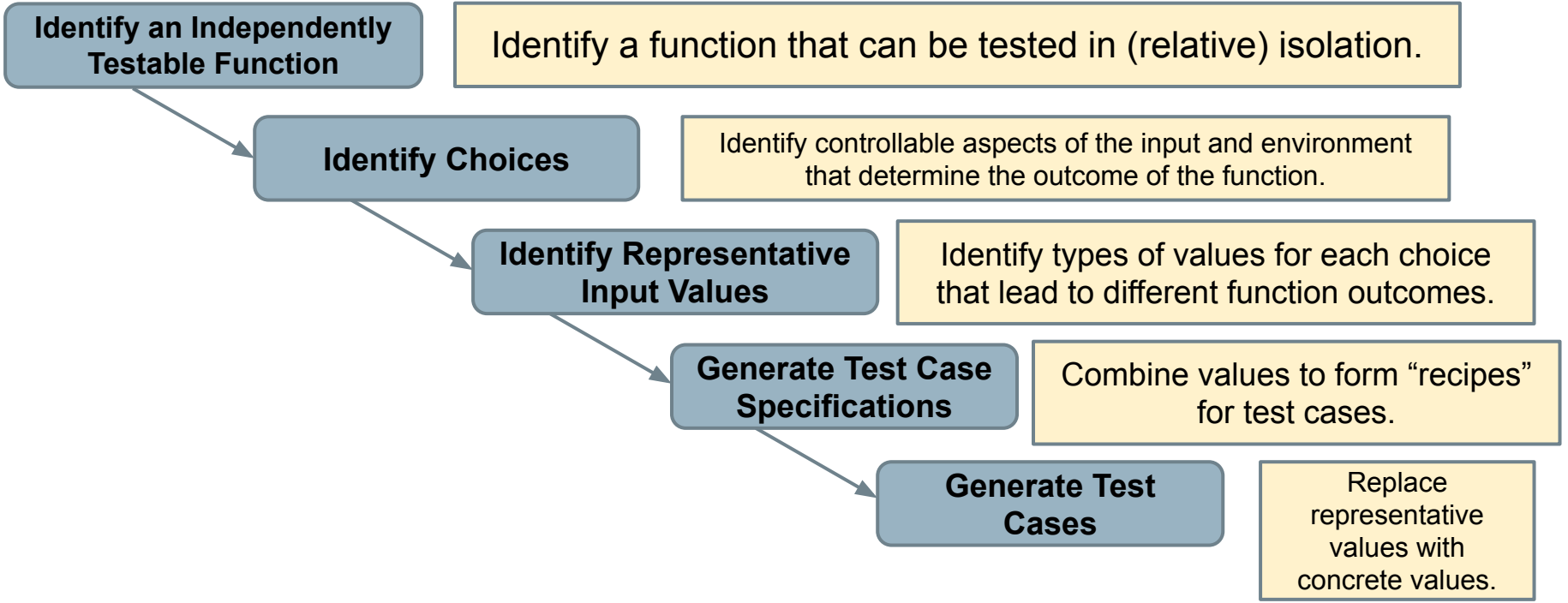
CHALMERS
UNIVERSITY OF TECHNOLOGY

UNIVERSITY OF GOTHENBURG

Lecture 11: Testing of Feature Interactions

Gregory Gay
TDA 594/DIT 593 - December 7, 2020

Creating System-Level Tests



Test Specifications

- **May end up with thousands of test specifications.**
- Which do you turn into concrete test cases?
- **Identify the important interactions.**

