

Towards End-user Web Scraping For Customization

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ABSTRACT

Websites are malleable: users can install browser extensions and run arbitrary Javascript in the developer console to change them. However, this malleability is only accessible to programmers with knowledge of HTML and Javascript. To broaden access to customization, our prior work developed an approach that empowers end-users to customize websites without traditional programming via a browser extension called Wildcard. However, Wildcard only opened part of the customization process to end-users, and still required programmers to write site-specific adapters to map website data to a table structure. This means that end-users can only customize a website if a programmer has written an adapter for it. Furthermore, end-users do not have the ability to extend adapters in order to perform new customizations or repair adapters to fix broken customizations.

In this paper, we extend Wildcard with a new system for *end-user web scraping for customization* which enables end-users to create, extend and repair adapters by demonstration. We describe three design principles that guided our system's development and are applicable to other end-user web scraping and customization systems: (a) users should be able to scrape data and use it in a single, unified environment, (b) users should be able to extend and repair the programs that scrape data via demonstration and (c) users should receive live feedback during their demonstrations.

We have successfully used our system to create, extend and repair adapters by demonstration on a variety of websites. We provide example usage scenarios that showcase each of our design principles.

CCS CONCEPTS

• **Software and its engineering** → **Integrated and visual development environments.**

KEYWORDS

end-user programming, software customization, web browser extensions

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1 INTRODUCTION

Many websites on the internet do not meet the exact needs of all of their users. End-user web customization systems like Chickenfoot [3], Thresher [6], Sifter [7] and Vegemite [11] help users tweak and adapt websites to fit their unique requirements, ranging from reorganizing or annotating content on the website to automating common tasks. In our prior work, we presented Wildcard [12], a customization system which enables end-users to customize websites through direct manipulation. It does this by augmenting websites with a table view that shows their underlying structured data. The table is bidirectionally synchronized with the original website, so end-users can easily customize the website by interacting with the table, including sorting and filtering data, adding annotations, and running computations in a spreadsheet formula language.

Wildcard has a key limitation. In order to enable end-users to customize a website, a Javascript programmer first needs to code an adapter that specifies how to scrape the website content and set up a bidirectional synchronization with Wildcard's table view. Even though programmers can share adapters with end-users, this means that an end-user can only use Wildcard on websites where some programmer has already written an adapter. Additionally, if an adapter doesn't scrape the desired data, or stops functioning correctly when a website changes, an end-user has no recourse to extend or repair it on their own.

In this paper, we describe an addition to Wildcard: a system that enables end-users to create, extend and repair website adapters by demonstration within the browser. Using this

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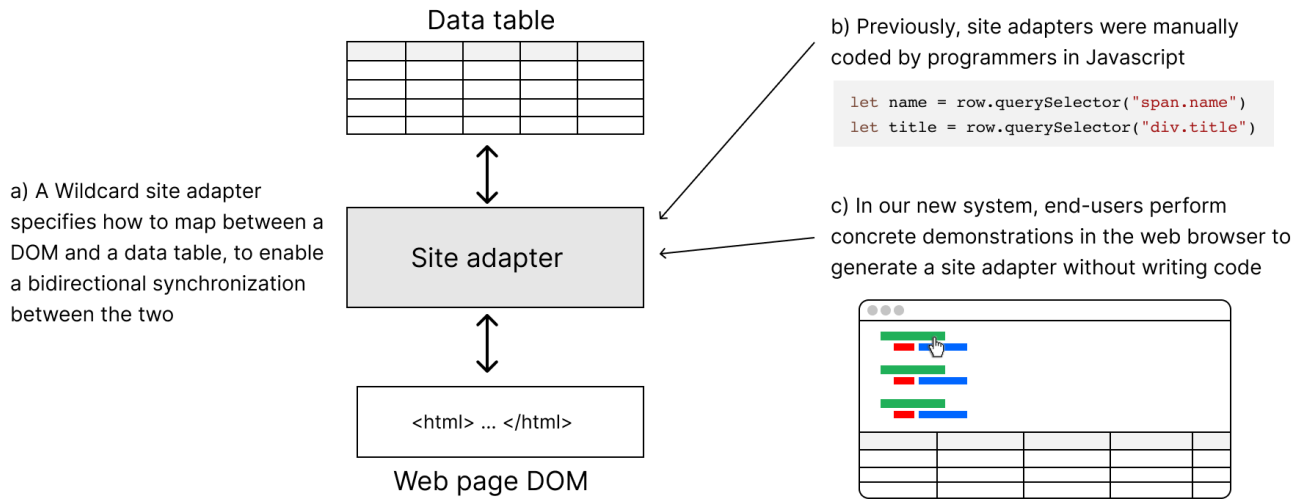


Figure 1: Our work enables end-users to create Wildcard site adapters by demonstration.

scraping system, an end-user can perform web customizations using Wildcard on arbitrary websites, without ever needing to code an adapter. Through a series of examples, we show that our system can create Wildcard adapters on a variety of websites via demonstration (Section 2). We also describe key aspects of our system and how web scraping for customization leads to a constraint that simplifies the *wrapper induction* [8] task used to generalize user demonstrations (Section 3).

