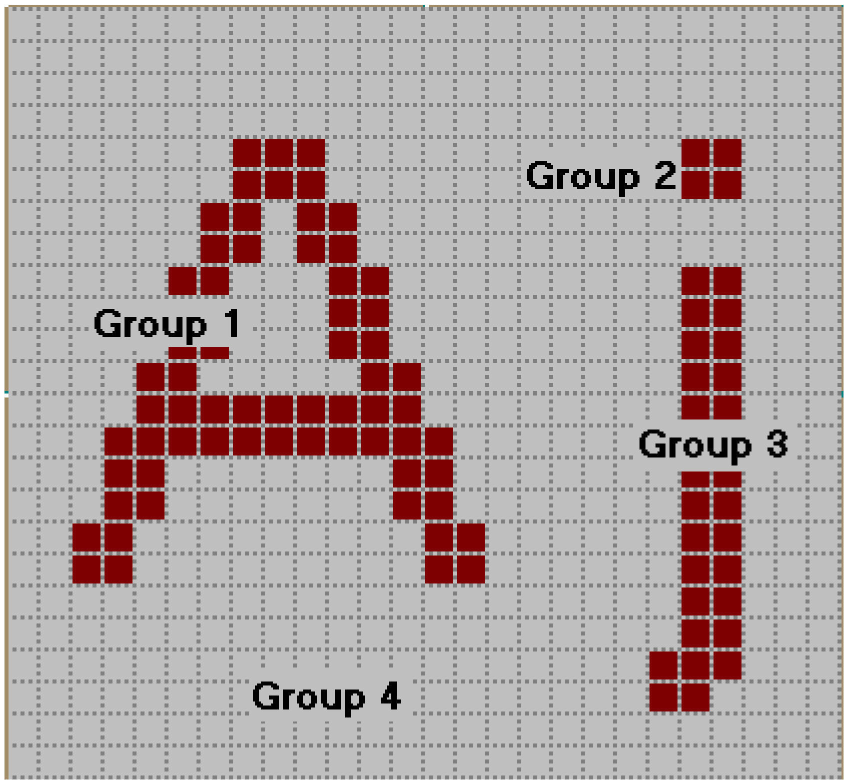


Figure 3: Zoomed image of characters 'A' and 'j' showing different groups in the image

After obtaining a screenshot of the desktop environment, the JSegMan sensor subsystem groups a set of pixels of the same intensity adjoining each other. Figure 3 shows the grouping of pixels for characters "Aj". Group 1 is a pixel group comprised of pixels in letter 'A'. Group 2 and 3 combined together represent the pixels of character 'j'. Group 4 is the pixel-group for background pixels.

Once pixel groups are identified, they are examined for specific shapes and for relationships between shapes. This is where it is identified that group 2 and 3 shown in Figure 3 need to be combined for a representation of character 'j'. In order to identify the group of pixels, one either needs to examine the arrangement of pixels within the group, or one could look at pixel-neighbor numbers.

Each pixel-group has an array of pixel-neighbor numbers associated with it. The pixel-neighbor numbers are encoding of the relationships between pixels within the group. Each pixel in a group has 0-8 neighbors. Looking at an individual pixel in a pixel-group, there are eight possible positions that a neighbor can be in: west, southwest, south, southeast, east, northeast, north, and northwest. We assign a numerical value to each neighbor position, respectively. Thus the west position is assigned to "0" and the northwest position is assigned to "7".

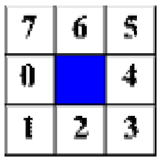


Figure 4 (a)

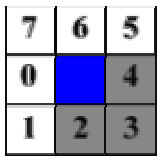


Figure 4 (b)

Each of these numbers corresponds to a bit in a single integer. Thus if a pixel is the top-right corner of a box, it has neighbors to the south (position 2), southeast (position 3), and to the east (position 4). The pixel-neighbor value of that top-right corner pixel is 2^2 + 2^3 +2^4 = 28.

For an entire pixel-group, we add up all the member pixels with pixel-neighbor values of 0, 1, 2, ..., 255. For example, a pixel-group representing a 5-by-5 solid box, the pixel-neighbor numbers will look like:

For an entire pixel-group, we add up all the member pixels with pixel-neighbor values of 0, 1, 2, ..., 255. For example, a pixel-group representing a 5-by-5 solid box, the pixel-neighbor numbers will look like:

```
pixel_neighbors[0] = 0
pixel_neighbors[1] = 0
pixel_neighbors[2] = 0
pixel_neighbors[3] = 0
pixel_neighbors[4] = 0
pixel_neighbors[5] = 0
pixel_neighbors[6] = 0
pixel_neighbors[7] = 1
....
pixel_neighbors[28] = 1
pixel_neighbors[29] = 0
pixel_neighbors[30] = 0
pixel_neighbors[31] = 3
....
pixel_neighbors[112] = 1
....
pixel_neighbors[124] = 3
....
pixel_neighbors[193] = 1
....
pixel_neighbors[199] = 3
....
pixel_neighbors[241] = 3
....
pixel_neighbors[255] = 9
```

Listing 5: Pixel neighbor numbers for a solid 5-by-5 box

The four corner pixels generate unique pixel-neighbor values (7, 28, 112, 193). There are three pixels on each edge if you exclude the corners (31, 124, 199, 241). There are nine pixels in the center that are completely surrounded by neighbors' (255).

We can detect a single-colored box by looking for pixel-groups with the following combination of pixel-neighbor numbers:

```
pixel_neighbors[7] == 1
AND
pixel_neighbors[28] == 1
AND
pixel_neighbors[112] == 1
AND
pixel_neighbors[193] == 1
AND
pixel_neighbors[31] > 1
AND
pixel_neighbors[124] > 1
AND
pixel_neighbors[199] > 1
AND
pixel_neighbors[241] > 1
```

Listing 6: Pixel neighbor numbers that uniquely identify the solid 5-by-5 box

Conjunctive tests such as the one described above for finding a box were used in the original C++ code for SegMan and were then ported to the Lisp side for flexibility. Eventually we developed a declarative form in which pixel patterns could be specified. The form allows not only neighboring values to be specified, but also other properties of a group:

1. count is the number of pixels in the group;
2. size is the area of the group's bounding box;
3. area (poor naming, for historical reasons) is the ratio of count to size;
4. height is the height of the group's bounding box;
5. width is the width of the group's bounding box;
6. red is a component of the group's RGB value;
7. green is a component of the group's RGB value;
8. blue is a component of the group's RGB value;
9. color is the group's numerical RGB value.

We define patterns to capture combinations of group properties. The group properties are accessible to an application through JSegMan substrate API's described later in this chapter.

Simple segmentation of the screen into pixel-groups gives us a lot of power in terms of recognizing features. However, simple segmentation only allows us to see shapes that consist of a single pixel-group. Often it is valuable to recognize features on the screen that are made up of more than one pixel-group. Examples of features made up of multiple pixel groups are icons, buttons, window borders, and strings of letters.

To recognize features that are not made up of a single pixel-group we must employ a two-step process. The first step is to find the pixel-groups that make up the feature. We do this by looking for specific pixel-groups that might be part of overall feature. We do this by selecting pixel-groups that have the right shape (the correct pixel-neighbor numbers). Not all pixel-groups with the correct shape are necessarily going to be part of the feature we are trying to detect. The second step is to choose from the candidate pixel-groups the ones that are in proximity to each other and in the correct spatial configuration. The SegMan system provides a variety of functions that find pixel-groups based on the spatial relationship to others.

