A Comprehensive Framework for Testing Graphical User Interfaces

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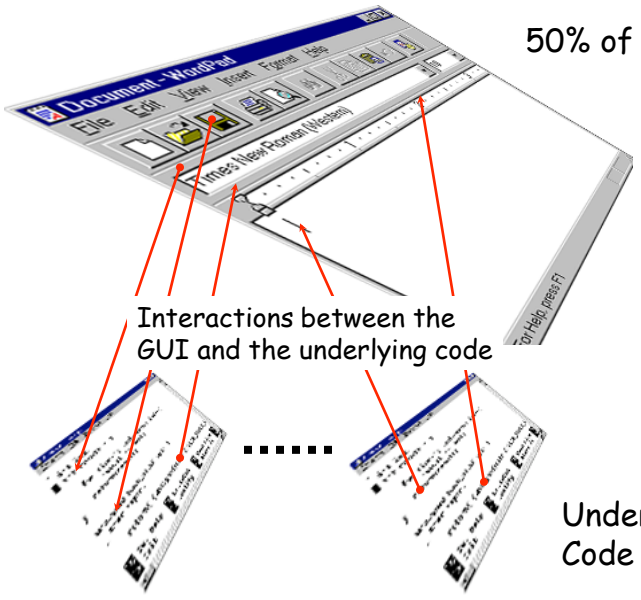
(with minor edits from original)

Research focus



Challenges of GUI Testing

- What is the test input to the GUI?
  - (Test case generation)
- How much testing is enough?
  - (Test coverage)
- Is the GUI executing correctly during testing?
  - (Test oracles)
- What test results can be salvaged from the previous test runs to test a new version?
  - (Regression testing)
- How to represent the GUI to handle all the above?
  - (Representation)

Overview of the Framework

- GUI representation
- Test case generation
- Test Oracles

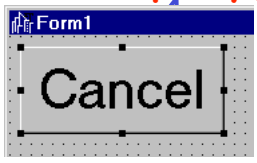
Creating the GUI Model

- Modeling
  - GUI's state in terms of objects & their properties
  - Events as state transducers
  - GUI's hierarchical structure
    - Classifying events

Modeling the GUI's State

- A GUI at time T is modeled using:
  - Objects $O = \{o_1, o_2, o_3, \ldots, o_m\}$
  - Properties $P = \{p_1, p_2, p_3, \ldots, p_l\}$, where p_i is an n_i-ary ($n_i >= 1$) ***Boolean*** relation of the form:

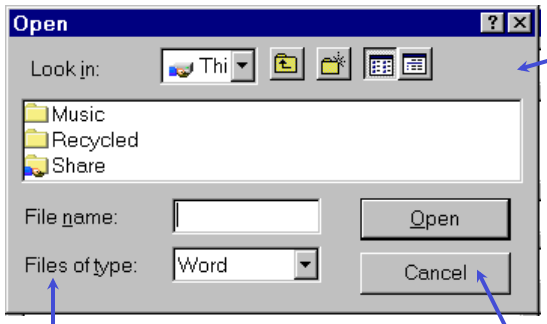
Property(o_i, o_a, o_b, ….,o_x, value) — True/False



Caption(Button, "Cancel")

GUI's state: $S = p_1 \wedge p_2 \wedge p_3 \wedge \ldots \wedge p_n$

Example: Modeling the GUI's State



Form1

WState(Form1, wsNormal)
Width(Form1, 1088)
Scroll(Form1, TRUE)

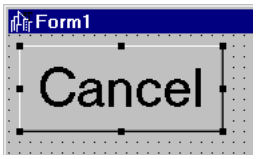
Label1

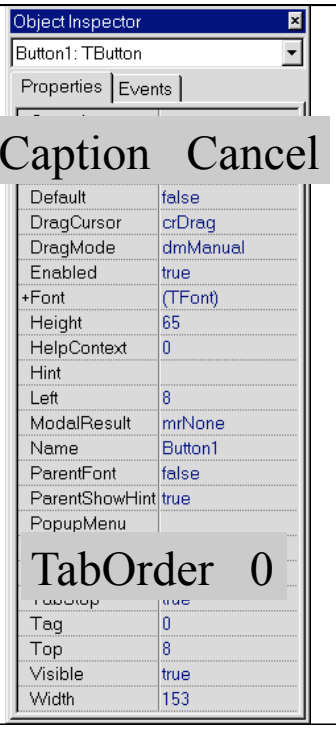
Align(Label1, alNone)
Caption(Label1, "Files of type:")
Color(Label1, clBtnFace)
Font(Label1, (tfont))

Button1

Caption(Button1, Cancel)
Enabled(Button1, TRUE)
Visible(Button1, TRUE)
Height(Button1, 65)

All Properties of Button1





Determining Objects & Properties

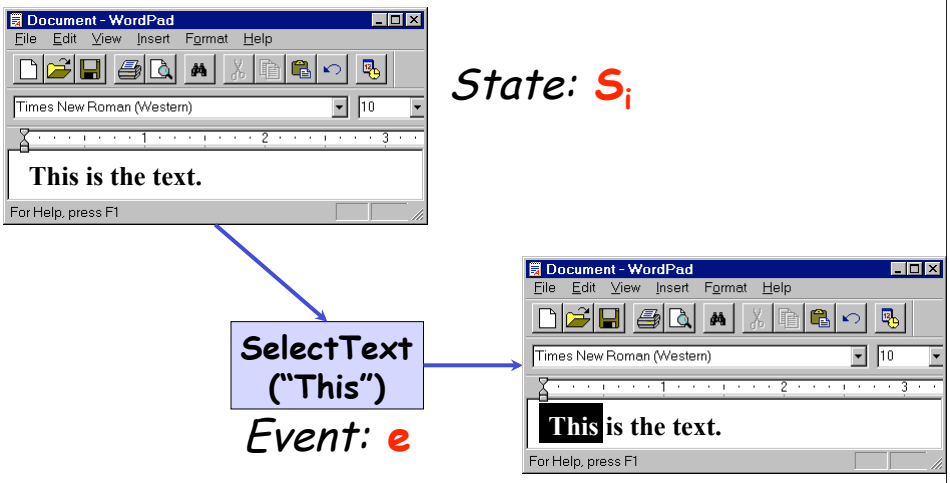
- Specifications (reduced set)
  - GUI being tested
- Toolkit/language (complete set)
  - All available properties

