CISPA
HELMHOLTZ CENTER FOR INFORMATION SECURITY

A Systematic Study of the Consistency of Two-Factor Authentication User Journeys on Top-Ranked Websites

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Network and Distributed System Security Symposium | 2023-03-02

Huffy Steering Wheel Bike, 1969
HuffyHistory, CC BY-SA 3.0, via Wikimedia Commons

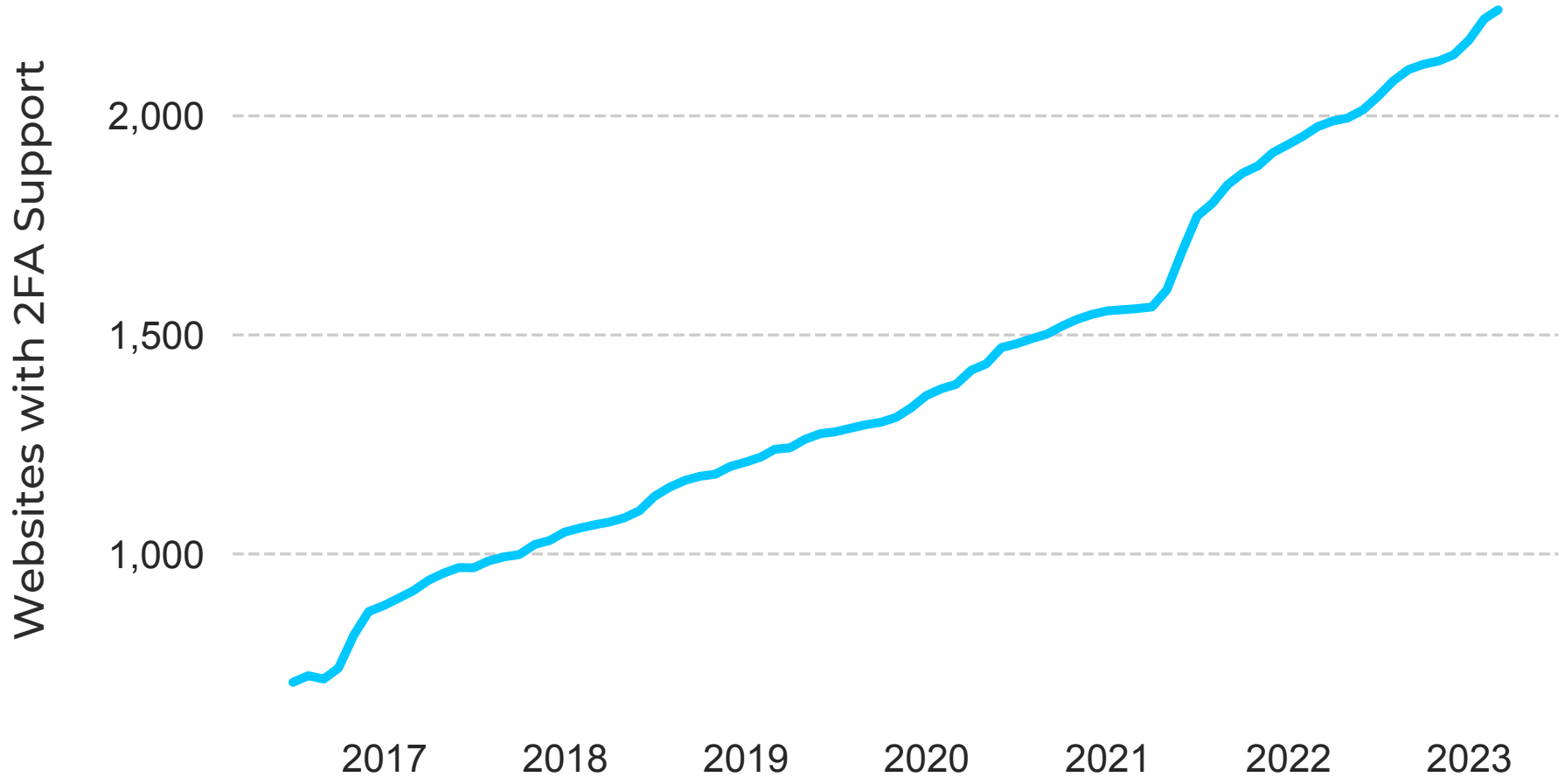
Would you buy this bicycle?

User Experience (UX) Heuristics

“Users spend most of their time on other sites. This means that users prefer your site to work the same way as all the other sites they already know.”