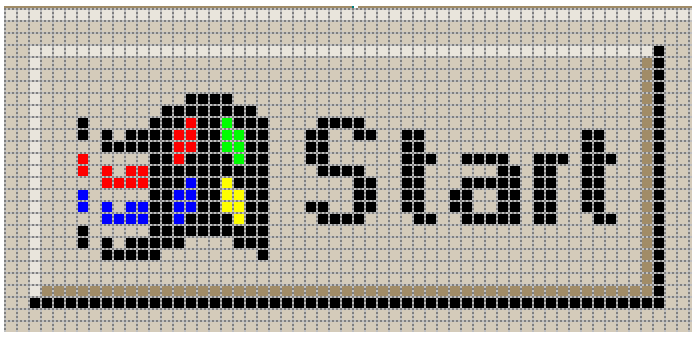


Figure 5: Windows "Start" button

For example, a standard Windows button is a rectilinear feature that appears to be raised out of the screen. This raised effect is created by applying a thin strip of color around the edges; lighter on the top and darker on the bottom. As far as JSegMan sensor subsystem is concerned, a button is made up of two pixel-groups: the two L-shaped regions, with rectangle enclosed inside these L-shapes that may contain other pixel groups. However, these three groups must be in the correct relationship to each other in order to form what looks like a button. The lighter L-shape (upper shading) must be directly above and to the left of the rectangle and the darker L-shape (lower shading) must be directly below and to the right of the rectangle. When these relationships hold, there is a feature recognizable to the human use as a button.

The following is pseudo code for recognizing a button:

```
PROCEDURE find_buttons (screen) DO
   rectangles = find_all(rectangles, screen)
   upper_shadings = find_all(upper_shading, screen)
   lower_shading = find_all(lower_shading, screen)
   buttons = EMPTY_LIST

   FORALL rect IN rectangles DO
      upshade = find_group_containing(rect, upper_shadings)
      lowshade = find_group_containing(rect, lower_shadings)
      IF distance_between(upshade, rect) < 5 AND
         distance_between(lowshad, rect) < 5 AND
         color(upshade) > color(lowshade) THEN DO append(rect, buttons)

   RETURN buttons
```

Listing 7: Pseudo code to find all buttons on screen

In the first stage, we find all the pixel-groups of the shapes we need: rectangles, upper-shading, and lower-shading. Buttons is an empty list into which we will collect all features that look like buttons. In the first stage, we iterate through the rectangles, looking for those in the proper relationship to the other shapes we have indicated. We find a pixel-group in the upper_shadings list that most closely contains the rectangle. We find a pixel-group in the lower_shadings list that most closely contains the rectangle. Containment is a useful relationship because, even though upper_shadings and lower_shadings are L-shaped, their bounding boxes enclose a much larger area that, ideally, will contain a rectangle if the feature is a button. The next check is proximity of the L-shapes to the rectangle. This is very important because a button might be contained in a window and L-shaped shaded areas also bound windows. But if the shading belonged to a window, one or both shadings will probably be further than five pixels away. Finally, we much make sure that the L-shape above the rectangle is lighter in color than the L-shape below the rectangle. If the upper L-shape was darker than the lower L-shape, perceptually, the feature will look recessed into the screen instead of raised.

All features that comprise of more than one pixel-group can be detected by applying one or more of the following relationships: contains, above, below, to the left, to the right. Additional details such as distance may be required to ensure robust recognition.

Description of system files and API's

The following discussion is what to find in each file that makes up the JSegMan system. It discusses the various Java classes and the functionality of the public API's available in each of the classes.

Pixel: This is a very basic class that stores information about a pixel on the screen. It stores information about coordinates of this pixel, its color, the pixel group it belongs to, pointer to next pixel in its group and its neighborhood number. It does not have any public API's.

PixelGroup: This class contains information about a group of pixels. The following public API's are available for this class.

- Absorb: This function takes a PixelGroup as an argument and merges it with the current PixelGroup.
- AddPixel: Add a single pixel to the current PixelGroup.
- Area: Return ratio of number of pixels in the rectangular area contained by the pixel group.
- Contains: Returns if a given PixelGroup is contained inside the current PixelGroup.
- CountNeighbors: Calculates the neighbor number for the pixel group, enabling it to be identified against known neighbor numbers.
- DistanceTo: Returns the shortest distance from this pixel group to another pixel group. This function is sometimes useful in distinguishing widgets too; for example the neighbor number for a window and button is computed to be the same, but the distance of the edges and the central region helps in distinguishing between a button and window.
- GetScreen: Takes a screenshot of current screen for processing.
- GrowGroup: Given a particular pixel coordinates, this function finds pixels in its neighbor having the same intensity and adds it to current pixel group.
- Height: Determines the maximum vertical distance between two pixels of this pixel group.
- IsToLeftOf: Determines if a given group is to left of the current pixel group.
- IsToRightOf: Determines if a given group is to right of the current pixel group.

- LeftDistanceTo: Determines distance from current pixel group to left edge of another pixel group.
- Perimeter: Determines the perimeter of given pixel group
- RightDistanceTo: Determines distance from current pixel group to right edge of another pixel group.
- SetColor: Allows to change the color intensity of a given pixel group in internal representation of data structures in JSegMan. This API is useful when we have colors in a widget that closely resemble each other, but are not exactly the same in their intensity.
- ShowMe: This function shows a frame of current desktop image along with the selected pixel group highlighted in the image.
- Width: Determines the maximum horizontal distance between two pixels of this pixel group.

PixelGroupList: PixelGroupList class is useful for aggregating group of pixels, in order to identify patterns. For example, in letter 'i', the dot at top at the step of 'i' are identified as separate groups, however they are added to same pixel group list and this aggregate representation is used for further reference to the letter 'i'.

- AddGroup: Add another pixel group to current pixel group list
- Contains: Determines if a given pixel group is part of current pixel group list.
- GetGroupAbove: Get pixel group above current pixel group list.
- GetGroupBelow: Get pixel group below current pixel group list.
- GetGroupToLeft: Get pixel group to left of current pixel group list.

- GetGroupToRight: Get pixel group to right current pixel group list.
- RemoveGroup: Remove a given pixel group from current pixel group list.

ScreenDifference: This class has just one public API. It takes two screenshots, or part of screen and determines if there is any difference between the two images. This is particularly useful to determine quickly if there has been any updates to the screen, before performing the complete screen processing task.

ScreenManipulator: ScreenManipulator class forms the effector subsystem of JSegMan. The following is a brief description of its public API's.

- DoubleClick: Performs a double click of left mouse button
- EndRecordEvents: Stops recording events being performed by effector subsystem to a file.
- KeyDown: Presses a key on the keyboard, and the key is held down until KeyUp, SingleClick or DoubleClick is called. This function can identify a given key to be pressed either by the character to be pressed or it ASCII value.
- KeyUp: Releases a previously pressed key. This function can identify a given key to be pressed either by the character to be pressed or it ASCII value.
- MouseDown: Presses the left mouse button and keeps it down until MouseRelease is called.
- MouseRelease: Release a previously pressed left mouse button.
- MouseMoveTo: Incrementally moves the mouse from one pixel coordinates to another.

- PlayEventsFromFile: Reads events recorded into file and plays them on current screen.
- PressKey: Press and release a key identified by character or its ASCII value.
- RecordEventsToFile: Begins recording of all events performed by JSegMan effector to a file for playback at a later time.
- RightMousePress: Press and release the right mouse button, thus simulating a single click.
- SingleClick: Performs a single click of right mouse button.
- WriteWord: An aggregate function of KeyPress that allows JSegMan effector subsystem to press a set of characters one after another.

ScreenProcessor: This class provides most functionality for JSegMan sensor subsystem. It helps in identifying pixel group patterns and storing them in an internal data structure. Most of the functions described here are called internally to do most of the work, but are also provided as public API. The following are the API's provided by this class.

- CountEightNeighbours: Performs a counting of neighbor pixels to determine pixel neighbor number.
- FindBasicGeometry: This function triggers determining of various patterns in on-screen widgets. It internally also calls other functions described below.
- FindButtons: Find all buttons and store them in its internal representation.
- FindCheckBoxAreas: Find all check boxes and store them in its internal representation.