Now we know how to represent the GUI's state

GUI Events

- GUI's state is not static
- Events change the GUI's state
- Events E = $\{e_1, e_2, e_3, \ldots, e_n\}$, associated with a GUI are functions from one GUI state S_i to another state S_j
- Notation: $S_j = e_1(S_i)$

Example: An Event



$S_j = e(S_i)$

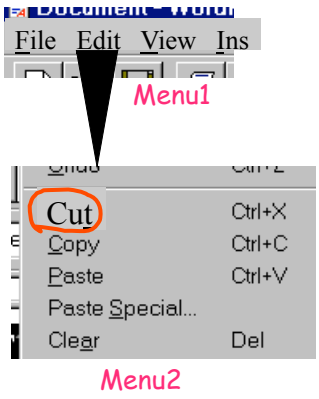
Representing Events

- Infeasible to give exhaustive specifications of the state mapping for each event
- No set limit to the number of objects a GUI can contain at any point in time
- There can be infinitely many states of the GUI
- Model the GUI events using operators, which specify their preconditions and effects

Operators

- An Operator is a 3-tuple
  - <Name, Precondition, Effects>
  - Name identifies an event and its parameters
  - Precondition is a boolean expression
  - Effects is a sequence of ADD and DEL commands on properties
- Operator Op is applicable in any state S_i in which:
  - The Precondition(Op) holds
- The resulting state S_j is determined by using Effects(Op)
  - ADD commands add their properties, and
  - DEL commands delete properties,
  - in the specified order

Operator Example



Operator :: *CUT*
Precondition:
isCurrent(Menu2).

Effects:
FORALL Obj in Objects
Selected(Obj) ⇒
ADD inClipboard(Obj)
DEL onScreen(Obj)
DEL Selected(Obj)
ADD isCurrent(Menu1)
DEL isCurrent(Menu2).

Primitive Operators

Now we know how to represent the events of the GUI

Model GUI Hierarchically

- Hierarchy
  - GUIs are designed as a hierarchy of objects
  - Objects are reused from libraries
  - Hierarchical model makes testing efficient
- Classification
  - A new classification of events aids in creating the hierarchical model of the GUI

Classifying Events

- Opening menus
  - Menu-open events
- Opening modal windows
  - Restricted-focus events
- Opening modeless windows
  - Unrestricted-focus events
- Interacting with underlying software
  - System-interaction events

GUI Modeling Steps

- From the GUI's specifications (formal/informal),
  - Identify objects and properties
  - Create operators for GUI events
  - Using the event classification, create hierarchical and system-interaction operators
    - Details later

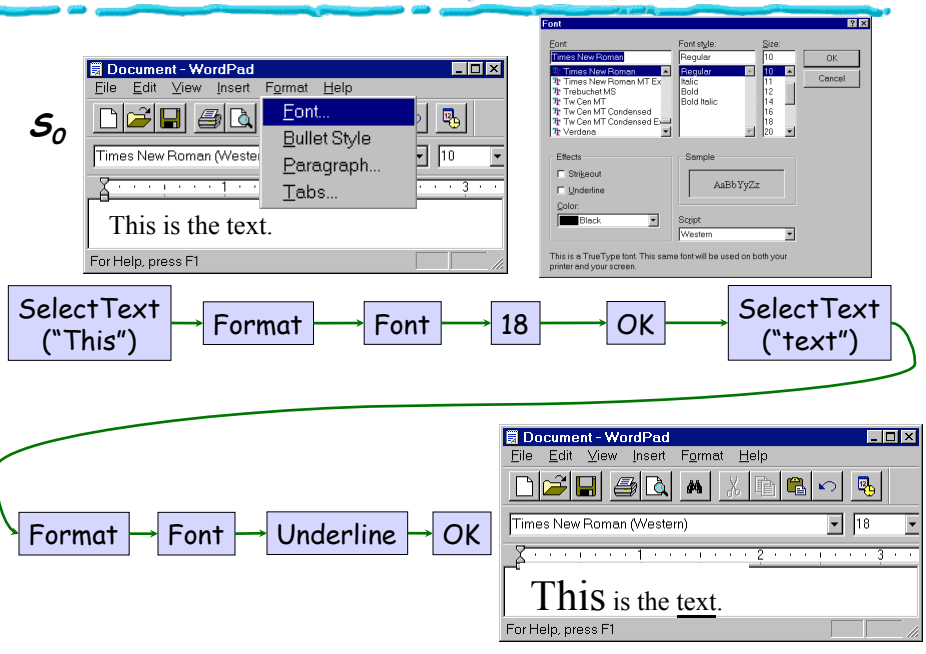
Generating GUI Test Cases

- Individual user events are not enough
  - Sequences of user events lead to different states
- Test case: sequence of user events