Today's Goals

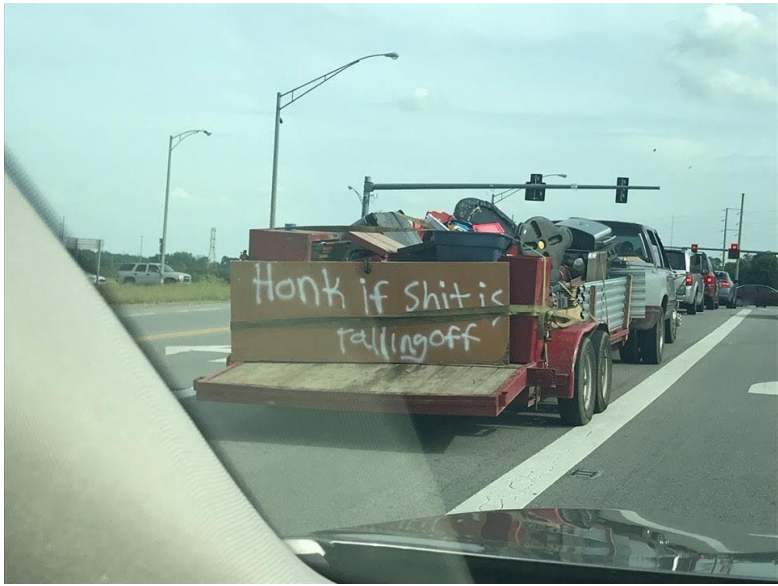
- Examine how feature interactions can create faults.
- Examine **how to select system tests** to increase likelihood of detecting interaction faults.
  - Category-Partition Method
  - Combinatorial Interaction Testing

Feature Interactions

- Features are expected to interact.
  - Usually this is planned!
  - Sometimes unplanned interactions break the system.
  - **We should select tests that thoroughly test feature interactions.**

Feature Interactions

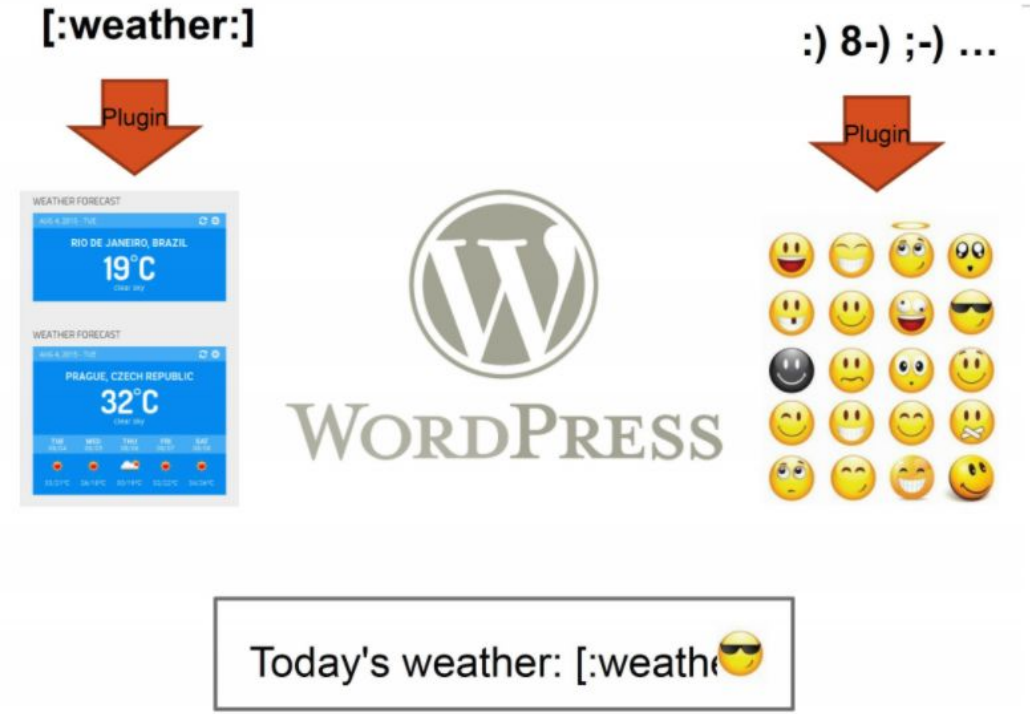
- **Feature interactions** result from combining **values** of individual **choices**.
  - **Inadvertent interactions** cause unexpected behavior
  - (ex. incorrect output, timing)
- Want to detect, manage, resolve inadvertent interactions.