Our key contribution is a set of three design principles that guided the development of our system, which also offer insights that might be applied to other end-user web scraping and customization tools (Section 4):

- **Unified Environment:** Users should be able to scrape data and interact with the scraped data in a single, unified environment. This minimizes the barrier to fluidly switching back and forth between the two tasks, rather than treating them as entirely independent tasks.
- **Editing By Demonstration:** Users should be able to not only create programs for scraping data by demonstration, but also extend and repair the programs by demonstration. This enables users to build on other user’s work, and is especially important in the context of web scraping since programs that scrape data sometimes break as the underlying website changes.
- **Live Programming:** Users should receive live feedback as they perform demonstrations. The system should indicate how it is generalizing from the user’s example and what the resulting data will look like, so that the user can adjust their demonstrations on the fly and quickly arrive at the desired result.

Finally, we share our broader vision for web scraping for customization, and some opportunities for future work, including a proposal for how Wildcard’s spreadsheet-like formula language might augment demonstrations to provide end-users with more expressiveness in the web scraping process (Section 6).

2 MOTIVATING EXAMPLES

In this section, we show how end-users can create, extend and repair adapters for Wildcard via demonstration. These demos are best viewed as videos in the online version of this paper (<https://kapaya.github.io/px21>).

2.1 Creating An Adapter

Jen wants to customize her experience on Weather.com by sorting the ten-day forecast based on the description of the weather on each day, allowing her to easily view all the sunny days. She starts the adapter creation process by clicking a context menu item within the Weather.com page, and hovers over a data value she might like to scrape.

- The selected row of data is annotated in the page with a border, to indicate that she will be demonstrating values from within that row (1 in Figure 2).
- The selected column of data is highlighted in the page with a green background, to show how the system has generalized her demonstration across all the rows in the data (3 & 4 in Figure 2).
- A table view appears at the bottom of the screen, and displays how the values will appear in the data table (5 in Figure 2).

File for up to 50% less than TurboTax Alt + click (option instead of alt on Mac) on a field you wish to scrape

1 A 2 Restart Cancel Done

3 10 Day Weather - Boston, MA
As of 12:26 am EST

4

5

6

7

Wildcard v0.2

	A	B	C	D
1	Tonight			
2	Sun 14			
3	Mon 15			
4	Tue 16			
5	Wed 17			
6	Thu 18			
7	Fri 19			
8	Sat 20			
9	Sun 21			
10	Mon 22			

10 Day Weather - Boston, MA
As of 12:26 am EST

Tonight --/25° Snow Showers 56% NE 10 mph

Sun 14 32°/28° Cloudy 24% NNW 8 mph

Mon 15 33°/31° PM Snow Showers 64% N 8 mph

Tue 16 36°/16° Rain/Snow 89% N 14 mph

FACT
You'll get your maximum refund, guaranteed.

Wildcard v0.2

	A	B	C	D
1	Tonight	Snow Showers		
2	Sun 14	Cloudy		
3	Mon 15	PM Snow Showers		
4	Tue 16	Rain/Snow		
5	Wed 17	Mostly Sunny		
6	Thu 18	Snow		
7	Fri 19	Rain		
8	Sat 20	Partly Cloudy		
9	Sun 21	Mostly Sunny		
10	Mon 22	Partly Cloudy		

Figure 2: Creating an adapter: 1) column data will be scraped into, 2) system's controls, 3) demonstrated column value and row from which columns should be demonstrated from 4) column values determined by generalization algorithm 5) column values populated in table, 6) next column to scrape data into and 7) button to save adapter created by demonstration

Jen tries hovering over several other elements in the page, taking advantage of the live feedback environment to decide what data would be useful. After considering several options, she decides to save the date field in the first column of the table, and commits the action by clicking.

Next, she performs a similar process to fill the next column with the weather descriptions. After filling both columns, she also tries hovering over previously scraped data, and the toolbar at the top of the page indicates which column corresponds to the previously scraped data. Finally, she ends the adapter creation process (7 in Figure 2) and is able to immediately sort the forecast by the weather description column, because Wildcard provides a **unified environment** that combines both scraping and customizing.

2.2 Extending An Adapter

Jen uses Wildcard on timeanddate.com as can be seen from 1 in Figure 3. In addition to sorting the list of holidays in a year by the day of the week, she also wants to sort them by category so she can view all the federal holidays together. Previously, she would have needed to find a programmer to help her edit the adapter code to incorporate this additional data, but using our system's support for **editing by demonstration**, Jen can extend the adapter herself.

While viewing the website, she clicks the "Edit Adapter" button (2 in Figure 3) above the Wildcard table to initiate the adapter editing process. As she hovers over the currently scraped values, the columns they belong to are highlighted. Finally, she clicks on "Federal Holiday" (3 in Figure 3) to add the new column of data to the table (4 in Figure 3) and saves the changes (5 in Figure 3). Jen then proceeds to sort the list by the type of holiday without the intervention of a programmer.