- FindHorizontalScrollbar: Find all horizontal scroll bars and store them in its internal representation.
- FindListBoxes: Find all list boxes and store them in its internal representation.
- FindTextAreas: Find all text areas and store them in its internal representation.
- FindVerticalScrollBars: Find all vertical scroll bars and store them in its internal representation.
- FindWord: Find a given work on screen and return its pixel coordinates.
- GetGroupsInside: Get a list of all groups contained inside a given pixel group.
- GetNeighborNum: Get the neighborhood number of a given pixel group.
- GetPixelPtr: Returns pointer to pixel at a given coordinate location.
- GetPixelPtrDown: Returns pointer to pixel below a given coordinate location.
- GetPixelPtrUp: Returns pointer to pixel above a given coordinate location.
- GetPixelPtrLeft: Returns pointer to pixel left of a given coordinate location.
- GetPixelPtrRight: Returns pointer to pixel right of a given coordinate location.
- GetPixelPtrUpLeft: Returns pointer to pixel above and to left of given coordinate location.
- GetPixelPtrUpRight: Returns pointer to pixel above and to right of given coordinate location.
- GetPixelPtrDownLeft: Returns pointer to pixel below and to left of given coordinate location.
- GetPixelPtrDownRight: Returns pointer to pixel below and to right of given coordinate location.
- GetWidth: Get width of screen

- GetHeight: Get height of screen
- SetNeighborNum: Allows to set neighborhood number of a pixel group. This value overrides the value computed by the system.

ScreenSource: This class allows for basic functions on the screen like capturing the screen and providing limited information about the image captures. The following is a description of API's made available by this class.

- CaptureScreen: Take screenshot of the entire or a part of the screen.
- GetR: Return R value of RGB given a particular pixel.
- GetG: Return G value of RGB given a particular pixel.
- GetB: Return B value of RGB given a particular pixel.
- GetHeight: Returns height of captured screen.
- GetWidth: Returns width of captured screen.

JSegMan as a programming environment

The JSegMan system provides complete access to the Windows user interface. As a result of this, using JSegMan one can interact with the user interface without using any Windows APIs.. This feature of JSegMan makes it attractive for running tests on new programs.

Say a new product has to be tested. Traditionally, it would require someone to sit down with the program and execute it giving it various inputs and comparing the outputs with the expected outputs. All such tests are a series of giving inputs to the program and then comparing the actual and expected outputs.

Now as we have a system that can identify the components of the user interface i.e. sensors and also components that can act on the user interface i.e. effectors, we can build programs using these sensors and effectors. Such programs can assume that they have all the knowledge of the user interface including the windows, window titles, buttons, check boxes, scroll bars, individual characters and characters grouped into words. Also its possible to act on the user interface with functions that allow to press a series of keys i.e. type a word, single click and double click mouse buttons.

All these functions provided by JSegMan serve as a base for a new set of programs to be written over the JSegMan system.

In order to create a system where the user is completely independent from the low level calls that interpret and manipulate the user interface, a JSegMan engine is used. The JSegMan engine's job is the continuously scan the user interface and make relevant information available to the user program(s). What we gain from this approach is that the user part of the code does not have to worry explicitly about scanning the user interface and do the processing. Instead, the user program will just focus on how it is going to use the user interface. Another advantage of this approach is that, if there are multiple programs who want to get information about the current state of the user interface, all of them will not be required to do the screen capture and low/high level processing and identifying of screen objects. Instead they will get that information from the JSegMan engine.

Similarly the actions like keystrokes and mouse button clicks are communicated to the user interface through the common JSegMan engine.

The remaining part of the sub-section illustrates how a sample user code will use the JSegMan engine. This is a simplistic demonstration of perceiving JSegMan as an engine. The JSegMan engine stores its findings about the user interface in a file. The user program finds out the information from this file. However, for performance reasons an efficient data structure like a hash table would be a better choice.

In order to start using the JSegMan engine, it has to be invoked by hand. Once the JSegMan engine is started, it continuously scans the user interface and put the information it finds on user interface into the common data structure, in current case - a file. The following user program will get the information from the engine by reading this file.

The code presented here is in Java.   This is a very simple demo, where this user program simply moves the mouse cursor over the objects that are found by the JSegMan engine one by one.

```
import java.util.*;
import java.io.*;
import java.lang.*;
import java.awt.*;

public class EngineDemo {
  public static void main(String[] args) throws Exception {

     /* The following is opening the file, 'widgets.log' in which
      *  the JSegMan engine stores its findings of the user interface
      * The engine stores the type of object (button, scrollbar etc.),
      *  and its top-left and bottom-right (x, y) co-ordinates of the
      *  objects founds.
      */
     File fp = new File("./","widgets.log");
     FileReader fs = new FileReader(fp);
     BufferedReader reader = new BufferedReader(fs);

     /* Make an instance of Robot object.
      * This can even be moved to the JSegMan engine
      */
     Robot bot = new Robot();

     int delay = 0;
     int flag = 1;
     String read =  new String();

     /* Let this user program run till there are no new objects */
     while(flag == 1)
     {
        /* Read findings of the JSegMan engine from the common data structure */
              read = reader.readLine();
              if(read == null) {
                  flag = 0;     /* If no new objects, set flag = 0 and exit */
                  System.exit(0);
              }

        /* Otherwise, read contents from the file */
              StringTokenizer st = new StringTokenizer(read);
```

```
               System.out.println(st.nextToken());
              while (st.hasMoreTokens()) {
                   String myString1 = st.nextToken();
                  int x = (int ) Integer.parseInt(myString1);
                   String myString2 = st.nextToken();
                  int y = (int ) Integer.parseInt(myString2);

                /* Move the mouse cursor to the objects found
                 *  by JSegMan engine one by one
                 */
                  if(x < 1024 && x > 0 && y < 768 && y > 0) {
                    bot.mouseMove(x, y);
                    bot.delay(1000);
                }
              }
      }

      System.out.println("Program Complete");
      System.exit(0);
  }
}
```

Listing 8: Sample code to point to all objects on screen identified by JSegMan sensor subsystem

JSegMan interaction with PDDL based planners

The Planning Domain Definition language is intended to represent the "physics" of a domain, in the sense it describes the current state of the domain, the actions possible in the current state, to what state those actions would lead us to. For the JSegMan system, PDDL is the glue between the JSegMan substrate and the planner. As most of the planners support PDDL, describing the desktop domain in PDDL makes it possible for any planner to be able to access the sensor/effector services provided by the JSegMan engine.

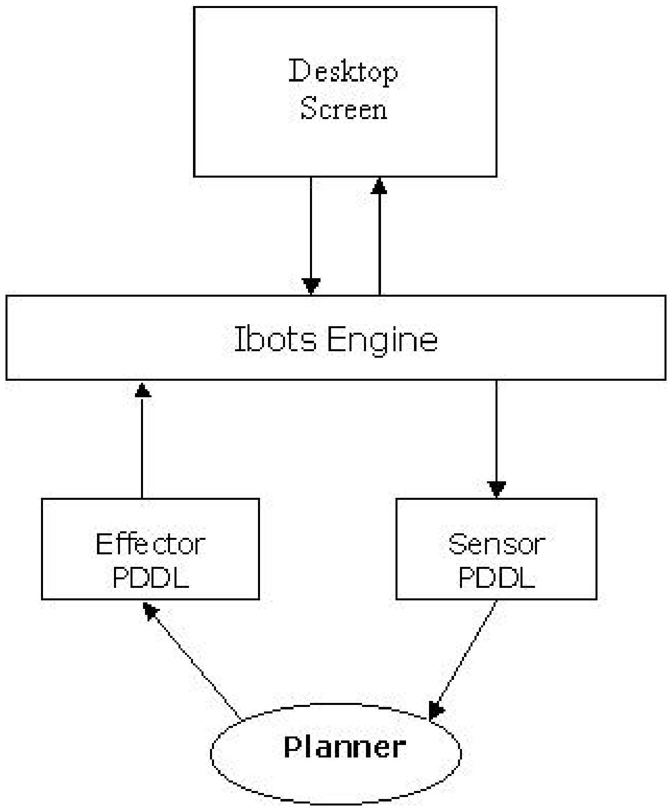


Figure 6: Architecture of interaction between user interface, JSegMan substrate and PDDL based planner

Sensor PDDL: The sensor PDDL is a text based data file written by the JSegMan engine and contains the current view of the desktop as output by the JSegMan engine. The planner that is acting on the desktop will read the current state of the desktop from this file. This includes the state of the windows, buttons, text boxes, radio buttons etc. in terms of their positions (for windows, buttons, etc), their current state i.e. if they are selected or not (for radio button, checkbox, listbox etc) and the possible states from there on (eg the item of a checkbox/radio button can be selected, selection of multiple items in a list etc.). The contents of this file are written in Planning Domain Definition Language and hence the information on the desktop domain can be easily communicated to the planner.