–Jakob’s Law

Increasing Adoption of 2FA

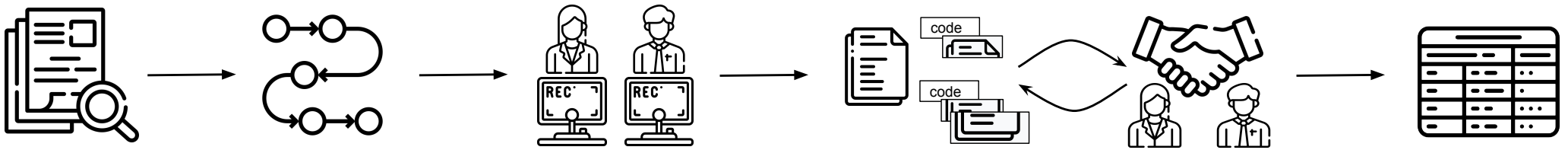


Data source: https://github.com/2factorauth/twofactorauth

How consistent is the 2FA user experience across different websites?

What are the factors to compare the 2FA user journeys of different websites?

Our Methodology



Literature review

Basic structure of user journeys

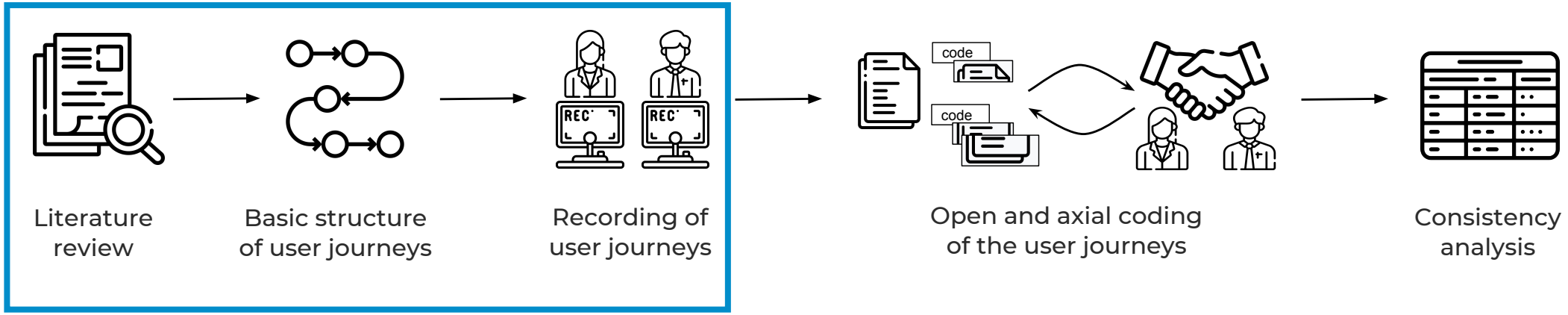
Recording of user journeys