2.3 Repairing An Adapter

Jen next visits Google Scholar to look up references for her thesis project. Unfortunately, the customization she had applied to sort publications by their title (which is not natively supported by Google Scholar) is no longer working. In fact, the column in the Wildcard table that contained all the publication titles is empty (1 in Figure 4), because the website's internals changed and broke the adapter's scraping logic. Jen can repair this on her own, again taking advantage of **editing by demonstration**.

Jen initiates the editing process (2 in Figure 4), and initially hovers over the desired value to demonstrate the column she wants to scrape. However, the **live programming** interface indicates to her that the values would be populated into column D; instead, she wants the values to be inserted into column A where they previously appeared. So, Jen clicks on the symbol for column A (3 in Figure 4) to indicate that she

wants to scrape the values into that column and demonstrates the first publication title (4 in Figure 4). The missing values are now back in the table (5 in Figure 4). She then proceeds to save her changes (6 in fig:repairing) and re-apply her customization to the website by sorting the publications by their title without the intervention of a programmer.

3 SYSTEM IMPLEMENTATION

We implemented our end-user web scraping system as an addition to the Wildcard browser extension. We start by describing our implementations of row and column generalization, live programming, and editing by demonstration, and then discuss some of the current limitations of our system.

3.1 Generalization Algorithms

In order to generate reusable scrapers from user demonstrations, our system solves the *wrapper induction* [8] task: generalizing from a small set of user-provided examples to a scraping specification that will work on other parts of the website, and on future versions of the website.




We take an approach similar to that used in other tools like Vegemite [11] and Sifter [7]:

- We generate a single *row selector* for the website: a CSS selector that returns a set of Document Object Model (DOM) elements corresponding to individual rows of the table.
- For each column in the table, we generate a *column selector*, a CSS selector that returns the element containing the column value within that row.

One important difference is that our algorithm only accepts row elements that have direct siblings with a similar structure. We refer to this as the *row-sibling* constraint. Later in this section, we describe how the constraint provides a useful simplification of the wrapper induction task and discuss the resulting limitations this puts on our system in a section that follows.

When a user first demonstrates a column value, the generalization algorithm is responsible for turning the demonstration into a row selector that will correctly identify all the row elements in the website and a column selector that will correctly identify the element that contains the column value within a row element. During subsequent demonstrations, the generalization algorithm uses the generated row selector to find the row element that contains the column value and generates a column selector which identifies the corresponding column element.

At a high level, the generalization algorithm's challenge is to traverse far enough up in the DOM tree from the demonstrated element to find the element which corresponds to the row. We solve this using a heuristic; the basic intuition is to find a large set of elements with similar parallel structure.

Home ▾ World Clock ▾ Time Zones ▾ Calendar ▾ Weather ▾ Sun & Moon ▾ Timers ▾ Calculators ▾ Apps & API ▾ Free Fun ▾   

Showing: 257 All holidays and national observances ▾ For: 2021 ▾

Jump to: [Next](#) | [JAN](#) | [FEB](#) | [MAR](#) | [APR](#) | [MAY](#) | [JUN](#) | [JUL](#) | [AUG](#) | [SEP](#) | [OCT](#) | [NOV](#) | [DEC](#)

Holidays and Observances in United States in 2021

Date	Name	Type	Details
Jan 1 Friday	New Year's Day	Federal Holiday	
Jan 6 Wednesday	Epiphany	Christian	
Jan 7 Thursday	Orthodox Christmas Day	Orthodox	
Jan 13 Wednesday	Stephen Foster Memorial Day	Observance	

Create Calendar With Holidays

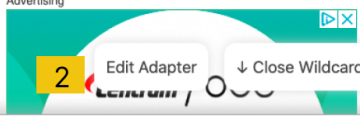
☒ Full year 2021

☐ Month February ▾

United States ▾


[View Calendar](#)

Advertising

 Edit Adapter ↓ Close Wildcard Table

Wildcard v0.2

	A	B	C	D
1	Jan 1	New Year's Day	Friday	
2	Jan 6	Epiphany	Wednesday	
3	Jan 7	Orthodox Christmas Day	Thursday	
4	Jan 13	Stephen Foster Memorial Day	Wednesday	
5	Jan 14	Orthodox New Year	Thursday	
6	Jan 18	Martin Luther King Jr. Day	Monday	
7	Jan 18	Robert E. Lee's Birthday	Monday	
8	Jan 18	Idaho Human Rights Day	Monday	
9	Jan 18	Civil Rights Day	Monday	
10	Jan 19	Robert E. Lee's Birthday	Tuesday	

Home ▾ World Clock ▾ Time Zones ▾ Calendar ▾ Weather ▾ Sun & Moon ▾ Timers ▾ Calculators ▾ Alt + click (option instead of alt on Mac) on a field you wish to extend 