The planner is expected to read the sensor PDDL file only once, initially. After that the planner takes actions on the domain which are communicated to the system through the effector PDDL. One interesting thing here is that the planner does not need to read the current state of the domain again after doing actions on the domain. The planner will update its view of the domain by merging the views from the initial PDDL file and applying an incremental action it took on the domain. However one may consider synchronizing the planner view of the domain and the current view of the domain to avoid ambiguities that may occur between the action specified by the planner and the thing acted upon by the effector.

Listing 9 describes the domain 'desktop' with a Window defined as an object in the 'desktop' domain:

```
(define (domain desktop)
    (:requirements :strips :equality :typing :conditional-effects)
    (:types location object)
    (:constants (Window - object))
    ...
```

Listing 9: Definition of existence of a Window object in PDDL

Listing 10 is a representation of PDDL, which describes an action on the Window object - i.e. moving the Window from one location to the other. As one can see, it defines the parameters, preconditions and the effects of the action. The planner will take this action if and only if the specified pre-conditions are met. It then goes through the specified parameters - here the locations and then performs the action. In case of JSegMan, the planner will write out the action in Effector PDDL file as described in the next section. The effector will then read commands from the Effector PDDL and do the corresponding actions on the desktop resulting in the action actually being performed. At the same time the planner will update its view of the domain based on the actions mentioned in the effects: of the section.

```
(:action move-window
    :parameters (?initial_position ?new_position - location)
    :precondition (and (at Window initial_position) (not
(= ?initial_position ?new_position)))
    :effect (at Window ?new_position)
```

Listing 10: PDDL action describing moving of a Window from one position to another

In the above example, we did not consider other objects included inside the Window, like the buttons, scroll-bar, icons etc inside the window - which will move along with the window.

We now see and example were we describe an action in which we drag in an icon object into a window as if we want to copy the file represented by the icon as in Windows Explorer.

```
(:action move-in-window
    :parameters (?x - Icon ?new_position - location)
    :precondition (not (= ?x Window)
    :effect (when (and (at ?x ?new_position) (at Window ?new_position))
                   (in ?x)) )
```

Listing 11: PDDL action describing drag-and-drop behavior of dragging an icon into a window

As we can see that in above example the PDDL defines a precondition to check if the Icon object and the Window are not the same thing - as it is not possible to move an object into itself.

This is a fine example that shows that we have to be very ver careful in describing the domains using PDDL and we need to describe the current states, preconditions and the effects extensively else the planner may be conveyed incorrect information and hence may come up with an infeasible plan.

We finally look at another action that takes out an object from the Window.

```
(:action move-out-window
    :parameters (?x - Icon)
    :precondition (not (=?x Window))
    :effect (not (in ?x))
```

Listing 12: **: PDDL action describing drag-and-drop behavior of dragging an icon out of a window**

This example is very similar to the PDDL that specified the action to put an Icon into a Window.

Effector PDDL: The effector PDDL contains information to be communicated from the planner to the JSegMan engine. Like the sensor PDDL, the effector PDDL is also a text based data file in PDDL syntax.

```
(:action move-mouse ...
(:action click-mouse ...
(:action double-click-mouse ...
(:action move-window...
(action click-start ...
```

Listing 13: PDDL file with a list of actions to be performed sequentially

The content of this includes information about where the planner wants the mouse to be or what characters should be typed on screen at a particular location etc.

The Effector PDDL may be specified like the Sensor PDDL using the kind of actions, or it may use more high level actions to specify actions which may include other sub-actions like locating the window to be moved, or locating the 'Start' button on the screen and then clicking on it.

Planner: The JSegMan engine and Sensor/Effector PDDL place the planner in the driver's seat. Now with these components, the planner is aware of the desktop domain and gives back commands to JSegMan engine as to what actions should be taken on the current domain. Thus the planner is completely independent of the nitty gritty details related to capturing the screen, identifying the objects etc. which is handled by the JSegMan engine and the planner communicates with the engine using PDDL. The knowledge of a screen object, like a window, should be identified by a particular arrangement of pixels on screen and the task of identifying it lies with the ibots sensor sub-system.

Chapter 4

Evaluation

There are lots of similarities between AI planning assumptions and properties imposed by user interface design guidelines. St. Amant[35] presents an overview of these similarities as shown in the following table.

Table 3: Similarities between classical planning assumptions and user interface design guidelines

Classical planning assumptions	**User interface design guidelines**
Deterministic effects. The effects of an action can be guaranteed to hold after its execution.	*Consistency.* A user action under a well-defined set of conditions should always produce the same predictable effect.
Exogenous events. The only changes in the Environment are due to actions of the Planner.	*User control.* From a conventional (non-agent-based) perspective, user control over the interface should be nearly absolute.
Passage of time. Plans remain appropriate In the interval between their generation and Their execution.	*Perceived stability.* In conventional user interfaces, the user should be able to depend on stability as time passes.
Reversible actions. When interleaving plan Generation and execution, irreversible Actions can be delayed to avoid dead-ends.	*Forgiveness*s. Actions should generally be reversible through an undo capability.

State information. Complete information is Available about the initial state of the world.	*Continuous representation.* Objects/actions of interest should be continuously visible.
Concurrent actions. Operators are atomic And non-overlapping; no parallel execution.	*Serial execution.* User decision-making and attention focuses on one task at a time.

By presenting the desktop environment to a planner based agent and interacting with the desktop without use of API's, this work presents a unique model of interaction between the user interface and agent. The user interface of an application thus becomes the operating environment for the interface agent, thus enabling the agent to be able to interact with any off-the-shelf application simply using its interface just like a human user would do.

Limitations of using planning domains for interface agents

While working with planners in desktop domain, several limitations were observed in the current implementation of planning systems for them to work well in desktop domain. A traditional planning environment consists of an initial state, goal state and a set of possible steps with pre-conditions and post-conditions. The planner then starts execution in the initial state and moves to goal state with the knowledge of conditions on intermediate steps. The following are the assumption [28] in a standard AI planning paradigm and how these assumptions impact and conflict with use of planning systems in desktop domains.

- There is a single causal agent, and this agent is the planner. This assumption may be true for traditional planning environments, but for the desktop environment it is not true. A desktop environment has many asynchronous events, including pop-ups, message alerts, error conditions etc. It is more of a problem in desktop environments, because the environment is multitasking, hence the asynchronous events that occur may not even be in any way related to the task under control of the planner. In order to overcome this limitation, the planner could either try to get out of the unknown state by searching for an "OK" button or close an unknown window by pressing the close button on the window, in order to suppress the error, or it may abort the current plan and start from scratch.
- The planner is given a well defined goal, which remains fixed over the course of planning. In the desktop domain application of planner this assumption may be a hindering issue if the planner is trying to control multiple applications through the JSegMan programmable substrate, and its priorities of application control change during its execution. This could be true, especially if the planner is trying to model the human behavior. Human users of desktop environments do multitasking and it is common for goals to change, and to move from one activity to another activity.
- The planner is assumed to have functionally complete and accurate knowledge of its starting situation. This assumption may not hold true for use of planning systems using JSegMan programmable substrate. JSegMan makes available only the present state of the desktop domain to its user applications. So the past knowledge of desktop environment state may not be available to the planner. However this limitation can be overcome by the planner, by doing a little initial investigation of the initial state of

the desktop domain and make sure that the state of the desktop is consistent with the initial state as assumed by the planner.