Open and axial coding of the user journeys

Consistency analysis

Our Methodology

Data collection



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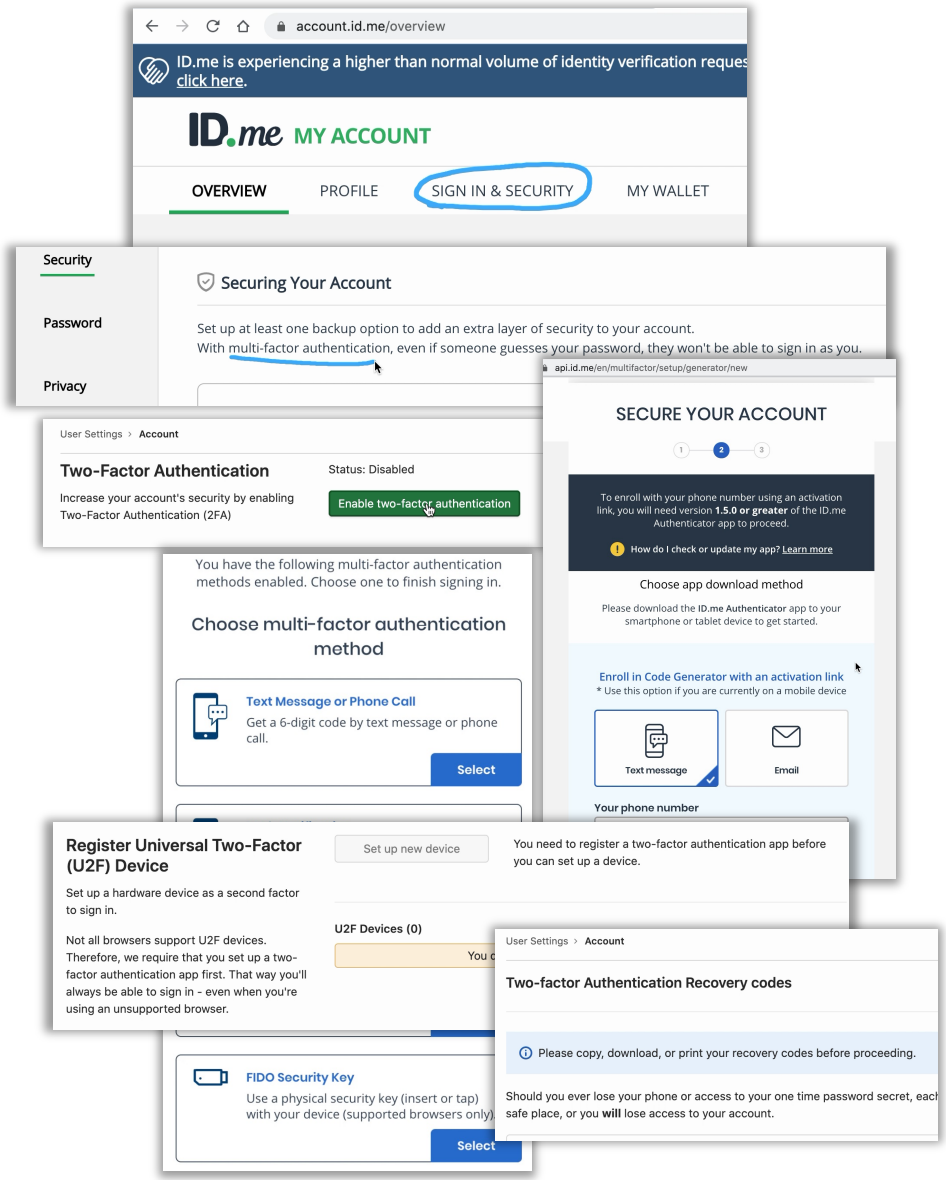
Data Collection: Approach



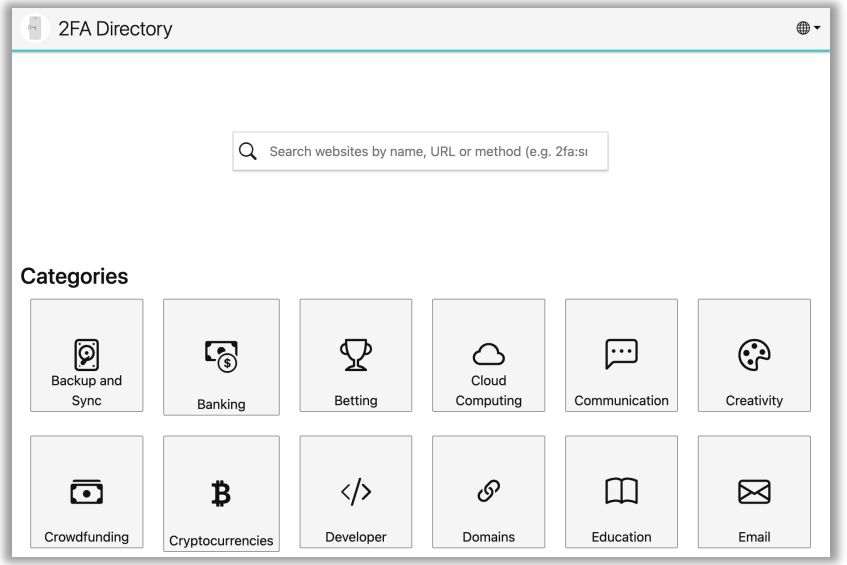
- Researchers independently explored and screen-recorded the 2FA user journeys

- Basic structure of exploration consists of 5 steps:
  - Discovery
  - Education
  - Setup
  - Usage
  - Deactivation

