Algorithms for User Interfaces

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Outline

- Story of why algorithms matter in programming
Outline

- Story of why algorithms matter in programming
- or a promise of never having to write a GUI event handler again
Motivation

Why is software like this?

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Algorithms for User Interfaces

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Why is software like this?
def ChangeCurrentHeightPx(self, event):
    self.LastUpdated = "Height"
    constrained = self.Controls["Constrain"].GetValue()
    # no matter what the percent & current stay bound together
    # get current height, and compute relative height and place new rel. ht
    height = float(self.Controls["AbsolutePx"]["Height"].GetValue())
    pct = height / self.InitialSize[self.Height]
    self.Controls["Relative%"]["Height"].SetValue(str(pct * 100))
    if constrained: # update width & width%
        self.Controls["Relative%"]["Width"].SetValue(str(pct * 100))
        width = pct * self.InitialSize[self.Width]
        self.Controls["AbsolutePx"]["Width"].SetValue(str(round(width)))

def ChangeCurrentHeightPct(self, event):
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    constrained = self.Controls["Constrain"].GetValue()
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    # get current rel. ht, and compute absolute height and place new abs. ht
    height = float(self.Controls["Relative%"]["Height"].GetValue())
    cur = height * self.InitialSize[self.Height] / 100
    self.Controls["AbsolutePx"]["Height"].SetValue(str(round(cur)))
    if constrained: # update width & width%
        self.Controls["Relative%"]["Width"].SetValue(str(height))
        width = height
        self.Controls["AbsolutePx"]["Width"].SetValue(str(round(width)))

if constrained:
    if self.LastUpdated == "Height":
        self.Controls["Relative%"]["Width"].SetValue(str(pct))
        width = pct * self.InitialSize[self.Width] / 100
        self.Controls["AbsolutePx"]["Width"].SetValue(str(round(width)))
    else:
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        height = pct * self.InitialSize[self.Height] / 100
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def ChangeCurrentWidthPx(self, event):
    self.LastUpdated = "Width"
    constrained = self.Controls["Constrain"].GetValue()
    # no matter what the percent & current stay bound together
    # get current width, and compute relative width and place new rel. wd
    width = float(self.Controls["AbsolutePx"]["Width"].GetValue())
    pct = width / self.InitialSize[self.Width]
    self.Controls["Relative%"]["Width"].SetValue(str(pct * 100))
    if constrained: # update height & height%
        self.Controls["Relative%"]["Height"].SetValue(str(pct))
        height = pct * self.InitialSize[self.Height]
        self.Controls["AbsolutePx"]["Height"].SetValue(str(round(height)))

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    self.LastUpdated = "Width"
    constrained = self.Controls["Constrain"].GetValue()
    # no matter what the percent & current stay bound together
    # get current rel. wd, and compute absolute width and place new abs. wd
    width = float(self.Controls["Relative%"]["Width"].GetValue())
    cur = width * self.InitialSize[self.Width] / 100
    self.Controls["AbsolutePx"]["Width"].SetValue(str(round(cur)))
    if constrained:
        if self.LastUpdated == "Width":
            self.Controls["Relative%"]["Height"].SetValue(str(pct))
            height = pct * self.InitialSize[self.Height] / 100
            self.Controls["AbsolutePx"]["Height"].SetValue(str(round(height)))
        else:
            self.Controls["Relative%"]["Width"].SetValue(str(pct))
            width = pct * self.InitialSize[self.Width] / 100
            self.Controls["AbsolutePx"]["Width"].SetValue(str(round(width)))
Motivation

- Reuse is a proven and successful route to improve quality of software, and increase programmer productivity
- Vasts amounts of well tested and proven code routinely reused
  - GUI components, delivering events, rendering, capturing user’s actions
  - Example: a typical TextBox widget: 100 methods, recognizes > 200 events
- Compositions are not reusable
  ⇒ ad-hoc solutions, defects, inconsistent behavior, costly development
- Incidental data structures that arise from a network of objects
- Incidental algorithms that arise from the concert of localized actions
- Minimal requirement for reuse: understandable model
  - Not satisfied by incidental data structures and algorithms
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Software is forever doomed!