- The planner is assumed to possess required knowledge to accurately model the world. To a great extent, human input it required, at least for the first time to build the knowledge in the planner and JSegMan sensor substrate to identify different widgets and their capabilities. Once the system has the knowledge of all the widgets in the GUI, it is possible for the system to work its way around other similar systems in a different setting. This, however is a fair assumption and applies equally to desktop and non-desktop domain applications of planners.
- The planner is assumed to possess the resources (time and memory) required to use this model to reason about the possible worlds associated with the different courses of action that might be pursued. Planning is, in general, an intractable problem. And, if the world is complex then modeling the world may also be intractable. This assumption is simply a warning to restrict the research to tractable planning domains. The desktop domain, at the first impression may seem tractable as long as there is a single application to be controlled, but it soon becomes quite complex with today's multi-tasking, multi-user and increasingly complex user interfaces.
- Planners, by their design, look at their entire execution environment with the same level of attention. This is not true with the desktop domains though. While working with desktop interfaces, the users have a point of focus where they concentrate on instead of looking at all parts of the desktop with equal attention.

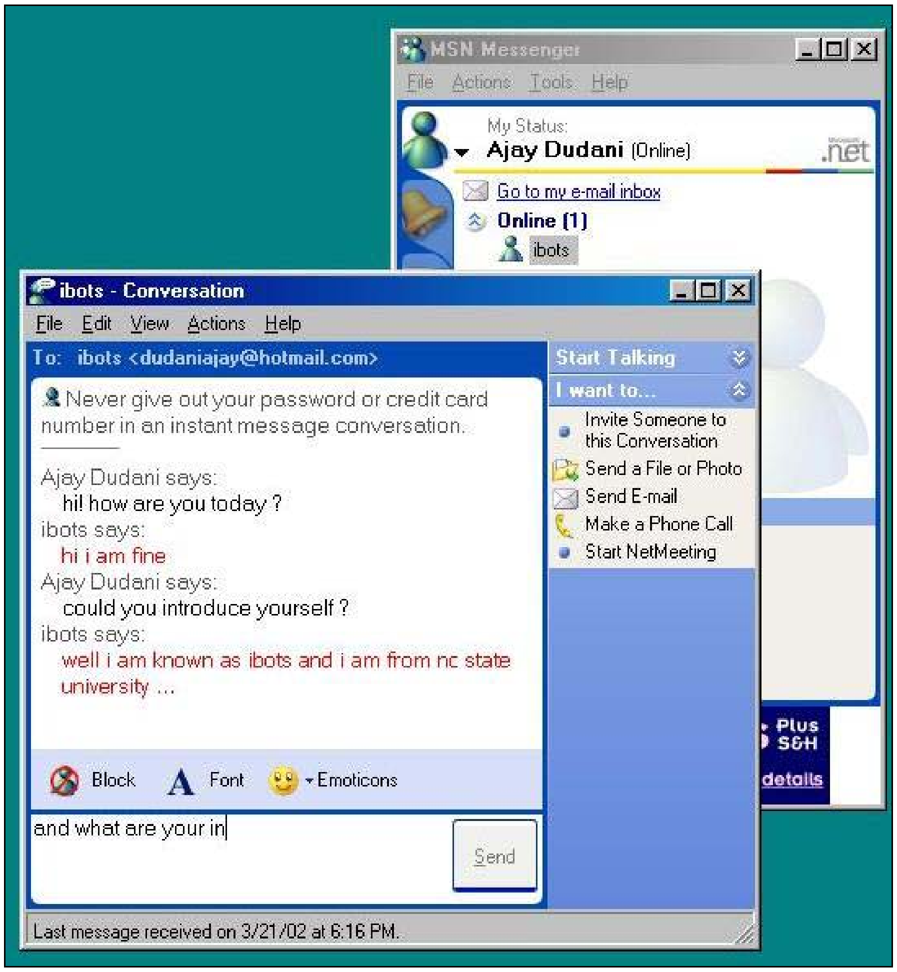
MSN Chatbot

The MSN Chatbot application is based on top of JSegMan programmable substrate. The chatbot use JSegMan API's in order to identify the list of online friends on MSN Chat, send messages to a particular friend and read messages from friends. The focus in this application was use of JSegMan in the chat application rather than the natural language processing aspect of chat [31].

There has been a lot of interesting research in the areas of natural language processing and intelligent exchange of messages. The research in this area, to a great extent is driven by the Turing test. The MSN chatbot work in this thesis, however, is used to demonstrate that JSegMan can manipulate any off-the-shelf application and the nature of interaction with the application is programmable.

The MSN chatbot application is written in Java and uses the JSegMan substrate as sensors and effectors to understand the MSN Chat interface. When the chatbot application is invoked, initially it requests JSegMan to take a screenshot of the entire desktop screen and perform its image processing algorithms on it to identify the MSN Chat window. It then selects a chat friend to start chat with, or wait for a message from an online friend. Once the conversation starts, the applications knows the messages send by chat friend through JSegMan sensors and responds back using JSegMan effectors. The following paragraph describe the action taken by the agent and JSegMan substrate to achieve the goal of interacting with MSN Chat by direct manipulation of its interface.

Read screen: This action is taken when chat application first starts up and repeatedly during the chat process. JSegMan captures the screen, performs image processing on captured screen and creates/updates internal data structures that store information on color, size and co-ordinates of various widgets on the screen.



Never give out your password or credit card number in an instant message conversation.

Ajay Dudani says:
hi! how are you today ?
ibots says:
hi i am fine
Ajay Dudani says:
could you introduce yourself ?
ibots says:
well i am known as ibots and i am from nc state university ...

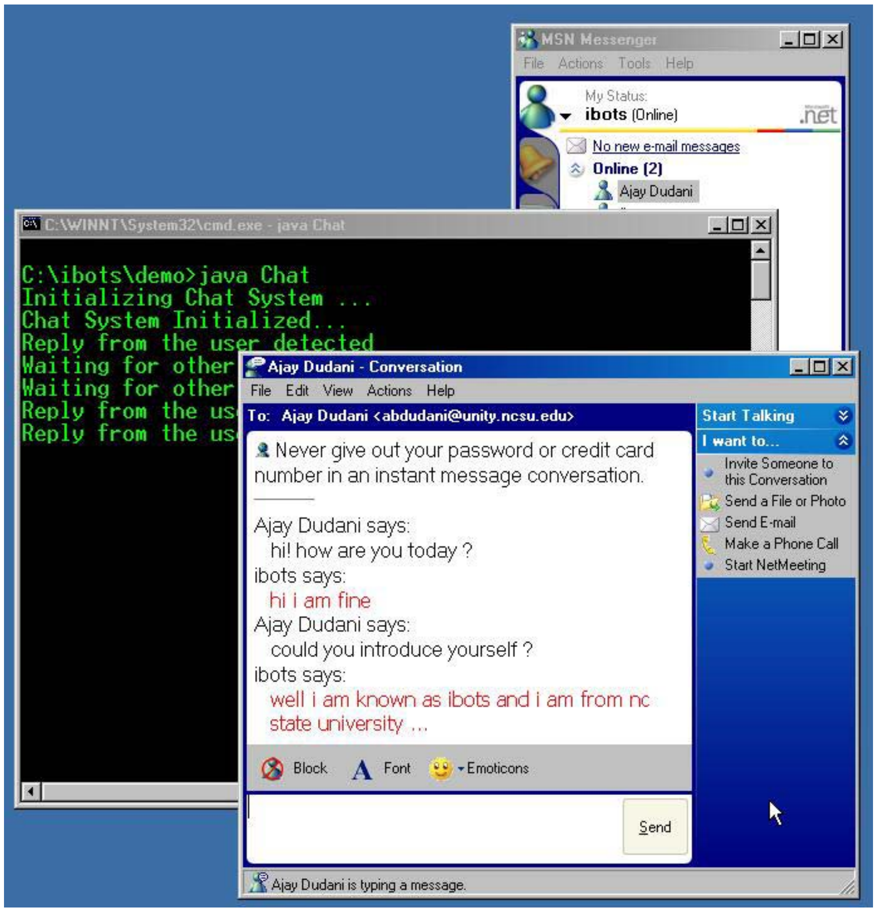
and what are your in

Last message received on 3/21/02 at 6:16 PM.