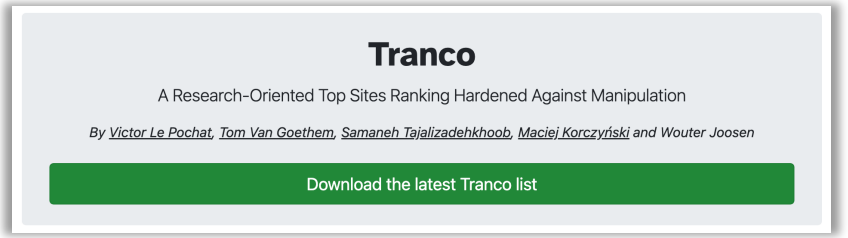
Data Collection: Data Set

- Websites chosen from the 2fa.directory data set
  - Websites ranked by Tranco data set
  - Top-ranked websites for each 2fa.directory category

- Final data set 85 websites

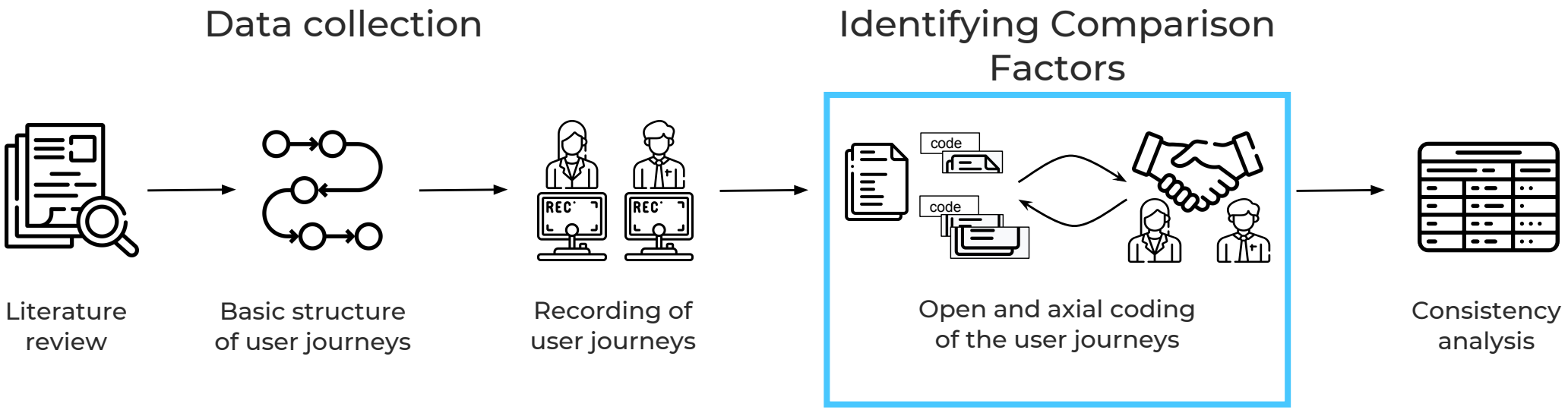


https://2fa.directory/



https://tranco-list.eu/

Our Methodology



Identifying Comparison Factors

- Emergent coding to identify factors: open and axial coding
  - Segment the user journeys into meaningful parts and assign codes (“concepts”)
  - Combine codes via induction and deduction into categories (=factors)

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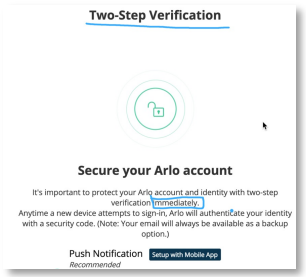
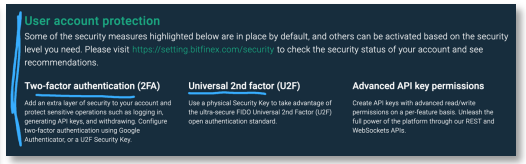
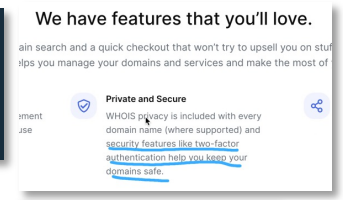
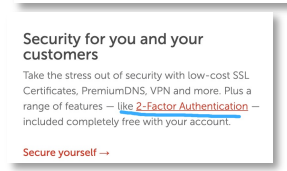
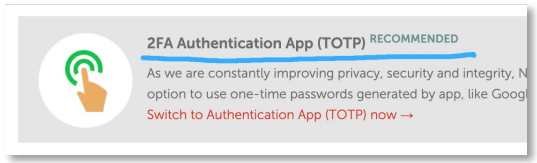




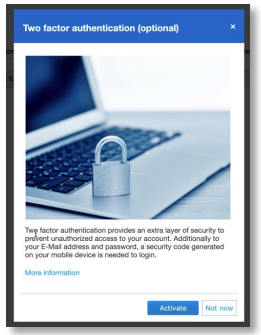
Code: “2FA advertised prior to account creation”