[A](#) [B](#) [C](#) [D](#) [Restart](#) [Delete](#) [Save](#)

Showing: 257 All holidays and national observances ▾ For: 2021 ▾

Jump to: [Next](#) | [JAN](#) | [FEB](#) | [MAR](#) | [APR](#) | [MAY](#) | [JUN](#) | [JUL](#) | [AUG](#) | [SEP](#) | [OCT](#) | [NOV](#) | [DEC](#)

Holidays and Observances in United States in 2021

Date	Name	Type	Details
Jan 1 Friday	New Year's Day	Federal Holiday	
Jan 6 Wednesday	Epiphany	Christian	
Jan 7 Thursday	Orthodox Christmas Day	Orthodox	
Jan 13 Wednesday	Stephen Foster Memorial Day	Observance	

Create Calendar With Holidays


☒ Full year 2021

☐ Month February ▾

United States ▾

[View Calendar](#)

Advertising



Wildcard v0.2

	A	B	C	D
1	Jan 1	New Year's Day	Friday	Federal Holiday
2	Jan 6	Epiphany	Wednesday	Christian
3	Jan 7	Orthodox Christmas Day	Thursday	Orthodox
4	Jan 13	Stephen Foster Memorial Day	Wednesday	Observance
5	Jan 14	Orthodox New Year	Thursday	Orthodox
6	Jan 18	Martin Luther King Jr. Day	Monday	Federal Holiday
7	Jan 18	Robert E. Lee's Birthday	Monday	State holiday
8	Jan 18	Idaho Human Rights Day	Monday	State holiday
9	Jan 18	Civil Rights Day	Monday	State holiday
10	Jan 19	Robert E. Lee's Birthday	Tuesday	State holiday

Figure 3: Extending an adapter: 1) table showing current columns and rows, 2) button for initiating adapter extension process, 3) new column value demonstrated and generalized, 4) new column values in the table and 5) button to save adapter extended by demonstration.

TITLE	CITED BY	YEAR
Privacy suites: shared privacy for social networks. J Bonneau, J Anderson, L Church SOUPS 9, 1-2	157	2009
Cognitive dimensions: Achievements, new directions, and open questions TRG Green, AE Blandford, L Church, CR Roast, S Clarke Journal of Visual Languages & Computing 17 (4), 328-365	82	2006
Modern code review: a case study at google C Sadowski, E Söderberg, L Church, M Sipko, A Bacchelli Proceedings of the 40th International Conference on Software Engineering ...	80	2018
Privacy stories: confidence in privacy behaviors through end user programming. L Church, J Anderson, J Bonneau, F Stajano SOUPS	70	2009
The Abstract is an Enemy: Alternative Perspectives to Computational Thinking. AF Blackwell, L Church, TRG Green PPIG, 5	39	2008

h-index 11 8

i10-index 11 7

2

Edit Adapter

Close Wildcard Table

1

Wildcard v0.2

	A	B	C	D
1		157	2009	
2		82	2006	
3		80	2018	
4		70	2009	
5		39	2008	
6		34	2012	
7		19	2010	
8		19	2008	
9		15	2009	
10		14	2016	

3

Programming Experience

Philosophy and Psychology...

Integrating Intelligences

Alt + click (option instead of alt on Mac) on a field you wish to scrape

6

ape

Restart Delete Save

TITLE	CITED BY	YEAR
Privacy suites: shared privacy for social networks. J Bonneau, J Anderson, L Church SOUPS 9, 1-2	157	2009
Cognitive dimensions: Achievements, new directions, and open questions TRG Green, AE Blandford, L Church, CR Roast, S Clarke Journal of Visual Languages & Computing 17 (4), 328-365	82	2006
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Privacy stories: confidence in privacy behaviors through end user programming. L Church, J Anderson, J Bonneau, F Stajano SOUPS	70	2009

Citations 642 400

h-index 11 8

i10-index 11 7

5

Wildcard v0.2

	A	B	C	D
1	Privacy suites: shared privacy for social netwo	157	2009	
2	Cognitive dimensions: Achievements, new dire	82	2006	
3	Modern code review: a case study at google	80	2018	
4	Privacy stories: confidence in privacy behavio	70	2009	
5	The Abstract is an Enemy: Alternative Perspec	39	2008	
6	Sketching across design domains: Roles and	34	2012	
7	Liveness in Notation Use: From Music to Prog	19	2010	
8	Formality in sketches and visual representation	19	2008	
9	Generative usability: security and user center	15	2009	
10	Software and How it Lives On-Embedding Live	14	2016	

Figure 4: Repairing an adapter: 1) empty column in table because website changed and adapter can no longer scrape values, 2) button for initiating adapter repair 3) column to scrape data into, 4) missing column value demonstrated and generalized, 5) missing column values back in the table and 6) button to save adapter repaired by demonstration.