Definition: GUI Test Case

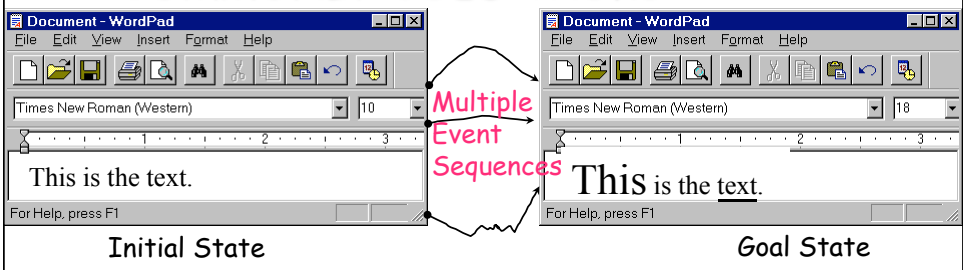
- Event is defined as:
  - $S_j = e(S_i)$
- *legal event sequence*
  - $e_1;e_2;e_3;\ldots;e_n$ is a legal event sequence
  - for state S_0
  - iff Exists $S_0;S_1;S_2;\ldots;S_n$ such that $S_i = e_i(S_{i-1})$, $1 <= i <= n$
- *A GUI test case is a pair*
  - $(S_0, e_1;e_2;e_3;\ldots;e_n)$
    - S_0 is any state, and
    - $e_1;e_2;e_3;\ldots;e_n$ is a legal event sequence

A Test Case for WordPad



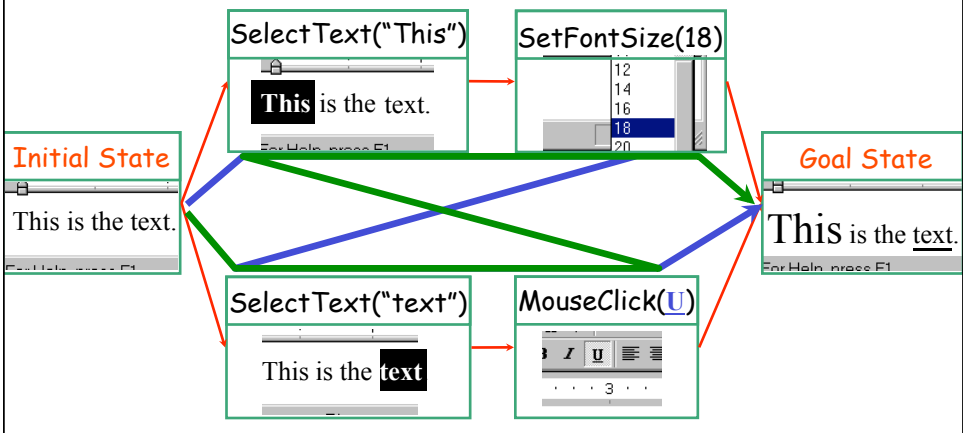
Selecting Test Sequences

- Infinitely many
- Randomly choose sequences
- Expert chooses sequences
- Automatically generate events for COMMONLY USED TASKS



Initial State Goal State

A Plan for a GUI Task

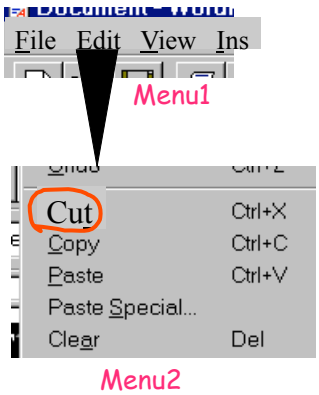


Overview of Test Generation

Phase	Step	Test Designer	Framework
Setup	1		Obtain planning operators from GUI model
	2	Code preconditions and effects of operators in model	
Test Case Generation	3	Specify a task (Initial and Goal States)	
	4		Generate Test Cases

Using Primitive Operators

- One operator for each event



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Selected(Obj) ⇒
ADD inClipboard(Obj)
DEL onScreen(Obj)
DEL Selected(Obj)
ADD isCurrent(Menu1)
DEL isCurrent(Menu2).

Exploit the GUI's Structure

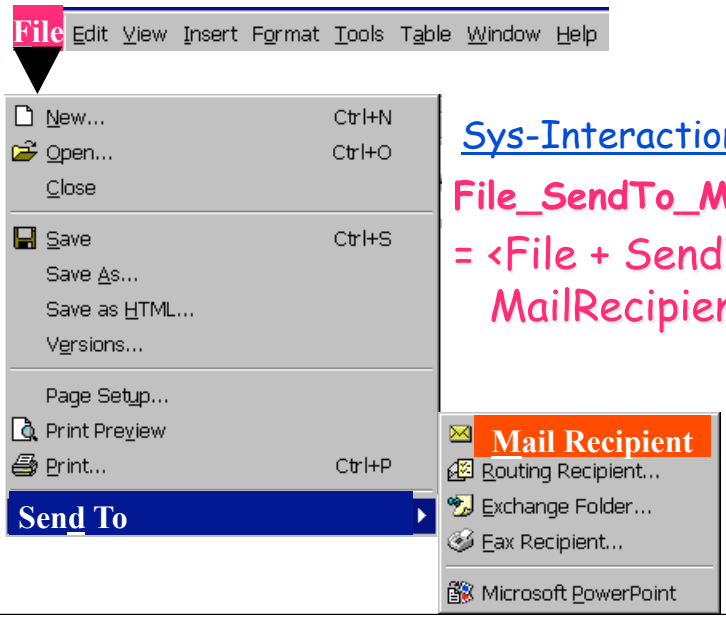
- Reduce the number of operators
  - System more efficient
  - Easier for the test designer

Operator Abstractions

Two types of abstractions

- Combine buttons ⇒ create system-interaction operators
- Decompose GUI hierarchically ⇒ create hierarchical operators