Code: “2FA advertised during/ after account creation”



Axial coding

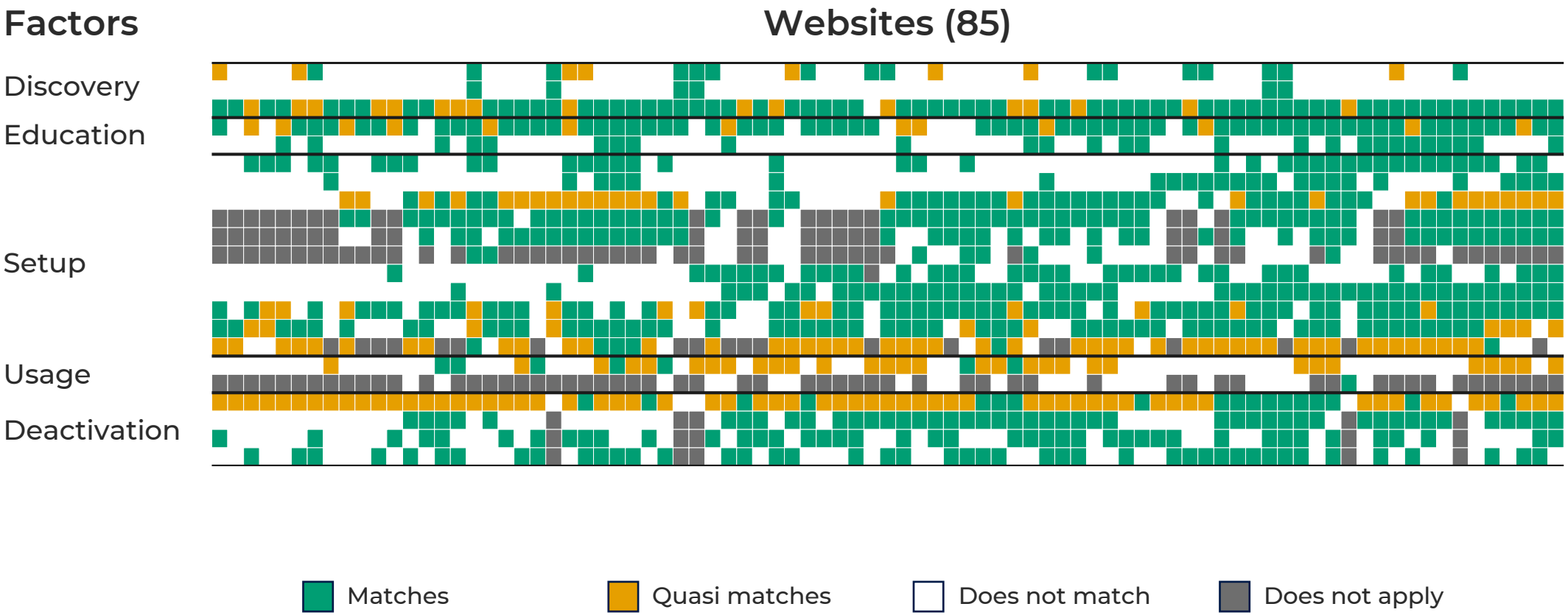
Factor:
“Promotion of 2FA”

Set of Comparison Factors

- 22 factors that either ■ match, ■ quasi-match, or □ do not match a website
  - 8 conditional factors that might ■ not be applicable to a website

Factors for Discovery						
D1	Promotion	■	■		□	
D2	Non-Optional	■			□	
D3	Common-Naming-and-Location	■	◪	◪	□	
Factors for Education						
E1	Descriptive-Notification	■	■		□	
E2	Additional-Information	■			□	
Factors for Setup						
S1	Option-Specific-Information	■			□	
S2	Step-Wise-Instructions	■			□	
S3	Multiselection	■	■		□	
S4	Grouped-Setting (S3)	■			□	■
S5	No-Enforced-Options (S3)	■			□	■
S6	Selectable-Primary-Option (S3)	■			□	■
S7	Settings-Changed-Verification	■			□	
S8	Settings-Changed-Notification	■			□	
S9	Confirm-Successful-Setup	■	■		□	
S10	Informed-2FA-Recovery-Options	■	■		□	
S11	Enforced-2FA-Recovery-Setup (S10)	■	■		□	■
Factors for Usage						
U1	Device-Remembrance	■	◪	◪	□	
U2	No-Preselected-Option (S3,S6)	■			□	■
Factors for Deactivation						
R1	Informed-Deactivation	■	■		□	
R2	Deactivation-Verification (R1)	■			□	■
R3	Deactivation-Notification (R1)	■			□	■
R4	Communicate-Successful-Deactivation (R1)	■			□	■