Figure 7: Human user end of MSN Chatbots demonstrating JSegMan working with off-the-shelf application

Starting chat with an online friend: The application requests JSegMan substrate to find the name of a particular chat friend in the MSN Chat window. JSegMan responds back to the application with the display co-ordinate information of the particular friend. Once the application has this information, the chat application can call the JSegMan effector sub-system to move the mouse to that particular co-ordinates and double-click on the name in order to start the chat. Thus, the intelligence and knowledge of functionality of off-the-application remains with the applications using the JSegMan substrate.

Read message: Once the chat application has initiated a chat with an online friend, it requests the messages exchanged with this friend through JSegMan substrate. The JSegMan substrate identifies all the text in the chat window and returns to chat application with the text. The natural language processing and intelligent response actions are left for the chat applications to figure out. Once this text is passed on to the chat application, it can either send back unintelligent responses or connect to a natural language processing intelligent chat bot like A.L.I.C.E [29] and send back responses based on A.L.I.C.E's responses to it.



```
C:\ibots\demo>java Chat
Initializing Chat System ...
Chat System Initialized...
Reply from the user detected
Waiting for other
Waiting for other
Reply from the us
Reply from the us
```

Never give out your password or credit card number in an instant message conversation.

Ajay Dudani says:
hi! how are you today ?
ibots says:
hi i am fine
Ajay Dudani says:
could you introduce yourself ?
ibots says:
well i am known as ibots and i am from nc state university ...

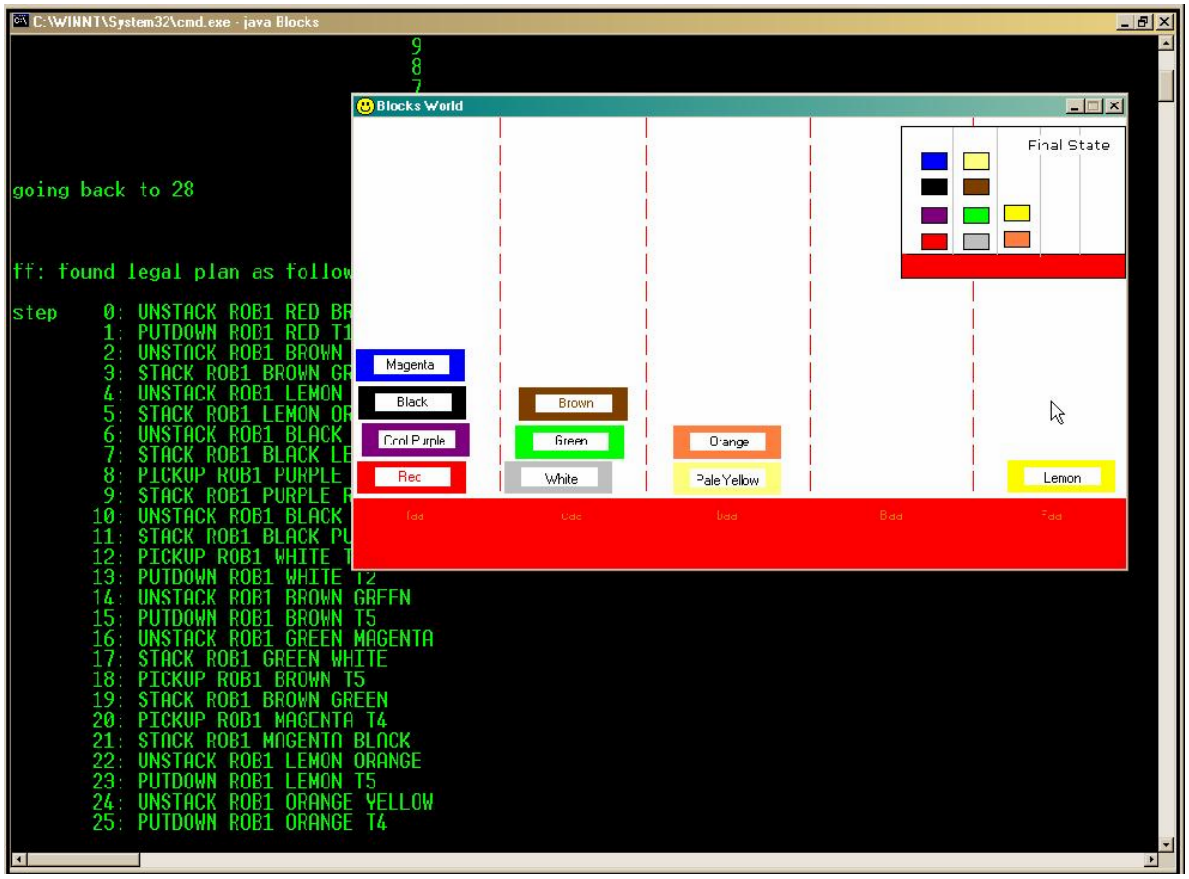
Figure 8: JSegMan end of MSN Chatbots demonstrating JSegMan working with off-the-shelf application

Send message: Once the chat application has a response it wants to send out to the chat friend, it calls on the JSegMan effector to select the appropriate chat window and type appropriate keystrokes to send out the message.

Blocks Work Problem in PDDL

In the late sixties and seventies the blocks world problem became a popular domain for AI research. The key to success was the representation of the world completely. Search techniques were then used for planning in this well understood world.

In this thesis, blocks world problem is presented and solved with the help of JSegMan and a PDDL based planner. The blocks world problem is represented by software as shown in Figure 9. The end-user can move the different colored blocks around in the application and move it from one stack to another. The final goal is to being the blocks in the state as shown in the small figure in top right corner in Figure 9. For this problem, the final state of the system is hardcoded in the planner goal. However, the initial state of blocks is not known and is determined at runtime using JSegMan sensors. As the planner starts generating steps to solve the blocks world problem, an application reads its steps and instructs the JSegMan effectors to act accordingly thus leading to the final state. The following paragraph describes steps involved in the PDDL planner and JSegMan while solving the blocks world problem.



```
                                         9
                                         8
                                         7



going back to 28



ff: found legal plan as follow

step    0: UNSTACK ROB1 RED BR
        1: PUTDOWN ROB1 RED T1
        2: UNSTACK ROB1 BROWN
        3: STACK ROB1 BROWN GR
        4: UNSTACK ROB1 LEMON
        5: STACK ROB1 LEMON OR
        6: UNSTACK ROB1 BLACK
        7: STACK ROB1 BLACK LE
        8: PICKUP ROB1 PURPLE
        9: STACK ROB1 PURPLE R
       10: UNSTACK ROB1 BLACK
       11: STACK ROB1 BLACK PU
       12: PICKUP ROB1 WHITE T
       13: PUTDOWN ROB1 WHITE T2
       14: UNSTACK ROB1 BROWN GREEN
       15: PUTDOWN ROB1 BROWN T5
       16: UNSTACK ROB1 GREEN MAGENTA
       17: STACK ROB1 GREEN WHITE
       18: PICKUP ROB1 BROWN T5
       19: STACK ROB1 BROWN GREEN
       20: PICKUP ROB1 MAGENTA T4
       21: STACK ROB1 MAGENTA BLACK
       22: UNSTACK ROB1 LEMON ORANGE
       23: PUTDOWN ROB1 LEMON T5
       24: UNSTACK ROB1 ORANGE YELLOW
       25: PUTDOWN ROB1 ORANGE T4
```