Create System-Interaction Operators

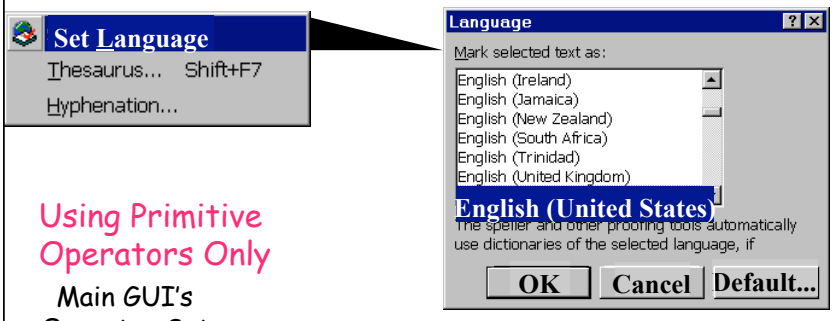


Sys-Interaction Operator:

File_SendTo_MailRecipient

= <File + SendTo + MailRecipient >

Create Hierarchical Operators



Using Primitive Operators Only

Main GUI's Operator Set

...
Set Language
SelectFromList()
Default
OK
Cancel
...

Using Abstraction

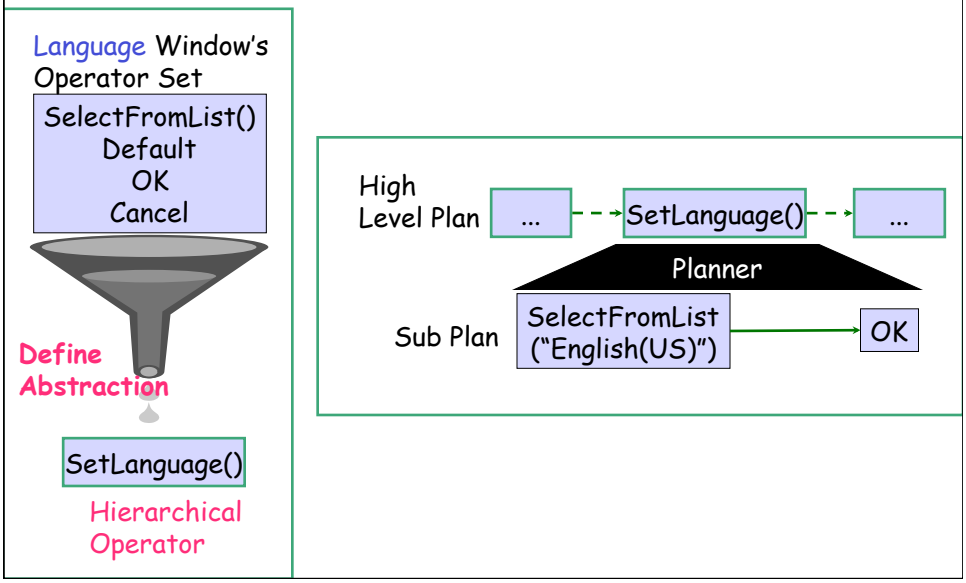
Main GUI's Operator Set

...
Set Language
...

Language Window's Operator Set

SelectFromList()
Default
OK
Cancel

Using Hierarchical Operators

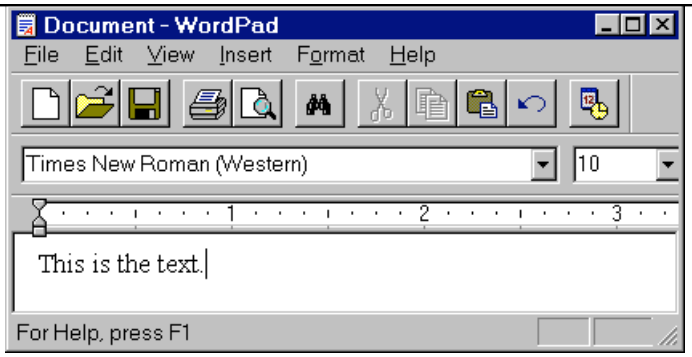


Effects of Exploiting the GUI's Structure

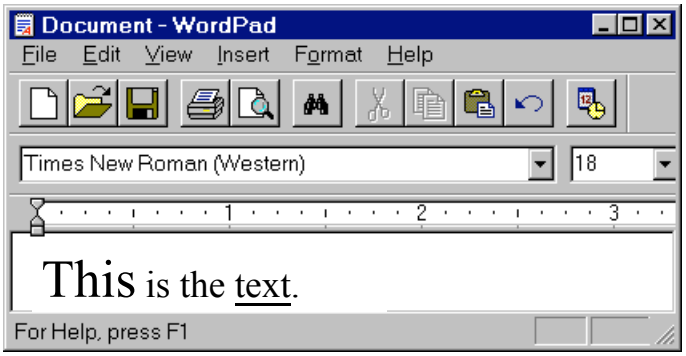
- Reduction in planning operators
  - 362 operators ⇒ 32 operators
  - Ratio 10:1 for MS Wordpad
  - 20:1 for MS Word
- Efficiency