Given a sorted array $A[0] \leq A[1] \leq \ldots \leq A[n-1]$, we want to determine if a given element $T$ is in the array. Binary search solves the problem by keeping track of a range within the array in which $T$ must be if it is anywhere in the array. Initially the range is the entire array. The range is shrunk by comparing its middle element to $T$, and then discarding half the range. The process continues until $T$ is found, or until the range in which it must lie is known to be empty. In an $n$-element table, the search uses roughly $\log_2(n)$ comparisons.
Software is forever doomed!

```c
int* binary_search(int* first, int* last, int x) {
    while (first != last) {
        int* middle = first + (last - first) / 2;
        if (*middle < x) first = middle + 1;
        else last = middle;
    }
    return first;
}
```
Motivation

Cancel that, programming is not forever doomed after all

- The problem: UI related code is
  - bloated and buggy
    - for example, Adobe’s desktop applications, event handling is estimated to account for a third of the code and over half of the defects
  - full of incidental data structures and algorithms

- An approach for improving the status quo
  - To understand the commonalities that exist in event-handling code
  - To define a model that captures these commonalities
  - To apply
    - replace incidental data structures with explicit data structures
    - replace incidental algorithms with explicit reusable algorithm

- Result: substantial increase in reuse, programming productivity, software correctness and quality
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1. Motivation

2. Command Parameter Synthesis

3. Property Models as Multi-way Dataflow Constraint Systems

4. What was achieved

5. Conclusions
Dialogs serve to assist the user in selecting values for parameters to some command.
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Understanding UIs: *Command Parameter Synthesis*

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- After the user edits a value,
  - The dialog is inconsistent
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Then it tries to restore consistency.
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Core of the Model: Multi-way Dataflow Constraint System

Each of which can be satisfied by any of a number of methods:

a: \[ \text{absolute_height} = \text{initial_height} \times \frac{\text{relative_height}}{100}; \]

b: \[ \text{relative_height} = \left(\frac{\text{absolute_height}}{\text{initial_height}}\right) \times 100; \]
Core of the Model: Multi-way Dataflow Constraint System

Variables ...

- Absolute Height
- Absolute Width
- Initial Height
- Initial Width
- Relative Height (%)
- Relative Width (%)
Core of the Model: Multi-way Dataflow Constraint System

- Variables ...
- tied together by **constraints** ...
Core of the Model: Multi-way Dataflow Constraint System

- Variables ...
- tied together by constraints ...
  - $\text{Height}_{\text{Absolute}} = \text{Height}_{\text{Initial}} \times (\frac{\text{Height}_{\text{Relative}}}{100})$
Variables ...

tied together by constraints ...

- $\text{Height}_{\text{Absolute}} = \text{Height}_{\text{Initial}} \cdot \left( \frac{\text{Height}_{\text{Relative}}}{100} \right)$

- each of which can be satisfied by any of a number of methods
Core of the Model: Multi-way Dataflow Constraint System

Variables ...

- tied together by constraints ...
  - \[ \text{Height}_{\text{Absolute}} = \text{Height}_{\text{Initial}} \cdot \left( \frac{\text{Height}_{\text{Relative}}}{100} \right) \]
  - each of which can be satisfied by any of a number of methods
    - a: \[ \text{absolute\_height} = \text{initial\_height} \ast \text{relative\_height} / 100; \]
    - b: \[ \text{relative\_height} = (\text{absolute\_height} / \text{initial\_height}) \ast 100; \]
Multi-way Dataflow Constraint Systems

- Restoring consistency is now just solving the system
Restoring consistency is now just solving the system

Solution defines a **dataflow**
Restoring consistency is now just solving the system