Consider the following sample HTML layout, which displays a truncated table of superheroes, with each row containing some nested structure:

The user performs a demonstration by clicking on element (a) in Figure 5 containing “Tony Stark.” Our algorithm traverses upwards from the demonstrated element, considering each successive parent element ((b1), (c1) and (d) in Figure 5) as a potential candidate for the row element. For each parent element n , the process is as follows:

1. compute a column selector s that when executed on n only returns the demonstrated element
2. for each sibling m of n , execute s on m and record whether the selector returned an element. Intuitively, if the selector returns an element, this suggests that the sibling m has some parallel structure to n
3. compute $n_{siblings}$, the number of sibling elements of n for which s returned an element

Notice how the *row-sibling constraint* simplifies the problem: row candidates without siblings that return an element after s is executed on them ((b1) in Figure 5) have $n_{siblings} = 0$, thus disqualifying them. Furthermore, a candidate element n is only accepted as the row element if the row selector $n_{selector}$ associated with it only matches itself and elements that are its direct siblings.

The algorithm stops traversing upwards once it reaches the BODY element. Then, it generates a selector $n_{selector}$ for each n and discards any n with an $n_{selector}$ that matches elements that are either not itself or a direct sibling. Finally, the algorithm picks an n with the largest, positive $n_{siblings}$, preferring nodes lower in the tree as a tiebreaker. $n_{selector}$ is used as the selector for the row and s is used as the selector for the column. The row and column selectors are used to generate a scraping adapter which returns the DOM elements corresponding to a superhero data row in the table and sets up the bidirectional synchronization.

3.2 Live Programming

Live programming is implemented by continually running the generalization algorithm on the DOM element under the user’s cursor, reverting if the user hovers away and committing when the user clicks. The generated row and column selectors are used to highlight all the matching elements on the website and create an adapter. Highlighting all the matching column elements on the website provides visual feedback about the system’s generalization to the user. Creating an adapter enables the system to populate the table view and set up the bidirectional synchronization. Because the table is populated and the bidirectional synchronization is set up, users can customize as they scrape.

3.3 Editing By Demonstration

Our system generates adapters with the row selector and the column selectors used to scrape the data. The row selector is a CSS selector that identifies all the row elements of the data and the column selectors are CSS selectors that identify each column’s column elements.

When the editing process is initiated, the adapter’s row selector and column selectors are used to highlight the previously scraped values on the website. Furthermore, the generalization algorithm takes the adapter’s row selector and uses it as the basis to generate new column selectors after each demonstration. When a new column is demonstrated, our system appends the generated column selector to the list of column selectors. This is how adapters are extended to create new columns. When an existing column is demonstrated, our system replaces the column’s current column selector with the generated column selector. This is how adapters are repaired to fix broken columns.

Extending and repairing adapters in this manner is feasible because column selectors are independent of each other: changing one column’s selector does not affect another column’s selector. This is not the case for system’s in which the output of demonstrations are dependent on each other. For example, in a web automation sequence that involves clicking on a button to open a menu and then entering text into the menu’s text input, the step that enters the text is not independent because it depends on the step that clicks the button to open the menu.

3.4 Limitations

The row-sibling constraint we mentioned earlier is important for the end goal of customization because row elements that are not direct siblings may not represent data on the website that should be related as part of the same table by customizations such as sorting and filtering.

For *Generalization Limitation 1* shown in Figure 6, without the constraint that row elements have to be direct siblings, the row generalization algorithm could determine the row selector to be *.avenger* (elements with blue border in Figure 6) because it matches the largest number of parallel structures (has the largest $n_{siblings}$). While this may be the correct result for the task of extraction, it is not for the task of customization. The selector matches all rows across the two tables so the sorting and filtering customizations could place rows in the incorrect table and thereby distort what the tables represent. Because of this, our system currently does not support such DOM structures but we plan to explore the possibility of extracting multiple tables from a website and joining them.

For *Generalization Limitation 2* shown in Figure 6, website contains one table of data in which rows are made up of the