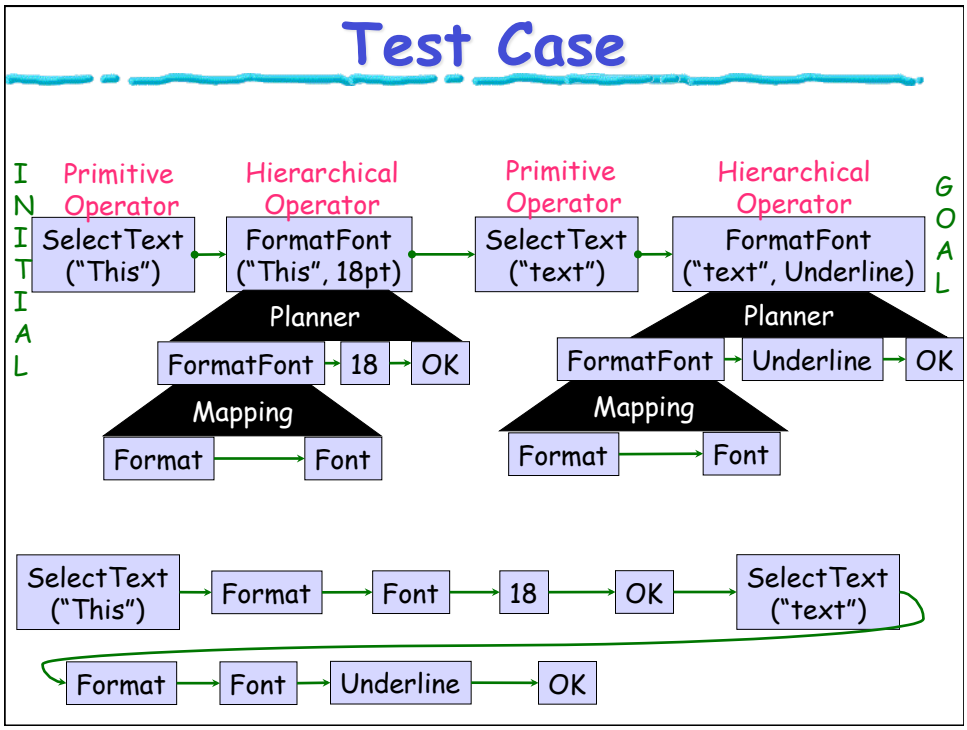
	Single Level		Hierarchical	
Task No.	Plan Length	Time (sec.)	Hier Plan Length	Time (sec.)
1	18	8.93	3	0.11
2	20	47.62	4	0.18
3	24	189.87	5	0.14
4	26	3312.72	6	7.18
5	-	-	3	0.10
6	-	-	4	13.01