Fire and Flood Control

- FireControl activates sprinklers when fire detected.
- FloodControl cuts water supply when water detected on floor.
- **Interaction means building burns down.**

WordPress Plug-Ins

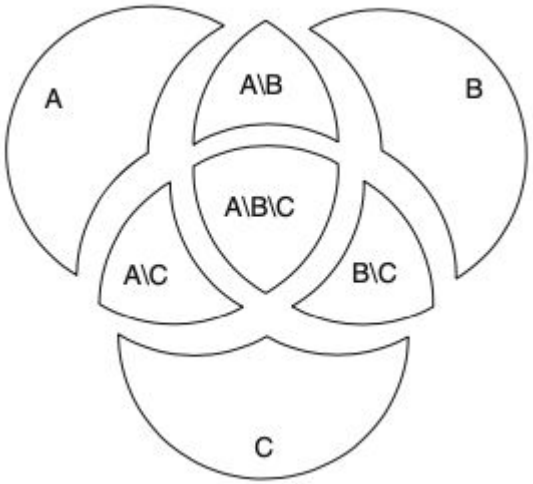


- Weather and emoji plug-ins tested independently.
- Their interaction results in unexpected behavior.

Feature Interactions

N-Way Interactions

- Interactions between two features are called 2-way interactions.
- If N features interact, this is an N-way interaction.
  - A, B, C have three 2-way interactions, one 3-way interaction.



N-Way Interactions

```
1  class Stack {
2
3    boolean push(Object o) {
4  #ifdef LOCKING
5      Lock lock = lock();
6      if(lock == null) {
7  #ifdef LOGGING
8        log("lock failed for: "+o);
9  #endif
10       return false;
11     }
12 #endif
13 #ifdef UNDO
14     rememberValue();
15 #endif
16     elementData[size++] = o;
17     /*...*/
18   }
19
20 #ifdef LOGGING
21   void log(String msg) { /*...*/ }
22 #endif
```

```
23 #ifdef UNDO
24   boolean undo() {
25 #ifdef LOCKING
26     Lock lock = lock();
27     if(lock == null) {
28 #ifdef LOGGING
29       log("undo-lock failed");
30 #endif
31       return false;
32     }
33 #endif
34     restoreValue();
35     /*...*/
36 #ifdef LOGGING
37     log("undone.");
38 #endif
39   }
40
41   void rememberValue() { /*...*/ }
42   void restoreValue() { /*...*/ }
43 #endif
44 }
```

- Features: Locking, Logging, Undo.
- Nested #ifdef indicate N-way interactions
  - 2-way: 3
  - 3-way: 1

Selecting Test Specifications

- We want to select *interesting* specifications.
- **Category-Partition Method**
  - Apply constraints to reduce the number of specifications.
- **Combinatorial Interaction Testing**
  - Identify a subset that covers all interactions between pairs of choices.

Category-Partition Method

Category-Partition Method

Creates a set of test specifications.

- **Choices**, **representative values**, and **constraints**.
  - **Choices:** What you can control when testing.
  - **Representative Values:** Logical options for each choice.
  - **Constraints:** Limit certain combinations of values.
- Apply more constraints to further limit set.

Identify Choices

- Examine parameters of function.
  - *Direct input*, *environmental parameters (i.e., databases)*, and *configuration options*.
- Identify characteristics of each parameter.
  - What aspects influence outcome? (**the choices**)
- **Choices** are also called ***categories*** if you look up category-partition method.

Example: Computer Configurations

- Web shop that sells custom computers.
- A *configuration* is a set of options for a *model*.
  - Some combinations are invalid (i.e., display port monitor with HDMI video output).
- Function: `checkConfiguration(model,configuration)`
  - What are the parameters?
  - What are the choices to be made for each parameter?