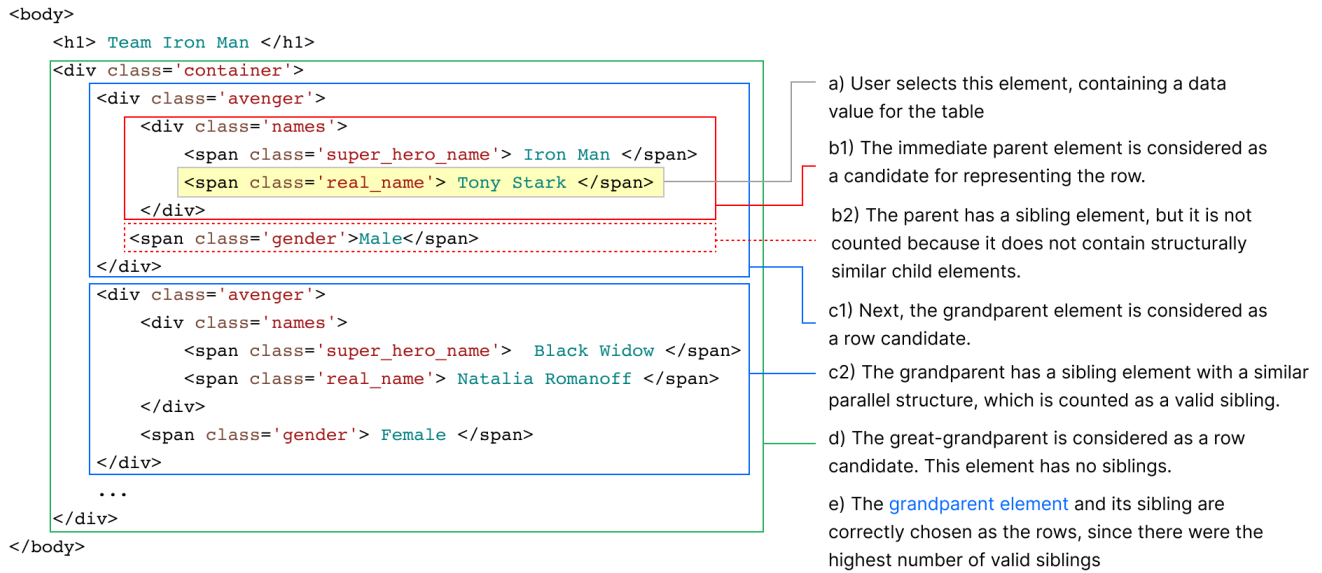


Figure 5: Our system applies a heuristic to identify DOM elements that correspond to rows in the data table.

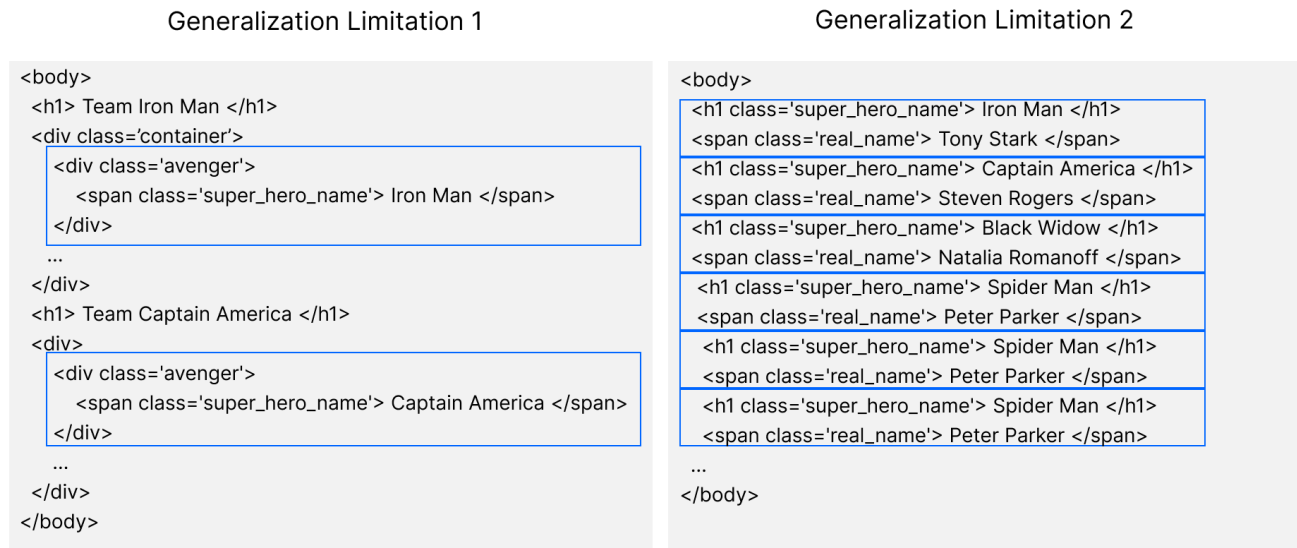


Figure 6: Our generalization algorithm cannot generalize on websites with the shown layouts. The elements with the blue border correspond to rows of the data in each layout respectively.

alternating H1 and SPAN tags (elements with blue border in Figure 6). For the task of extraction, the DOM elements can be scraped using the shown classes to output a table in which the values of the H1 tags form the first column and the values of the SPAN tag form the second column. For the

task of customization, our system would need to know what the row boundaries were in order for customizations such as sorting and filtering to work as expected. In Wildcard, this can be done with a hand-coded adapter by creating artificial row boundaries. In the above DOM structure, an artificial

row boundary could be created by representing a row as an H1 tag and the SPAN tag that immediately follows it. These artificial rows would form a single unit which would not distort the website after a sorting or filtering customization. We plan to explore how such artificial row boundaries might be created via demonstration in order to support these structures (which are not uncommon, and can be seen, for example, in HackerNews).

4 DESIGN PRINCIPLES

Below, we discuss the three design principles underlying our work and how they relate to the broader field of end-user web scraping and customization.