Initial State

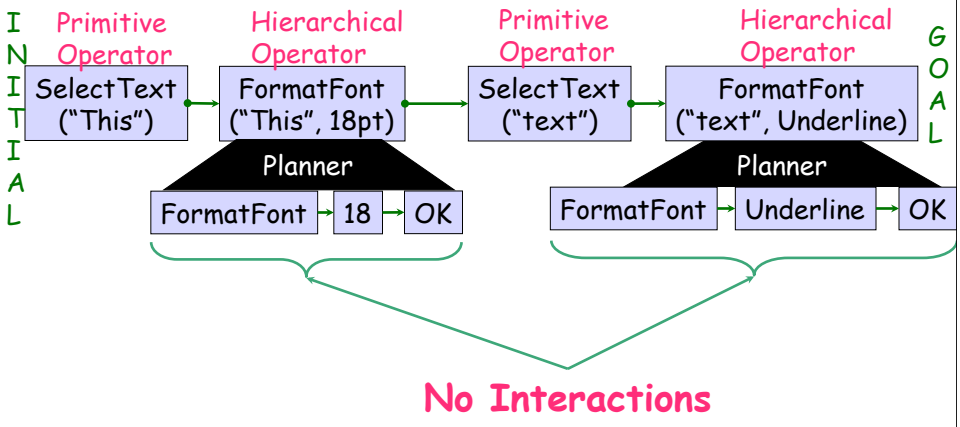


Goal State

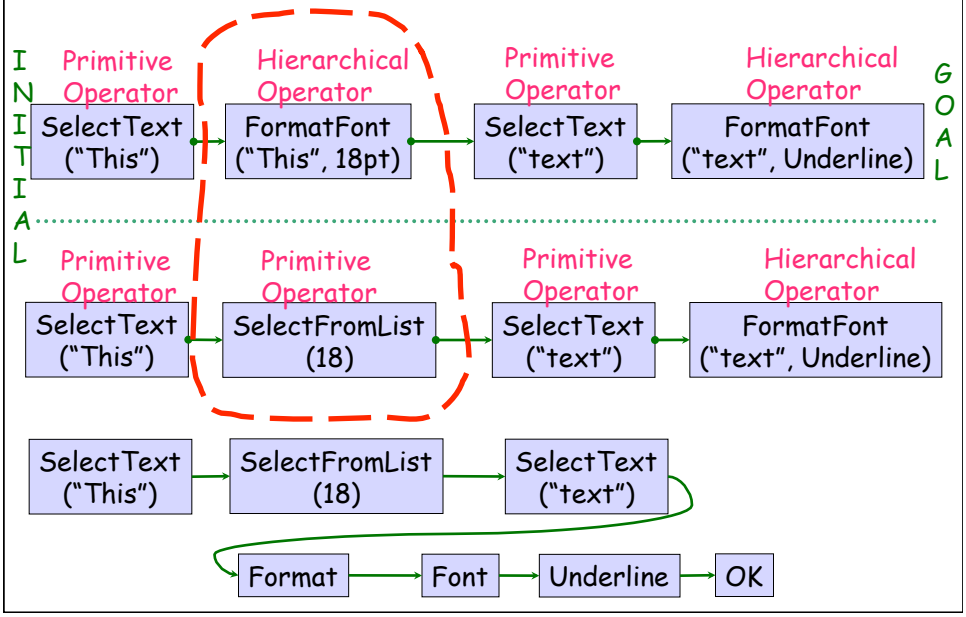




Different from HTN Planning



Alternative Test Case



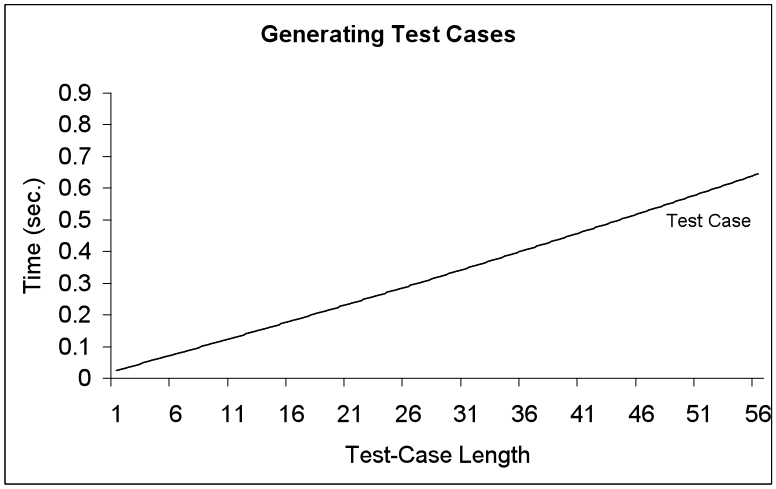
Methods to Generate Alternative Test Cases

- Different results from planner
- Hierarchical operator decompositions
- Linearizations of the partial-order plan

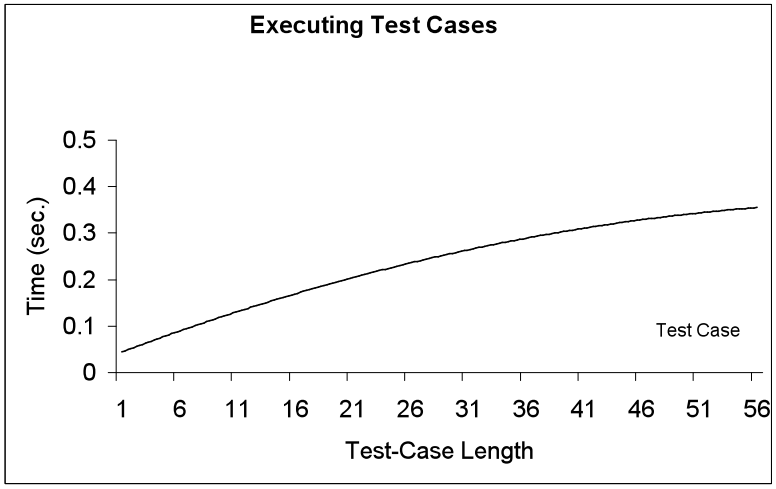
Experiments

- Purpose
  - To determine whether planning is a feasible approach for GUI test case generation
    - Execution time
    - Human effort
- Experimental design
  - GUI: our version of MS Wordpad (36 modal windows, 362 events)
  - Tasks: 50 tasks (initial & goal states)
  - Test cases: generated 290 test cases (6-56 events) using the IPP AI planner
  - Hardware platform: 350 MHz Pentium based machine, 256 MB RAM