Solution defines a dataflow

- Selection of methods (in order) such that
  - all constraints enforced
  - no two methods output to same variable
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Solution defines a dataflow
  - Selection of methods (in order) such that
    - all constraints enforced
    - no two methods output to same variable
  - e.g. a, e → c
Picking the “right” solution

- Programmer only defines relations and their methods, not which method to execute and when ⇒ often multiple solutions
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- Programmer only defines relations and their methods, not which method to execute and when \(\Rightarrow\) often multiple solutions
  - Need a way to order them
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- Priorities

<table>
<thead>
<tr>
<th>Method</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Height</td>
<td>1</td>
</tr>
<tr>
<td>Initial Width</td>
<td>2</td>
</tr>
<tr>
<td>Relative Height</td>
<td>3</td>
</tr>
<tr>
<td>Absolute Height</td>
<td>4</td>
</tr>
<tr>
<td>Relative Width</td>
<td>5</td>
</tr>
<tr>
<td>Absolute Width</td>
<td>6</td>
</tr>
</tbody>
</table>
Picking the “right” solution

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- Priorities = Hierarchical Stay Constraints
Picking the “right” solution

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- **Priorities** = Hierarchical Stay Constraints
  - Stay constraint = does nothing, so its variable *stays* the same
Picking the “right” solution

- Programmer only defines relations and their methods, not which method to execute and when ⇒ often multiple solutions
  - Need a way to order them
- In general, want to prefer methods that change older values
- **Priorities** = Hierarchical Stay Constraints
  - Stay constraint = does nothing, so its variable *stays* the same
  - Hierarchy = groups of constraints with certain strength
Explicit Algorithm for Command Parameter Synthesis

- Each UI element has a variable in a constraint system
- Event handling code becomes auto-generated boilerplate
  - Value modification generates a request to the constraint system to modify one variable and its priority, and solve
  - At all times, the UI element shows the value of the variable in the constraint system
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Incidental Data Structure → Explicit Model
Incidental Data Structure → Explicit Model
Incidental Data Structure $\rightarrow$ Explicit Model

What was achieved
def ChangeCurrentHeightPx(self, event):
    self.LastUpdated = "Height"
    constrained = self.Controls["Constrain"].GetValue()
    # no matter what the percent & current stay bound together
    # get current height, and compute relative height and place new rel. ht
    height = float(self.Controls["AbsolutePx"]["Height"].GetValue())
    pct = height / self.InitialSize[self.Height]
    self.Controls["Relative%"]["Height"].SetValue(str(pct * 100))
    if constrained:
        width = self.Controls["AbsolutePx"]["Width"].GetValue()
        self.Controls["Relative%"]["Width"].SetValue(str(width))
        width = width * self.InitialSize[self.Width]
        self.Controls["AbsolutePx"]["Width"].SetValue(str(round(width)))

    def ChangeCurrentHeightPct(self, event):
        self.LastUpdated = "Height"
        constrained = self.Controls["Constrain"].GetValue()
        # no matter what the percent & current stay bound together
        # get current rel. ht, and compute absolute height and place new abs. ht
        height = float(self.Controls["Relative%"]["Height"].GetValue())
        cur = height * self.InitialSize[self.Height] / 100
        self.Controls["AbsolutePx"]["Height"].SetValue(str(round(cur)))
        if constrained:
            width = self.Controls["AbsolutePx"]["Width"].GetValue()
            self.Controls["Relative%"]["Width"].SetValue(str(width))
            width = width * self.InitialSize[self.Width] / 100
            self.Controls["AbsolutePx"]["Width"].SetValue(str(round(width)))