4.1 Unified Environment

In the previous iteration of Wildcard, web scraping was an entirely separate activity from customization. Programmers that wrote scraping adapters would need to switch into an IDE to write code as part of customizing a new website.

This type of divide between tasks appears in other domains. In data science, workflows revolve between cleaning and using data but this often happens in different environments. The creators of Wrex [5], an end-user programming-by-example system for data wrangling, reported that “although data scientists were aware of and appreciated the productivity benefits of existing data wrangling tools, having to leave their native notebook environment to perform wrangling limited the usefulness of these tools.” This was a major reason Wrex was developed as an add-on to Jupyter notebooks, the environment in which data scientists use their data. In web scraping, if a user comes across an omission while working with data scraped from a website, they need to switch from the environment in which they are using the data to the environment in which they wrote their scraping code in order to edit and re-run it. In web customization, Vegemite [11], a system for end-user programming of mashups, reported that participants of its user study thought “it was confusing to use one technique to create the initial table, and another technique to add information to a new column.” This hints at the need for a unified environment and a unified workflow.

In this work, we have combined scraping and customization into a single, unified environment with a unified workflow. The goal is to minimize the environment switch between *extracting* the data and *using* the data. A user might start out by scraping some data on a website, and then switch to customizing the website using the results. Then, they might realize they need more data to perform their desired task, at which point they can easily extend the adapter by demonstrating new columns. All of these tasks take place right in the browser, where the user was initially already

using the website. Instead of bringing the data to another tool, we have brought a tool to the data. This directly relates to the idea of “in-place toolchains” [1] being an integral part of end-user programming systems.

Of course, there is value in specialized tools: Wildcard has nowhere near the full capabilities of spreadsheet software or databases. Nevertheless, we believe a single, unified environment for scraping and customization presents a significantly lower barrier to entry for customization.

4.2 Editing By Demonstration

Many end-user web scraping and macro systems allow users to *create* programs by demonstration but do not offer a way to *edit* them by demonstration. In Rousillon [4], a web scraping program created by demonstration can only be edited through a high-level, block-based programming language called Helena [2] which does not support providing new demonstrations to extend or repair the scraping code. In Vegemite [11], a web automation program created through demonstration can only be edited by editing the text-based representation of the program.

In Wildcard, if a website’s hand-coded adapter ceases to function because the website changes, the table may lose its data which means that an end-user’s customizations may also cease to function. Furthermore, end-users are powerless to extend the scraping adapter to add columns to the table in order to perform new customizations. This goes against MacLean et. al.’s vision of user-tailorable systems [13] that give users “a feeling of ownership of the system, to feel in control of changing the system and to understand what can be changed.” Providing an easy way for users to edit programs is therefore fundamental to fully democratizing web customization.

Editing by demonstration makes end-users first-class citizens in the customization ecosystem. Because users interact with the scraped data directly in the context of the website, it is easy to initiate the scraping system in editing mode: the scraping system is simply booted up using metadata stored with the scraping adapter to the state when the demonstration was completed. Users that have gone through the creation process will immediately realize what to do in order to extend or repair the adapter. Users that have not gone through the creation process might have a harder time but we provide visual clues (such as highlighting the row to perform demonstrations from with a green border) and live programming (immediately preview the results of demonstrations) that serve as guides.

As discussed in Section 3, editing by demonstration in the web scraping domain is feasible because column selectors are independent of each other. However, this is not the case with row selectors because column selectors are dependent

on them. Our system therefore does not support editing rows but this an acceptable limitation given our focus on extension and repair which only involve column selectors.

4.3 Live Programming

In some end-user web scraping systems like Rousillon [4], users only get *full* feedback about the program's execution (generalization and the scraped values) after providing all the demonstrations. This means they cannot adjust their demonstrations in response to the system's feedback as they demonstrate.

Our end-user web scraping system employs live programming techniques to eliminate this edit-compile-debug cycle by running the generalization algorithm and generating an adapter after each user demonstration. As we showed in Section 2, when a user demonstrates a value of a column they wish to scrape, our system immediately shows how it has generalized the user's demonstration across the other rows of the data by highlighting the all relevant values. It also populates the table with the scraped data based on the latest demonstration. The highlighting and table population serve to give users a view of how their demonstration has been generalized and what data will be available in the table once scraped.

Many successful end-user programming systems such as spreadsheets and SQL provide users with immediate results after entering commands. Our live programming environment is particularly similar to that of FlashProg [14], a framework that provides user interface support for programming-by-demonstration systems like FlashExtract [9], and relates to the idea that an important quality of end-user programming is "interaction with a living system" [1].

Unlike text-based commands which are only valid once complete (e.g `SELECT * FRO` versus `SELECT * FROM user_table`), the target of demonstration commands (the value of a DOM element under the cursor) is the same during both hover and click (incomplete command versus complete command). This allows us to take a small step further by executing a command before a user completes it, thereby providing them with a preview of the results on hover.