Example: Computer Configuration

- **Model:** Identifies a product and determines constraints on available components. Identified by a model number. Characterized by a set of slots. Slots may be required (must be filled) or optional (may be left empty).

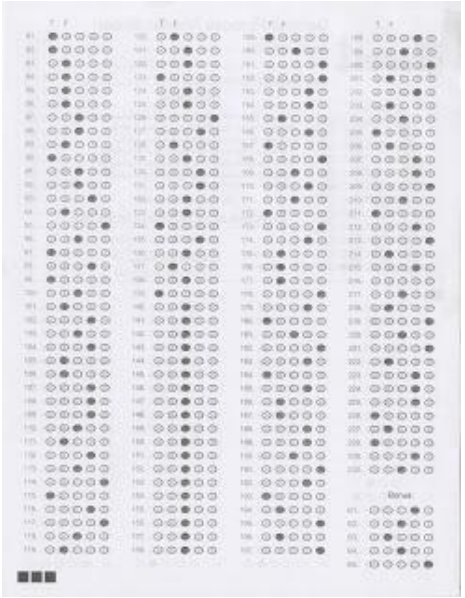
- **Configuration:** Set of <slot, component> pairs. Must correspond to the required and optional slots of the model. Available components and a default for each slot are determined by the model. Slots may be empty (may be default for optional slots). Components can be compatible or incompatible with a model or with each other.

Example: Configuration Choices

- **Parameter: Model**
  - Model number
  - Number of required slots (must have a component)
  - Number of optional slots (component or empty)
- **Parameter: Configuration**
  - Selected configuration valid for model?
  - Number [required/optional] slots with non-empty selections.
  - Selected components for [required/optional] slots OK?
- **Parameter: Product Database**
  - Number of models in database
  - Number of components in database

Identify Representative Values

- Many values can be selected for each choice.
- Partition each choice into *types of values*.
  - Consider all outcomes of function.
  - Consider logical ranges or groupings.
- A test specification is a selection of values for all choices.
  - Concrete test case fills values for each abstract selection.



Values for Each Choice

Parameter: Model

- Choice: Model number
  - malformed
  - not in database
  - valid
- Choice: Number of required slots
  - 0
  - 1
  - many
- Choice: Number of optional slots
  - 0
  - 1
  - many

Parameter: Product Database

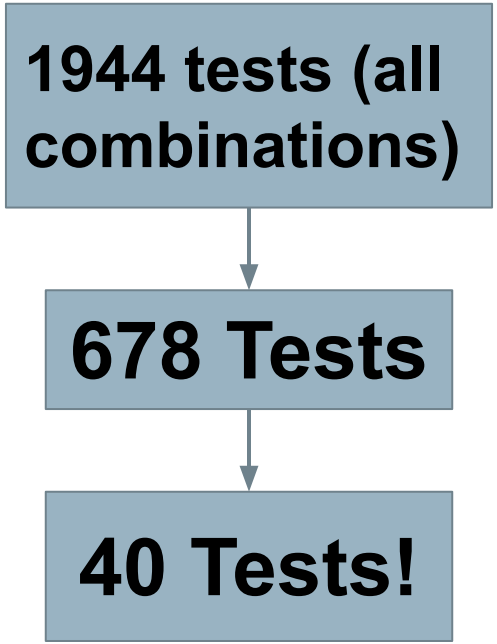
- Choice: Number of models in database
  - 0
  - 1
  - many
- Number of components in database
  - 0
  - 1
  - many

Parameter: Configuration

- Choice: Configuration Matches Model
  - complete correspondence
  - omitted slots in configuration
  - extra slots in configuration
  - mismatched number of required and optional slots
- Choice: Number of empty required slots that are empty
  - all required slots filled
  - some required slots empty
  - all required slots empty
- Choice: Number of optional slots that are empty
  - all optional slots filled
  - some optional slots empty
  - all optional slots empty
- Choice: Selected components for required slots
  - all valid
  - some kept at default
  - >= 1 incompatible with slot
  - >= 1 incompatible with another component
  - >= 1 not in database
- Choice: Selected components for optional slots
  - all valid
  - some kept at default
  - >= 1 incompatible with slot
  - >= 1 incompatible with another component
  - >= 1 not in database

Generate Test Case Specifications

- Test specification = selection of values for choices.
- **Constraints** limit number of specifications.
  - Eliminate impossible pairings.
  - Remove unnecessary options.
  - Choose a subset to turn into concrete tests.