Final Dataset



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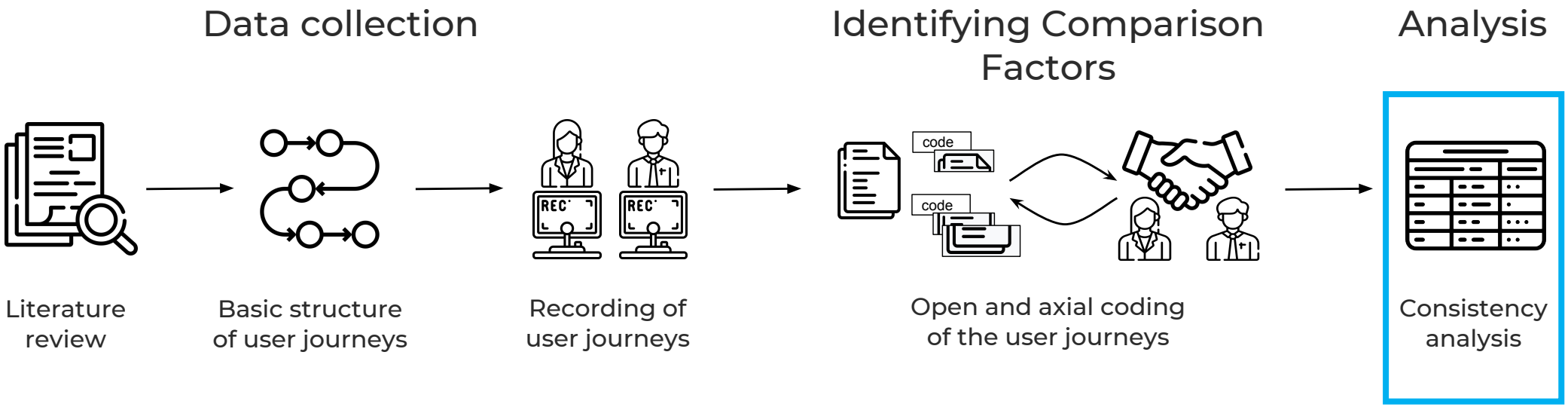
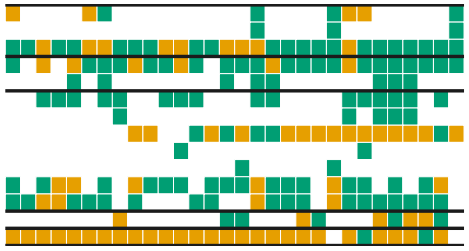


Consistency Across All Websites

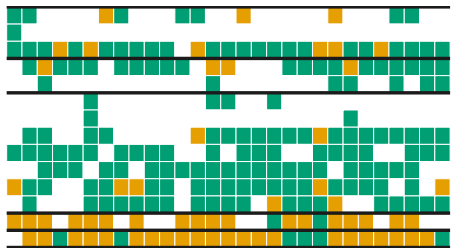
2FA user journeys and individual factors are
not very consistent across all 85 websites

Clusters of User Journeys

No predominant start-to-end strategy exists that is followed by the majority of websites

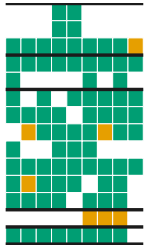


Cluster 1
(n = 30)

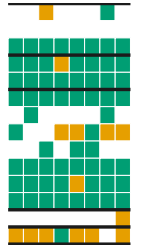


Cluster 2
(n = 29)

Cluster 3
(n = 4)



Cluster 4
(n = 9)



Cluster 5
(n = 8)

Cluster 6
(n = 5)

	Cluster 1 (n = 30)	Cluster 2 (n = 29)	Cluster 3 (n = 4)	Cluster 4 (n = 9)	Cluster 5 (n = 8)	Cluster 6 (n = 5)
How to inform and instruct users	1	1	1	2	2	2
How to support multiple 2FA options	1	2	2	2	1	1
Strategy for device remembrance	1	2	1	1	1	2

Qualitative Data Analysis

Consistent Discovery for Self-Motivated Users

Two-Factor Authentication is an opt-in feature on most websites

Consistent naming and location of the 2FA settings

Vast majority of websites did not *immediately* promote 2FA before/during/after account setup