Figure 9: Solving blocks world problem with JSegMan and PDDL based planner

Once we have the blocks world in its initial state, the application to solve the blocks world problem is invoked. At startup, this application requests for a screenshot and identification of objects in the blocks world problem. It gets an understanding of the initial state of blocks world and generates the problem file that will be used as input to Fast Forward (FF) PDDL planner. The problem file (Listing 14) along with domain definition file (Listing 15) is given as input to FF which generates the steps to reach the goal state from initial state. These steps are output to a file by FF. The solver application reads these steps from the file and instructs the JSegMan effectors to move the blocks accordingly in order to reach the goal as specified by the FF planner.

```
(define (domain blocksworld)
(:predicates (clear ?x)
             (on-table ?x)
             (arm-empty)
             (holding ?x)
             (on ?x ?y))

(:action pickup
  :parameters (?ob)
  :precondition (and (clear ?ob) (on-table ?ob) (arm-empty))
  :effect (and (holding ?ob) (not (clear ?ob)) (not (on-table ?ob))
               (not (arm-empty))))

(:action putdown
  :parameters  (?ob)
  :precondition (holding ?ob)
  :effect (and (clear ?ob) (arm-empty) (on-table ?ob)
               (not (holding ?ob))))

(:action stack
  :parameters  (?ob ?underob)
  :precondition (and (clear ?underob) (holding ?ob))
  :effect (and (arm-empty) (clear ?ob) (on ?ob ?underob)
               (not (clear ?underob)) (not (holding ?ob))))

(:action unstack
  :parameters  (?ob ?underob)
  :precondition (and (on ?ob ?underob) (clear ?ob) (arm-empty))
  :effect (and (holding ?ob) (clear ?underob)
               (not (on ?ob ?underob)) (not (clear ?ob)) (not (arm-empty)))))
```

Listing 14: PDDL domain definition file for blocks world problem

The domain definition file for blocks world problem is shown in Listing 14. There are four operations defined in this file. The pickup and putdown operations are used to define lifting and putting down of a block on a table. Similarly the stack and unstack operations are used to define lifting and putting down of block on another block or a stack of blocks. Each operation is defined by a list of parameters involved in the operations, preconditions required for the operation to be executed and postconditions that represent the changes in the world as a result of the operation. The changes along with the state of world before operation represent the new state of world that all further operations will operate on.

```
(define (problem tower4)
   (:domain blocksworld)
   (:objects a b c d )
   (:init (on-table a) (on-table b) (on-table c) (on-table d)
          (clear a)  (clear b) (clear c) (clear d) (arm-empty))
   (:goal (and (on a b) (on b c) (on c d) )))
```

Listing 15: PDDL problem definition file for a sample blocks world problem

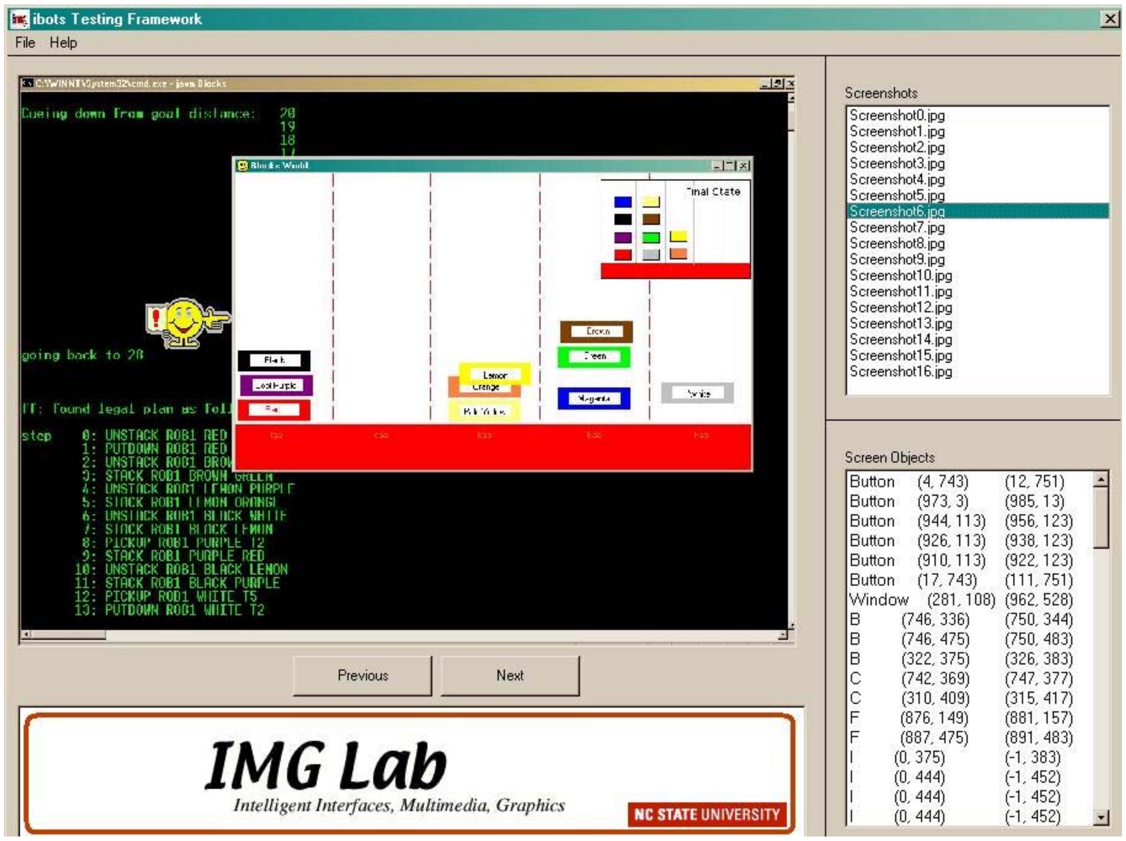
The problem file for blocks world problem is shown in Listing 15. The problem file includes a universal set of objects involved in the planning problem along with initial state and final state that is to be achieved by the planner. This problem file describes a problem where four blocks are placed on the table and as a final state, they need to be stacked on top of one another. The planner would use the operations - pickup, putdown, stack and unstack, defined in operations file to reach from initial state to final state.

JSegMan in GUI testing environment

JSegMan, in a way, is an extension to the functionality provided by Java. It allows for moving of mouse and key strokes and adds identification of screen widgets along with that. Since JSegMan is independent of the underlying operating system, it can be used for GUI testing in different environments once the basic widget definitions of that environment is in place in JSegMan.

GUI regression testing involves determining the test cases and test inputs along with correct test outputs. The test cases are then executed and verified with correct output. The failed tests are then analyzed for further investigation.