- Seven choices with three values, one with four values, two with five values.
  - $3^7 \times 5^2 \times 4 = 218700$ test specifications
- Not all combinations correspond to reasonable specifications.

Parameter: Model

- Choice: Model number
  - malformed
  - not in database
  - valid
- Choice: Number of required slots
  - 0
  - 1
  - many
- Choice: Number of optional slots
  - 0
  - 1
  - many

Parameter: Product Database

- Choice: Number of models in database
  - 0
  - 1
  - many
- Number of components in database
  - 0
  - 1
  - many

Parameter: Configuration

- Choice: Configuration Matches Model
  - complete correspondence
  - omitted slots in configuration
  - extra slots in configuration
  - mismatched number of required and optional slots
- Choice: Number of empty required slots that are empty
  - all required slots filled
  - some required slots empty
  - all required slots empty
- Choice: Number of optional slots that are empty
  - all optional slots filled
  - some optional slots empty
  - all optional slots empty
- Choice: Selected components for required slots
  - all valid
  - some kept at default
  - >= 1 incompatible with slot
  - >= 1 incompatible with another component
  - >= 1 not in database
- Choice: Selected components for optional slots
  - all valid
  - some kept at default
  - >= 1 incompatible with slot
  - >= 1 incompatible with another component
  - >= 1 not in database

Constraints Between Values

- IF-CONSTRAINT
  - This value only needs to be used under certain conditions (**if X is true, use value Y**)
- ERROR
  - Value causes error regardless of values of other choices.
- SINGLE
  - Only a single test with this value is needed.
  - Corner cases that should give “good” outcome.

Example - Substring

```
substr(string str, int index)
```

Choice: Str length

length = 0 — property zeroLen, TRUE if length = 0

length = 1

length >= 2

Choice: Str contents

contains letters and numbers — if !zeroLen

contains special characters — if !zeroLen — SINGLE

empty — if zeroLen

Choice: index

value < 0 — ERROR

value = 0

value = 1

value > 1

8 (error cases) + 6 (single cases) + ($1^7*2^1*3^2$) (RSMANY = true/OSMANY = true) + ($1^5*2^3*3^2$) (false/true) + ($1^5*2^3*3^2$) (true/false) + ($1^3*2^5*3^2$) (false/false) = 464 test specifications

Example - Configuration Constraints

Parameter: Model

- Choice: Model number
  - malformed **[error]**
  - not in database
  - valid
- Choice: Number of required slots
  - 0 **[single]**
  - 1
  - many **[property RSMANY]**
- Choice: Number of optional slots
  - 0 **[single]**
  - 1
  - many **[property OSMANY]**

Parameter: Product Database

- Choice: Number of models in database
  - 0 **[error]**
  - 1 **[single]**
  - many
- Number of components in database
  - 0 **[error]**
  - 1 **[single]**
  - many

Parameter: Configuration

- Choice: Configuration Matches Model
  - complete correspondence
  - omitted slots in configuration **[error]**
  - extra slots in configuration **[error]**
  - mismatched number of required and optional slots **[error]**
- Choice: Number of empty required slots that are empty
  - all required slots filled
  - some required slots empty **[if RSMANY]**
  - all required slots empty
- Choice: Number of optional slots that are empty
  - all optional slots filled
  - some optional slots empty **[if OSMANY]**
  - all optional slots empty
- Choice: Selected components for required slots
  - all valid
  - some kept at default **[single]**
  - >= 1 incompatible with slot
  - >= 1 incompatible with another component
  - >= 1 not in database **[error]**
- Choice: Selected components for optional slots
  - all valid
  - some kept at default **[single]**
  - >= 1 incompatible with slot
  - >= 1 incompatible with another component
  - >= 1 not in database **[error]**