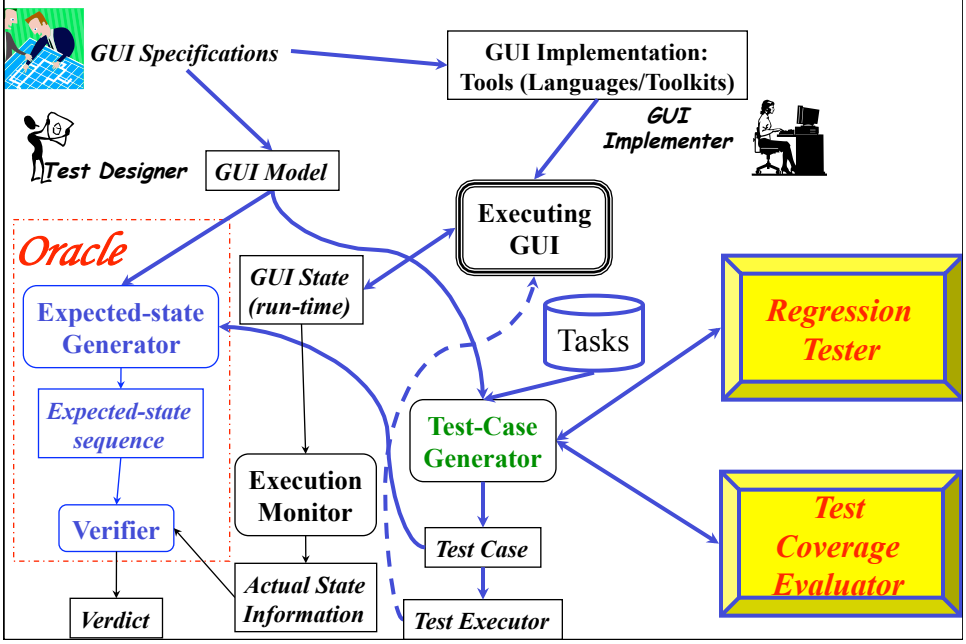
Test Case Generation



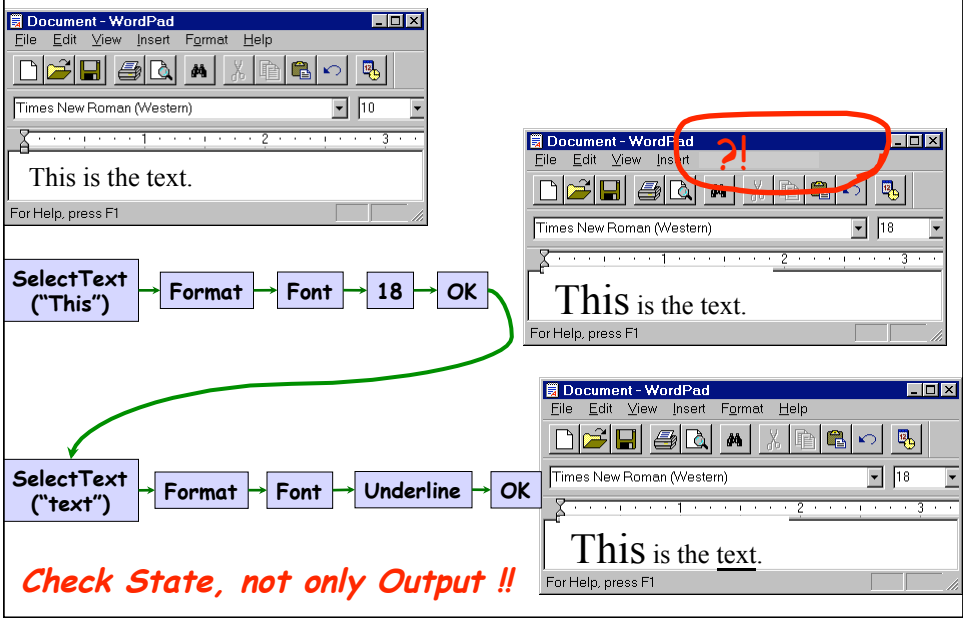
Automated Execution



Test Oracles

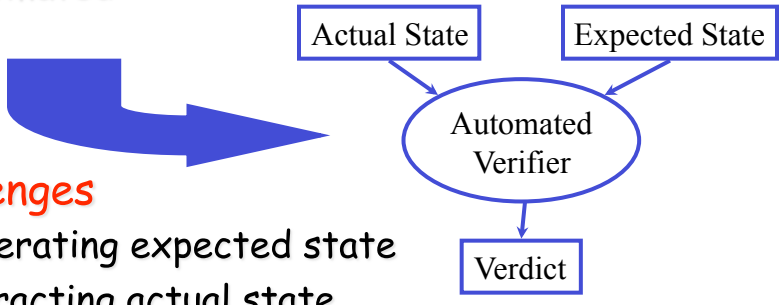


Test Oracles: What is the Correct Behavior



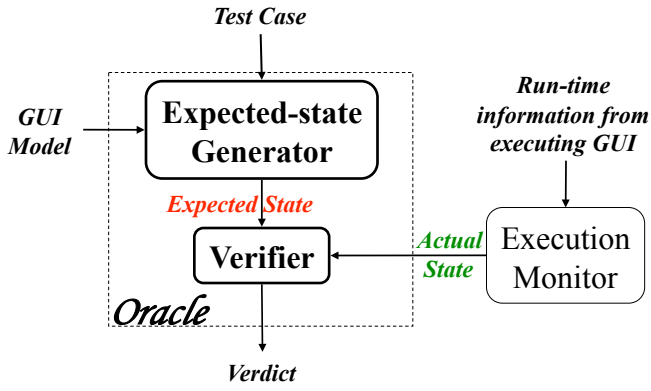
Determine Correct Behavior

- To check the GUI's state after each event
- Approaches
  - Manual
  - Automated



- Challenges
  - Generating expected state
  - Extracting actual state
  - Comparing expected & actual states

Overview of GUI Oracle



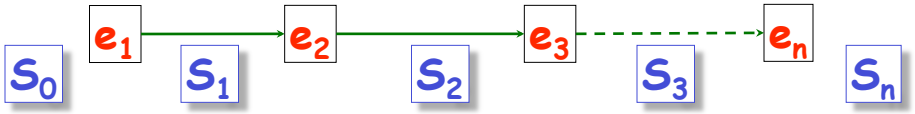
Expected State

- Obtaining Next State
  - Given a test case T with S_0, the initial state, and
  - A sequence of events

  - The next state S_y is obtained from the current state S_x and operator Op
    - Delete property P from S_x if Effects(Op) contains the command "DEL P"
    - Add property P in S_y if Effects(Op) contains the command "ADD P"

Deriving Expected State

- Obtain $S_1 = e_1(S_0)$
- And $S_i = e_i(S_{i-1})$



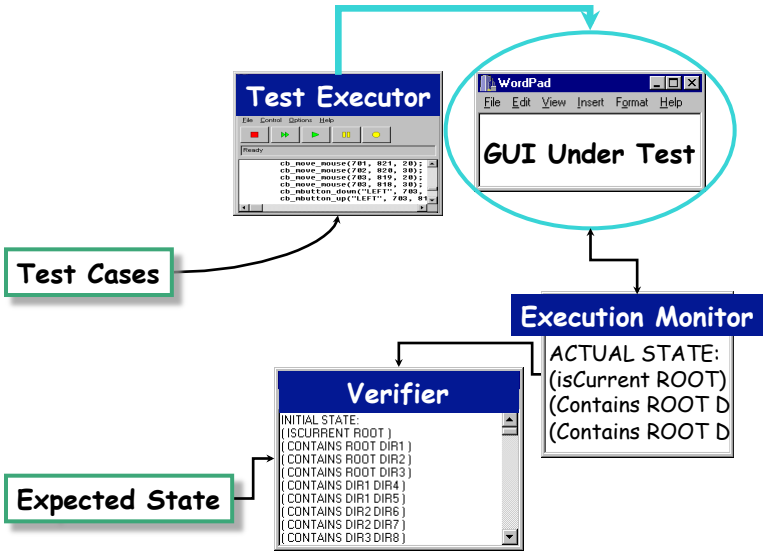
- Expected state is a conjunction of properties of the form
  - Property(Objects…, Value)