Qualitative Data Analysis

Mixed Strategies for 2FA Setup and Configuration

Almost even split between three strategies:
1) “offering only one 2FA options”
2) “offering multiple 2FA options but only one can be active at a time”
3) “offering multiple 2FA options and supporting multiple active ones”

Half of the websites enforce a certain option (e.g., phone number) before allowing further options

Discussion

- Consistency does not guarantee good usability and UX
  - Example outlier in our data set: icloud.com
  - Consistent problematic design (e.g., nudges and descriptions in our data set)
  - This work: No attempt to assign a quality measurement to individual factors and overall 2FA UX

Discussion

- Consistency does not guarantee good usability and UX
  - Example outlier in our data set: icloud.com
  - Consistent problematic design (e.g., nudges and descriptions in our data set)
  - This work: No attempt to assign a quality measurement to individual factors and overall 2FA UX

- Limitations of qualitative studies and the study setup
  - Subjective bias by involved researchers
  - Skewed toward top-websites in English from certain categories
  - Only desktop client in Germany and collection between 06/21–08/21
  - Only user journey for account creation and initial 2FA setup

Conclusion

- Contributes a methodology for comparing 2FA user journeys on websites and the first systematic study of the consistency of those journeys

- No incumbent, consistent start-to-end design pattern for 2FA user journeys
  - Clusters of user journeys and individually consistent factors

- Call to action: Industry associations and the community could draft recommendations and guidelines for 2FA implementers
  - More insights needed: User and developer studies
  - Measure the impact of regulations on 2FA user journeys
  - Extending our methodology: Account recovery, other form factors, or passkeys

Backup Slides

Did users have negative experiences in transferring their 2FA knowledge?

Anectodal Evidence From Prior Work

- Did users have negative experiences in transferring their 2FA knowledge?
- Has this stopped them from enabling or using 2FA?

- Ciolino et al. ‘19 and Reynolds et al. ‘18:
  Evidence that users struggled with 2FA when the 2FA user journey did not match their expectations or previous experiences

S. Ciolino et al., “Of two minds about two-factor: Understanding everyday FIDO U2F usability through device comparison and experience sampling,” in SOUPS ’19

J. Reynolds et al., “A tale of two studies: The best and worst of Yubikey usability,” in IEEE SP ’18.

Survey Among 2FA Adopters

- Did users have negative experiences in transferring their 2FA knowledge?
- Has this stopped them from enabling or using 2FA?

- Survey on Prolific with 308 participants that have 2FA experience

- Summary: 60 (19.5%) participants reported using a website less, abandoning a website, or refusing the adoption of a (specific) 2FA option due to differences in experience

S. Ghorbani Lyastani, M. Backes, and S. Bugiel, “A systematic study of the consistency of two-factor authentication user journeys on top-ranked websites (extended version),” 2022. [Online]. Available: https://arxiv.org/abs/2210.09373

FIDO UX Guidelines

- Similar steps in the user journey (promotion, invitation, registration, login)
  - Implement some best practices (“learn more,” confirm successful registration with a clear indication to users, encourage users to set up multiple keys for recovery/backup, “Security Settings”)

- Goal: Promote biometric awareness for passwordless logins or security keys for consumers on regulated industry websites (banking, healthcare)
  - Not suitable as general guidelines
  - Either no intention to cover a 2FA setting or limit themselves to security keys as a second factor

Consistency Analysis: Individual Factors

Shannon entropy $H(x)$ of **non-conditional** factors:

	Comparison Factor	$\mathbf{H(x)}$	max
Two-point scale	Non-optional	0.37	1.0
	Additional-information	0.90	
	Option-specific-information	0.99	
	Stepweise-instructions	0.87	
	Settings-changed-verification	0.99	
	Settings-changed-notification	1.00	
Three-point-scale	Promotion	1.12	1.57
	Descriptive-notification	1.11	
	Multiselection	1.57	
	Confirm-successful-setup	1.24	
	Informed-2FA-recovery-options	1.26	
	Informed-deactivation	1.05	
Four-point-scale	Common-name-and-location	1.00	2.0
	Device-remembrance	1.60	