Activity - `find` service

https://bit.ly/31i2YcK

`find(pattern,file)`

- Finds instances of a pattern in a file
  - **`find("john",myFile)`**
    - Finds all instances of `john` in the file
  - **`find("john smith",myFile)`**
    - Finds all instances of `john smith` in the file
  - **`find(""john" smith",myFile)`**
    - Finds all instances of `"john" smith` in the file

Activity - `find` Service

https://bit.ly/31i2YcK

- Parameters: pattern, file
- What can we vary for each?
  - What can we control about the pattern? Or the file?
- What values can we choose for each choice?
  - **File name:**
    - File exists with that name
    - File does not exist with that name
- What constraints can we apply between choice values? (if, single, error)

Example - `find` Service

$(2^2*3^3*4^1) = 108$ test specifications

- Pattern size:
  - Empty
  - single character
  - many characters
  - longer than any line in the file
- Quoting:
  - pattern has no quotes
  - pattern has proper quotes
  - pattern has improper quotes (only one “)
- Embedded spaces:
  - No spaces
  - One space
  - Several spaces

- File name:
  - Existing file name
  - no file with this name
- Number of occurrence of pattern in file:
  - None
  - exactly one
  - more than one
- Pattern occurrences on any single line line:
  - One
  - more than one

ERROR and SINGLE Constraints

4 (error) + 2 (single) + (1^2*2^3*3^1) = 30

- Pattern size:
  - [error] Empty
  - single character
  - many character
  - [error] longer than any line in the file
- Quoting:
  - pattern has no quotes
  - pattern has proper quotes
  - [error] pattern has improper quotes (only one “)
- Embedded spaces:
  - No spaces
  - One space
  - Several spaces

- File name:
  - Existing file name
  - no file with this name [error]
- Number of occurrence of pattern in file:
  - None
  - exactly one [single]
  - more than one
- Pattern occurrences on target line:
  - One
  - more than one [single]

29

IF Constraints

4 (error) + 2 (single) + (1^3*2^3) (quoted = true) + (1^4*2^2) (quoted = false) = 18

- Pattern size:
  - [error] Empty
  - single character
  - many character
  - [error] longer than any line in the file
- Quoting:
  - pattern has no quotes
  - [property quoted] pattern has proper quotes
  - [error] pattern has improper quotes (only one “)
- Embedded spaces:
  - No spaces
  - [if quoted] One space
  - [if quoted] Several spaces

- File name:
  - Existing file name
  - no file with this name [error]
- Number of occurrence of pattern in file:
  - None
  - exactly one [single]
  - more than one
- Pattern occurrences on target line:
  - One
  - more than one [single]

30

Let’s take a break.

Combinatorial Interaction Testing

Limiting Num. of Test Specifications

Bandwidth Mode	**Language**	**Fonts**
Desktop Site	English	Standard
Mobile Site	French	Open-Source
Text Only	German	Minimal
	Swedish	
Advertising	**Screen Size**	
No Advertising	Phone	
Targeted Advertising	Tablet	
General Advertising	Full Size	
Minimal Advertising		

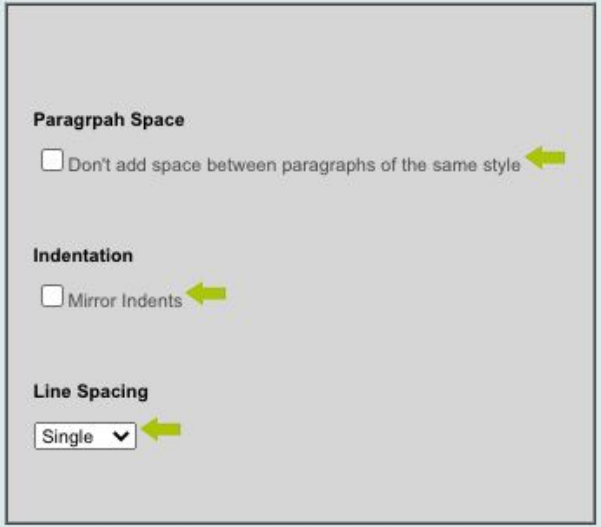
- Full set = 432 specifications
- No natural IF, SINGLE, ERROR constraints for these features.
- What is important to cover?