    def ChangeConstrainState(self, event):
        constrained = self.Controls["Constrain"].GetValue()
        # If the ratio is constrained, determine which dimension
        # was last updated and update the OTHER dimension.
        # For example: If Height was last updated, use Height as
        # Width’s new percent, and update Width’s absolute value
        if constrained:
            if self.LastUpdated == "Height":
                pct = float(self.Controls["Relative%"]["Height"].GetValue())
                self.Controls["Relative%"]["Width"].SetValue(str(pct))
                width = pct * self.InitialSize[self.Width] / 100
                self.Controls["AbsolutePx"]["Width"].SetValue(str(round(width)))
            else:
                pct = float(self.Controls["Relative%"]["Width"].GetValue())
                self.Controls["Relative%"]["Height"].SetValue(str(pct))
                height = pct * self.InitialSize[self.Height] / 100
                self.Controls["AbsolutePx"]["Height"].SetValue(str(round(height)))

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    height = float(self.Controls["AbsolutePx"]["Height"].GetValue())
    pct = height / self.InitialSize[self.Height]
    self.Controls["Relative%"]["Height"].SetValue(str(pct * 100))

    if constrained:
        # update width & width%
        self.Controls["Relative%"]["Width"].SetValue(str(pct * 100))

        width = pct * self.InitialSize[self.Width]
        self.Controls["AbsolutePx"]["Width"]["AbsolutePx"]["Width"]["Width"].SetValue(str(round(width)))

    def ChangeCurrentWidthPx(self, event):
        self.LastUpdated = "Width"
        constrained = self.Controls["Constrain"].GetValue()
        # no matter what the percent & current stay bound together
        # get current width, and compute relative width and place new rel. wd
        width = float(self.Controls["AbsolutePx"]["Width"].GetValue())
        pct = height / self.InitialSize[self.Width]
        self.Controls["Relative%"]["Width"].SetValue(str(pct * 100))

        if constrained:
            # update height & height%
            self.Controls["Relative%"]["Height"]["Relative%"]["Height"] = self.Controls["Relative%"]["Height"]["Relative%"]["Height"] * (height / self.InitialSize[self.Height])

            height = height * (self.InitialSize[self.Height] / 100)
            self.Controls["AbsolutePx"]["Height"].SetValue(str(round(height)))

    def ChangeCurrentHeightPct(self, event):
        self.LastUpdated = "Height"
        constrained = self.Controls["Constrain"].GetValue()
        # no matter what the percent & current stay bound together
        # get current rel. ht, and compute absolute height and place new abs. ht
        height = float(self.Controls["Relative%"]["Height"].GetValue())
        cur = height * (self.InitialSize[self.Height] / 100)
        self.Controls["AbsolutePx"]["Height"].SetValue(str(round(cur)))

        if constrained:
            # update width & width%

            width = width * (self.InitialSize[self.Width] / 100)
            self.Controls["AbsolutePx"]["Width"]["AbsolutePx"]["Width"]["Width"].SetValue(str(round(width)))

    def ChangeConstrainState(self, event):
        constrained = self.Controls["Constrain"].GetValue()
        # If the ratio is constrained, determine which dimension
        # was last updated and update the OTHER dimension.
        # For example: if Height was last updated, use Height as
        # Width’s new percent, and update Width’s absolute value
        if constrained:
            if self.LastUpdated == "Height": # update width px & %
                width = height * self.InitialSize[self.Width] / 100
                self.Controls["Relative%"]["Width"]["Relative%"]["Height"] = self.Controls["Relative%"]["Height"]["Relative%"]["Height"] * (height / self.InitialSize[self.Height])

                height = height * (self.InitialSize[self.Height] / 100)
                self.Controls["AbsolutePx"]["Height"]["AbsolutePx"]["Height"]["Height"].SetValue(str(round(height)))

            else: # update width px & %
                width = height * self.InitialSize[self.Width] / 100
                self.Controls["Relative%"]["Height"]["Relative%"]["Height"] = self.Controls["Relative%"]["Height"]["Relative%"]["Height"] * (height / self.InitialSize[self.Height])

                height = height * (self.InitialSize[self.Height] / 100)
                self.Controls["AbsolutePx"]["Height"]["AbsolutePx"]["Height"]["Height"].SetValue(str(round(height)))
Declarative Specification of Command Parameter Synthesis