There are limits to this approach. Providing live feedback on websites with a large number of DOM elements or complex CSS selectors can slow down the generalization process, especially if a user is constantly moving their cursor. Furthermore, many datasets are too large to preview in the table in their entirety; the user might benefit more from the live feedback if it could summarize large datasets. For example, FlashProg provides a summary of the generalization through a color-coded minimap next to the scrollbar of its extraction interface.

5 RELATED WORK

End-user web scraping for customization relates to existing work in end-user web scraping by a number of tools.

FlashProg [14] is a framework that provides user interface support for FlashExtract [9], a framework for data scraping by examples. FlashProg's interface provides immediate visual feedback about the generalization and scrapes the matched values into an output tab. In addition, it has a program viewer tab that contains a high level description of what the generated program is doing and provides a list of alternative programs. Finally, it has a disambiguation tab that utilizes conversational clarification to disambiguate programs, the conversations with the user serving as inputs to generate better programs. Though FlashProg has many desirable features we aim to implement in future iterations, it does not offer a unified environment within a browser for scraping and customizing websites.

Rousillon [4] is a tool that enables end-users to scrape distributed, hierarchical web data. Its interface does not provide *full* live feedback about its generalizations or the values to be scrapped until all the demonstrations have been provided and the generated program has been run. If run on a website it has encountered before, Rousillon makes all the previously determined generalizations visible to the user by color-coding the values on the website that belong to the same column. This is a desirable feature for our system as users will not have to actively explore in order to discover which values are available for scraping and how they are related to each other. On the extension and repair front, Rousillon presents the web scraping code generated by demonstration as an editable, high-level, block-based language called Helena [2]. While Helena can be used to perform more complex editing tasks like adding control flow, it presents a change in the model used for creation. Our system maintains the model used for creation by allowing users to extend and repair web scraping code via demonstration.

Vegemite [11] is a tool for end-user programming of mashups. It has two interfaces: one for scraping values from a website and another for creating scripts that operate on the scraped values. The web scraping interface does not provide live feedback about the generalization on hover but after a user clicks, the interface shows the result of the system's generalization by highlighting the all matched values. Furthermore, even though the interface also has a table, the table is only populated with the scraped values after all the demonstrations have been provided. The scripting interface utilizes CoScripter [10] which is used to record operations on the scraped values for automation. For example, the scripting interface can be used to demonstrate the task of copying an address in the table, pasting it into a walk score calculator and pasting the result back into the table. The script would

then be generalized to all the rows and re-run to fill in the remaining walk scores. CoScripter provides the generated automation program as text-based commands, such as “paste address into ‘Walk Score’ input,” which can be edited after the program is created via “sloppy programming” [11] techniques. However, this editing does not extend to the web scraping interface used for demonstrations.

Sifter [7] is a tool that augments well structured websites with advanced sorting and filtering functionality. Like Wildcard, it uses web scraping to extract data from websites in order to enable customizations (sorting and filtering). Unlike Wildcard, it does not support adding annotations to websites and running computations on the scraped data using a spreadsheet formula language. Both of these significantly expand the types of customizations end-users can make to websites. Sifter performs the web scraping automatically using a variety of heuristics and solicits guidance from the user if this fails. While automatic web scraping seems desirable, it is unclear how useful it is if the goal is customization. Given a row with ten scrapable values, and therefore ten columns, would a user prefer to simply demonstrate the value for the single column they are interested in or un-demonstrate the nine values they are not interested in? This is a question we can only answer after performing a user study.

6 CONCLUSION AND FUTURE WORK

In this paper, we presented our progress towards *end-user web scraping for customization*, to empower end-users in Wildcard’s ecosystem to create, extend and repair scraping adapters. There are several outstanding issues and open questions we hope to address in future work.

Like existing approaches, web scraping in our current implementation is limited to what can be demonstrated. This is problematic if users want to scrape the URL associated with a link element, which is not visible, or only scrape a substring of a value. To solve this, we plan to harness Wildcard’s formula language. End-users will be able to use formulas targeted at web scraping to access DOM element properties and attributes. For example, a formula like `=GetAttribute(link_column, 'href')` could be used to scrape URLs of link elements. End-users will also be able to use formulas targeted at data processing. For example, a formula like `=GetSubstring(name_column, 1, 2)` could be used to scrape substrings of text values. Such web scraping and data processing formulas will give end-users some of the power available to programmers that write web scraping code in Javascript which supports a wide variety of DOM access and processing ability.

To assess our design principles, we plan to carry out a broader evaluation of our system through a user study. So far, we have only tested the system amongst ourselves and

a small number of colleagues. More testing is needed to understand whether it can be successfully used among a broader set of users across a wider variety of websites. Furthermore, we plan to incorporate the program viewer and disambiguation features of FlashProg [14] to give users more insight and control into the generalization process.

Our end goal is to empower end-users to customize websites in an intuitive and flexible way, and thus make the web more malleable for all of its users.

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