Combinatorial Interaction Testing

- Cover all k-way interactions (k < N).
  - Typically **2-way (pairwise)** or 3-way.
- Set of all combinations grows exponentially.
- Set of pairwise combinations grows logarithmically.
  - (last slide) 432 combinations.
  - Possible to cover all pairs in 16 tests.

Example - Paragraph Effects

Paragraph spaces has two values: selected and unselected.
Mirror indents has two values: selected and unselected.
And finally, line spacing has three values: single, multiple and double.



Paragraph Space	Indentation	Line Spacing
Selected	Selected	Single
Unselected	Unselected	Double
		Multiple

2 * 2 * 3 = 12 combinations

Example - Paragraph Effects

Single	Indent Selected	Paragraph Selected
Single	Indent Unselected	Paragraph Selected
Single	Indent Selected	Paragraph Unselected
Single	Indent Unselected	Paragraph Unselected
Multiple	Indent Selected	Paragraph Selected
Multiple	Indent Unselected	Paragraph Selected
Multiple	Indent Selected	Paragraph Unselected
Multiple	Indent Unselected	Paragraph Unselected
Double	Indent Selected	Paragraph Selected
Double	Indent Unselected	Paragraph Selected
Double	Indent Selected	Paragraph Unselected
Double	Indent Unselected	Paragraph Unselected

Single	Indent Selected	Paragraph Selected
Single	Indent Unselected	Paragraph Selected
Single	Indent Selected	Paragraph Unselected
Single	Indent Unselected	Paragraph Unselected
Multiple	Indent Selected	Paragraph Selected
Multiple	Indent Unselected	Paragraph Selected
Multiple	Indent Selected	Paragraph Unselected
Multiple	Indent Unselected	Paragraph Unselected
Double	Indent Selected	Paragraph Selected
Double	Indent Unselected	Paragraph Selected
Double	Indent Selected	Paragraph Unselected
Double	Indent Unselected	Paragraph Unselected

Single	Indent Selected	Paragraph Selected
Single	Indent Unselected	Paragraph Selected
Single	Indent Selected	Paragraph Unselected
Single	Indent Unselected	Paragraph Unselected
Multiple	Indent Selected	Paragraph Selected
Multiple	Indent Unselected	Paragraph Selected
Multiple	Indent Selected	Paragraph Unselected
Multiple	Indent Unselected	Paragraph Unselected
Double	Indent Selected	Paragraph Selected
Double	Indent Unselected	Paragraph Selected
Double	Indent Selected	Paragraph Unselected
Double	Indent Unselected	Paragraph Unselected

Example - Paragraph Effects

- Goal of CIT is to produce **covering array**.
  - Set of configurations that covers all K-way combinations.
    - (2-way here).
  - Cover in 6 test specifications.

Single	Indent Selected	Paragraph Selected
Single	Indent Unselected	Paragraph Unselected
Multiple	Indent Selected	Paragraph Selected
Multiple	Indent Unselected	Paragraph Unselected
Double	Indent Selected	Paragraph Unselected
Double	Indent Unselected	Paragraph Selected

Example - Website Display

Bandwidth Mode
Desktop Site
Mobile Site
Text Only
Fonts
Standard
Open-Source
Minimal
Screen Size
Phone
Tablet
Full Size

Bandwidth Mode	**Fonts**	**Screen Size**
Desktop Site	Standard	Phone
Desktop Site	Open-Source	Tablet
Desktop Site	Minimal	Full Size
Mobile Site	Standard	Tablet
Mobile Site	Open-Source	Full Size
Mobile Site	Minimal	Phone
Text Only	Standard	Full Size
Text Only	Open-Source	Phone
Text Only	Minimal	Tablet

- Cover all combinations for two variables.
- Add a third, account for all combinations of pairs of values.
  - Each test specification can cover up to three pairs.