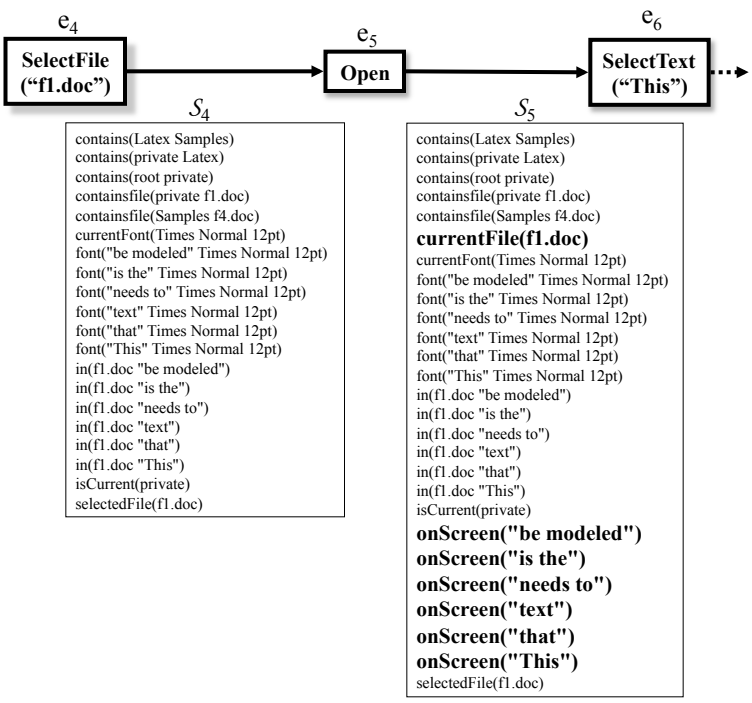
Obtaining Actual GUI's State

- Execution monitor
  - Compatible with expected state
  - Returns property(objects…, value)

    e.g., Caption(button1, "cancel")
  - Actual state can be obtained by
    - Screen scraping
    - Queries

Automated Execution





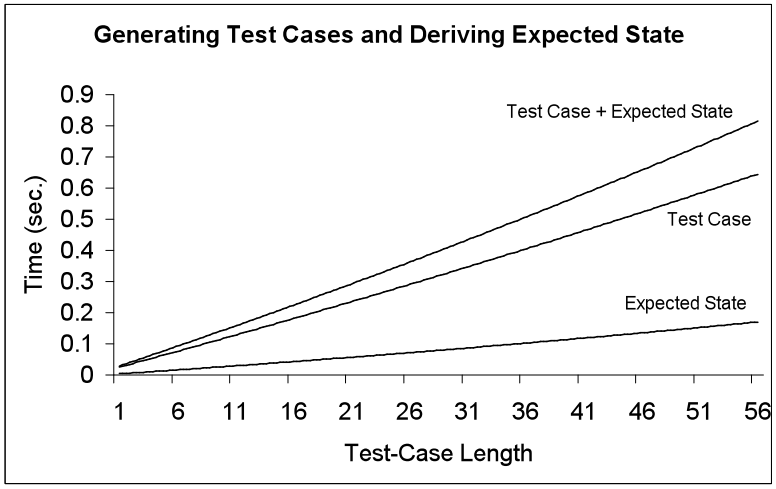
Comparing Actual and Expected States

- Verifier
- Three levels of checking
  - Changed property set *(operators)*
  - GUI relevant property set *(specifications)*
  - Complete property set *(toolkit/language)*
- Hybrid approach
  - Use all 3

Experiments

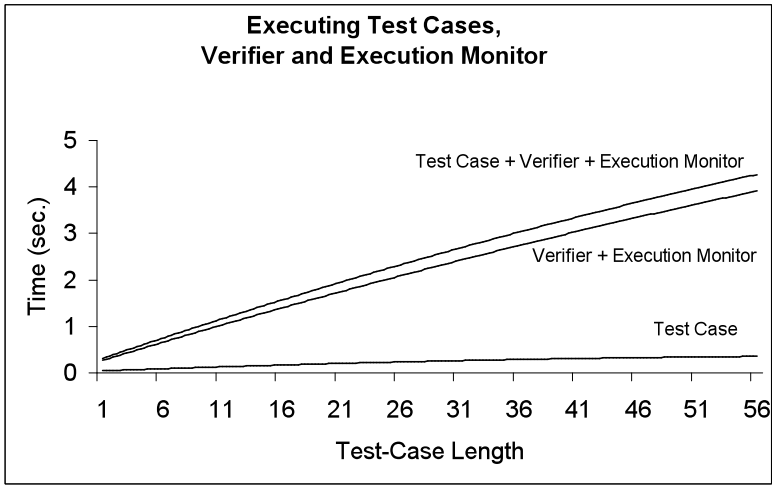
- Purpose: determine
  - Time to derive expected state
  - Time to execute monitor and verifier
- Experimental design
  - GUI: our version of MS Wordpad (36 modal windows, 362 events)
  - Test cases: generated 290 test cases (6-56 events) using an AI planner
  - Hardware platform: 350 mhz pentium based machine, 256 MB RAM
  - Properties: reduced set
  - Level of checking: GUI relevant property set

Deriving Expected State



Total CPU time (all 290 test cases and expected states)
75.84 sec.

Automated Execution



GUI Relevant-properties checking
Total running time < 10 minutes

Putting it All Together