JSegMan provides a convenient environment for this type of regression testing. Once the test cases have been identified, a plan can be written to execute it. The plan captures details of the test case including starting state, sequence of steps to go through and end state of a test. This way GUI testing can be represented as a planning problem, allowing the test case to decide between multiple paths in its execution and to handle exception conditions. One of the important aspects of regression testing is to be able to isolate the failed test cases and then analyzing them to determine where they went wrong. This is possible with JSegMan system. The plan representation of the test case can request for screenshots to be taken as it moves ahead step by step executing the plan. This screenshot is stored along with a log file on the disc, which can be later loaded in a test utility later on to closely study every widget in every state of test case execution. The GUI test utility allows the tester to be able to step through or jump to different states of test case execution and be able to point out various widgets available in different steps. Following is a demonstration of the GUI test utility for the blocks world problem that was executed using a planner running on the JSegMan substrate.



```
Cueing down from goal distance:   20
                                  19
                                  18
                                  17

going back to 20

IT: found legal plan as foll

step     0: UNSTACK ROB1 RED
         1: PUTDOWN ROB1 RED
         2: UNSTACK ROB1 BROW
         3: STACK ROB1 BROWN GREEN
         4: UNSTACK ROB1 LEMON PURPLE
         5: STACK ROB1 LEMON ORANGE
         6: UNSTACK ROB1 BLACK WHITE
         7: STACK ROB1 BLACK LEMON
         8: PICKUP ROB1 PURPLE T2
         9: STACK ROB1 PURPLE RED
        10: UNSTACK ROB1 BLACK LEMON
        11: STACK ROB1 BLACK PURPLE
        12: PICKUP ROB1 WHITE T5
        13: PUTDOWN ROB1 WHITE T2
```

```
Screenshot0.jpg
Screenshot1.jpg
Screenshot2.jpg
Screenshot3.jpg
Screenshot4.jpg
Screenshot5.jpg
Screenshot6.jpg
Screenshot7.jpg
Screenshot8.jpg
Screenshot9.jpg
Screenshot10.jpg
Screenshot11.jpg
Screenshot12.jpg
Screenshot13.jpg
Screenshot14.jpg
Screenshot15.jpg
Screenshot16.jpg
```

```
Button   (4, 743)     (12, 751)
Button   (973, 3)     (985, 13)
Button   (944, 113)   (956, 123)
Button   (926, 113)   (938, 123)
Button   (910, 113)   (922, 123)
Button   (17, 743)    (111, 751)
Window   (281, 108)   (962, 528)
B        (746, 336)   (750, 344)
B        (746, 475)   (750, 483)
B        (322, 375)   (326, 383)
C        (742, 369)   (747, 377)
C        (310, 409)   (315, 417)
F        (876, 149)   (881, 157)
F        (887, 475)   (891, 483)
I        (0, 375)     (-1, 383)
I        (0, 444)     (-1, 452)
I        (0, 444)     (-1, 452)
I        (0, 444)     (-1, 452)
```

Figure 10: GUI Testing environment for planner solving the blocks world problem

As shown in the above figure, the top pane on the right side gives a list of screenshots that were taken during the execution of the program by the planner. The bottom pane on the right shows all the widgets that were identified in the selected screenshot. On selecting a particular widget, the little yellow smiley pointer points to that particular widget on the screenshot image. Such an environment will allow the GUI tester to step through each step and identify the details on failure of test cases.

System Evaluation

The JSegMan substrate was implemented in Java, and a similar implementation of this substrate, SegMan, exists in C++. The Java implementation of the JSegMan substrate is about 4000 lines of code. To measure the performance of the system developed in Java, a set of 25 runs was performed on a Dell P4 (1700 MHz, 256 MB RAM) running Windows 2000 operating system. The mean processing times (in ms) over a representative set of desktops and standard deviation observed are reported below.

Table 4: Comparison of JSegMan (Java) with its SegMan (C++)

Function	**Mean time (C++)**	**Standard Deviation (C++)**	**Mean time (Java)**	**Standard Deviation (Java)**
Screen capture and processing	1435	28	1720	24
Finding particular text on screen	1532	29	1815	27
Move mouse from one location to another	230	8	285	11
Press keystrokes	190	5	240	7

A good deal of the computation for these values is shared between the functions and can be cached across function calls, however, making the average cycle time for screen processing tasks somewhere between one and two seconds.

The times indicated in Table 4 are calculated by an application using JSegMan interface, and hence include time for function calls to JSegMan substrate. Although these times do not accurately reflect processing times taken by humans, especially for tasks of identifying objects on screen.

However, the humans interact with user interfaces much faster than the times indicated in Table 4. Human interaction times indicated for these tasks are less than one second. In this regard, the JSegMan system is too slow to perform the task of observing user actions and learning from it or collaborating with users.

The following is a list of widgets identified by JSegMan sensor substrate:

- Upper case characters A-Z
- Lowercase characters a-z
- Numbers 0-9
- Windows logo used in Start button
- Minimize, maximize and close buttons placed at top right corner of a standard window
- Up arrow and down arrow on a vertical scroll bar
- Right arrow and left arrow on a horizontal scroll bar

- Resize tool at bottom right corner of a standard window used to resize a window
- Radio button and check button
- Standard windows and dialog boxes
- Drop down list box, text box and text area

The effector module of JSegMan can move the mouse to/from any pixel on the screen. As for the keystrokes, all the keys on a standard 101 keyboard are supported.

Chapter 5

Conclusion

Goals Revisited

Usually agents interact with application using application programming interfaces rather than working with actual interface of off-the-shelf application using it interfaces. By use of APIs to interact with an application valid and significant results have been produced, however it is not accurate enough for cognitive modeling. Building a perceptual and motor extension to a cognitive model or intelligent application such that it can interact with the desktop interface only using the information and controls available to the end-user through the user interface is quite appealing. An early system, SegMan, is based on this approach, but this system was written specifically to work with Windows operating system only. As a part of this thesis work, an implementation of JSegMan substrate is done in Java, which is capable of running not only under Windows, but also for KDE and GNOME desktops under XWindows environments. The system is known to work under Windows and Linux, but should work on other operating systems, which have a Java Virtual Machine implementation available on them.

This system also demonstrates use of PDDL, as a domain definition language for desktop domain. The PDDL representation of desktop domain is used by Fast Forward problem.

This is demonstrated by using planner output from FF to solve the blocks world problem using JSegMan substrate.

Finally, this work also demonstrated use of JSegMan programming environment and its use with planners for GUI testing.

However, the system does not achieve the goals of observing and helping users. One of the main reasons for this being the difference in speed of image processing and recognition as done by the system compared to humans.

System Limitations

The JSegMan system works well with the limited set of widget database added to its sensor subsystem. Many other widget definitions can be added to this database to allow JSegMan to identify them during its image process, however there are certain limitations to the nature of such widgets that can be identified by JSegMan sensor subsystem.

Patterns in desktop cannot be identified by JSegMan substrate. For example, if there exist a set of items like icons as a horizontal or vertical list, JSegMan is not able to identify the pattern and look for objects following a similar pattern. This task can however be achieved by the application using JSegMan substrate.

The sensor subsystem is designed to work in desktop environments where images it has to process are generated by the operating system and have sharp edges with well defined shape and size. As a result, the JSegMan sensor subsystem is not efficient in identifying objects in a screenshot of real world environment or gaming environments. Overall, scalability of JSegMan substrate outside the desktop environment is an issue.

The time required for image processing of the desktop may be unacceptable for some applications that want to use JSegMan substrate, this is especially true for gaming environments. The main reason for this is that JSegMan sensor substrate uses pixel level processing. An object-level processing model may lead to a more efficient system.

Although it is possible to share the JSegMan sensor, performing image processing across various applications, it does not hold true for the JSegMan effector subsystem. If two different applications try to use the JSegMan effector mouse or keyboard simultaneously, it may work but will not lead to desired results. This aspect of sharing of JSegMan effector currently needs to be handled outside JSegMan system.

Future Directions

There are a couple of directions in which this work can be extended in the future. One is improvement in image processing sub-system thus leading to a faster implementation. This will allow work to be extended to be able to watch the users, learn from user actions and apply its own knowledge about the desktop environment to help the users.

Another direction for this work is extension of the link between user-interfaces and agents to domains beyond the desktop domain. This includes three dimensional environments and games. Some work has already been done in this direction by Shah

[33] and Rajyaguru[34] as a part of their Masters thesis at North Carolina State University, Raleigh under the direction of Dr. Robert St. Amant.

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