sheet image_resize {
  input:
    initial_width : 5 * 300;
    initial_height : 7 * 300;
  interface:
    preserve_ratio : true;
    absolute_width : initial_width;
    absolute_height : initial_height;
    relative_width; relative_height;
  logic:
    relate {
      absolute_height <== relative_height * initial_height / 100;
      relative_height <== absolute_height * 100 / initial_height;
    }
    relate {
      absolute_width <== relative_width * initial_width / 100;
      relative_width <== absolute_width * 100 / initial_width;
    }
    when (preserve_ratio) relate {
      relative_width <== relative_height;
      relative_height <== relative_width;
    }
}
Declarative Specification of Command Parameter Synthesis

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  input:
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    preserve_ratio : true;
    absolute_width : initial_width;
    absolute_height : initial_height;
    relative_width; relative_height;
  logic:
    relate {
      absolute_height <= relative_height * initial_height / 100;
      relative_height <= absolute_height * 100 / initial_height;
    }
    relate {
      absolute_width <= relative_width * initial_width / 100;
      relative_width <= absolute_width * 100 / initial_width;
    }
    when (preserve_ratio) relate {
      relative_width <= relative_height;
      relative_height <= relative_width;
    }
}
Declarative Specification of Command Parameter Synthesis

sheet image_resize {
    input:
        initial_width : 5 * 300;
        initial_height : 7 * 300;
    interface:
        preserve_ratio : true;
        absolute_width : initial_width;
        absolute_height : initial_height;
        relative_width; relative_height;
    logic:
        relate {
            absolute_height <= relative_height * initial_height / 100; // a
            relative_height <= absolute_height * 100 / initial_height; // b
        }
        relate {
            absolute_width <= relative_width * initial_width / 100; // c
            relative_width <= absolute_width * 100 / initial_width; // d
        }
        when (preserve_ratio) relate {
            relative_width <= relative_height; // e
            relative_height <= relative_width; // f
        }
}
Before, every new feature required more spaghetti (incidental) code, specific to each dialog

Now, each new feature can be defined as a reusable algorithm in a library
A script is a recorded sequence of commands
  - e.g. remove red-eye, skin blemishes, extra weight

What do we record from our model as part of the script?

Remember that probably not every value is useful
  - Some are provided by the document
  - Some are provided by the user

Only want to capture what the user intended
Scripting

- A script is a recorded sequence of commands
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What do we record from our model as part of the script?

Remember that probably not every value is useful
  - Some are provided by the document
  - Some are provided by the user

Only want to capture what the user intended
Capturing the User’s Intent

- Command looks at Absolute Height, Absolute Width,
- but what we wanted to change is Relative Height
Capturing the User’s Intent

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Capturing the User’s Intent

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Experiences

- Early experience deploying our approach for command parameter synthesis at Adobe
  - Code reductions of a factor of 8 to 10
  - Fewer defects
  - Consistency among user interfaces
Experiment

- Rewriting user interface code for a major desktop application
- Four teams of roughly three engineers each,
- each tasked with rewriting a large number of dialogs and palettes
- Three teams (AE1–AE3) used the declarative approach, fourth team (TF) a modern vendor-supplied object-oriented UI framework
Results: Productivity

- AE1–AE3 teams combined completed roughly 75 dialogs and palettes, with 50 more underway
- TF team completed fewer than 10 altogether
Results: Defect Count

- AE1
- AE2
- AE3
- TF

Bugs Reported vs Reporting Week graph.
Future Directions

- Opportunities for user interfaces using property models
  - Recently worked on algorithms for enabling/disabling
  - Presets and defaults will follow
  - Perfecting the model for command parameter synthesis
- Incidental structures present in many areas of software
  - Want to know how the approach generalizes
  - Currently developing ideas about applying the declarative approach/constraint systems to other kinds of document modeling