Example - W

Bandwidth Mode	Language	Fonts
Desktop Site	English	Standard
Mobile Site	French	Open-Source
Text Only	German	Minimal
	Swedish	
Advertising	**Screen Size**	
No Advertising	Phone	
Targeted Advertising	Tablet	
General Advertising	Full Size	
Minimal Advertising		

Language	Advertising	Bandwidth Mode	Fonts	Screen Size
English	No Advertising	Desktop Site	Standard	Phone
English	Targeted Advertising	Mobile Site	Open-Source	Tablet
English	General Advertising	Text Only	Minimal	Full Size
English	Minimal Advertising	Mobile Site	Minimal	Phone
French	No Advertising	-	-	-
French	Targeted Advertising	Desktop Site	Minimal	Full Size
French	General Advertising	Mobile Site	Standard	Tablet
French	Minimal Advertising	Text Only	Open-Source	Phone
German	No Advertising	Text Only	Minimal	Tablet
German	Targeted Advertising	-	-	-
German	General Advertising	Desktop Site	Open-Source	Phone
German	Minimal Advertising	Mobile Site	Standard	Full Size
Swedish	No Advertising	Mobile Site	Open-Source	Full Size
Swedish	Targeted Advertising	Text Only	Standard	Phone
Swedish	General Advertising	-	-	-
Swedish	Minimal Advertising	Desktop Site	Minimal	Tablet

Constraints

- Remove all ERROR/SINGLE cases before CIT.
  - Error output, one-time corner cases
- Constraints on value combinations specified:
  - OMIT(Text-Only, *, *, Full Size, *)
  - OMIT(*, *, *, Full Size, Minimal)
- Further reduces number of test specifications.

CIT Tools

- Pairwise Independent Combinatorial Testing (Microsoft): https://github.com/microsoft/pict
- Automated Combinatorial Testing for Software (NIST): https://csrc.nist.gov/projects/automated-combinatorial-testing-for-software
- .. Many more: http://www.pairwise.org/tools.asp

https://bit.ly/3G2l00a

Activity - Browser Configuration

Allow Content to Load	Notify About Pop-Ups	Allow Cookies	Warn About Add-Ons	Warn About Attack Sites	Warn About Forgeries
Allow	Yes	Allow	Yes	Yes	Yes
Restrict	No	Restrict	No	No	No
Block		Block			

- Full set of test specifications = 144
- Create set covering all pairwise value combinations.
  - Hint: Start with two variables with most values. Add one variable at a time.

Activity Solution

Allow Content	Allow Cookies	Pop-Ups	Add-Ons	Attacks	Forgeries
Allow	Allow	Yes	Yes	Yes	Yes
Allow	Restrict	No	No	Yes	No
Allow	Block	No	No	No	Yes
Restrict	Allow	Yes	No	No	No
Restrict	Restrict	Yes	-	-	Yes
Restrict	Block	No	Yes	Yes	No
Block	Allow	No	-	-	Yes
Block	Restrict	-	Yes	No	-
Block	Block	Yes	No	Yes	No

We Have Learned

- Process for deriving system-level tests often results in **too many test specifications**.
- Two methods that **identify important interactions**:
  - **Category-Partition Method:** Use constraints to eliminate unnecessary tests.
  - **Combinatorial Interaction Testing:** Identify important pairs of input values.

Next Time

- Automated test case generation using search/optimization.

- Assignment 4 - Due Sunday
  - Modularity/Design Patterns
  - Questions?

UNIVERSITY OF
GOTHENBURG

CHALMERS
UNIVERSITY OF TECHNOLOGY