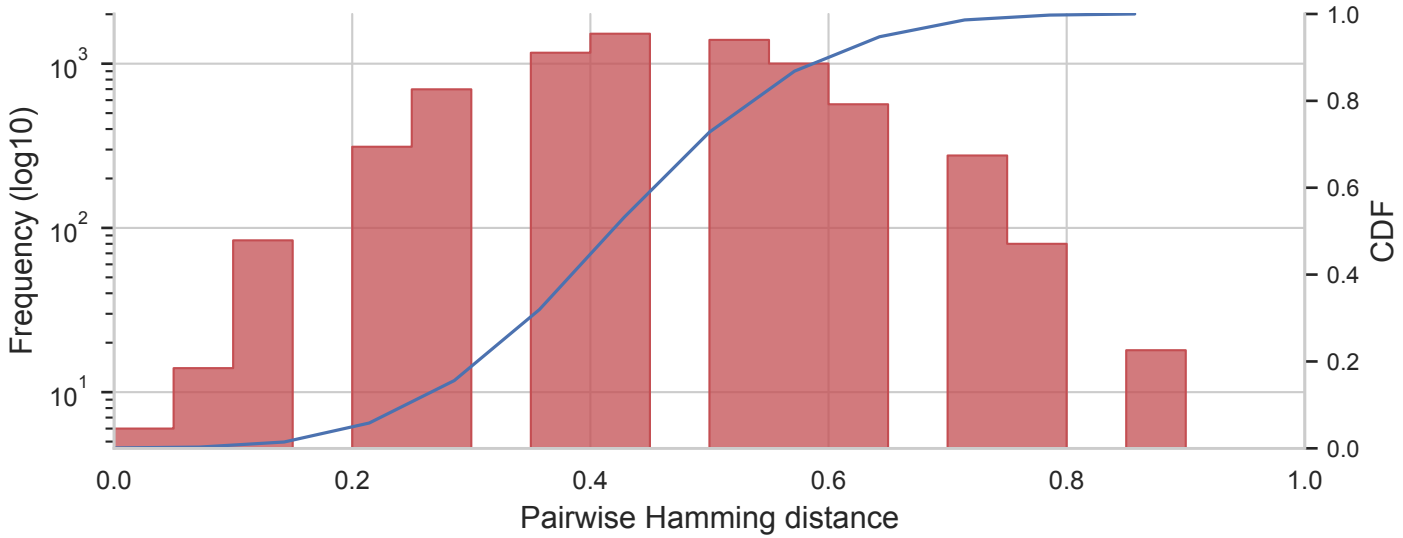
$\mathrm{H(x)} = 0$: Identical values

$\mathrm{H(x)} = \max$: Evenly split between values

Only the factors *Non-optional* and *Common-name-and-location* show high consistency across all websites

Consistency Analysis: Pairwise Comparison

- Pairwise Hamming distance of **non-conditional** factors between websites
  - "Overlap without weights"



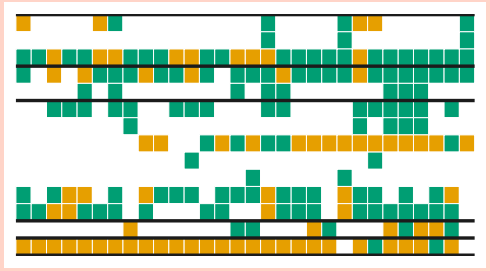
- 2FA user journeys are not very consistent across **all** 85 websites
  - Average website differs in 6–7 of 14 factors from the other websites

Clustering

- Are there clusters of websites with similar user journeys?

- Two-stage clustering process
  - Non-conditional factors: primary view of the websites' strategies for 2FA UX
  - Conditional factors: Subcluster for a more differentiated view of these strategies

Clustering: Non-conditional factors



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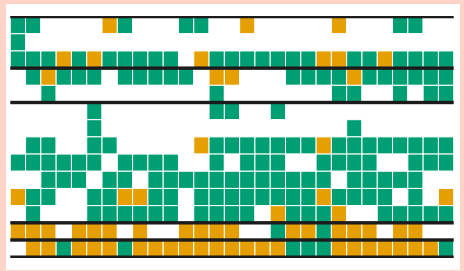
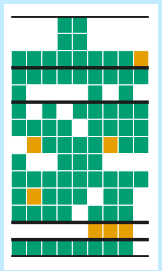


Cluster 2 (n = 29)

Cluster 3 (n = 4)



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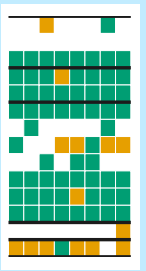


Cluster 5 (n = 8)

Cluster 6 (n = 5)

Verify 2FA settings changes and notify about them

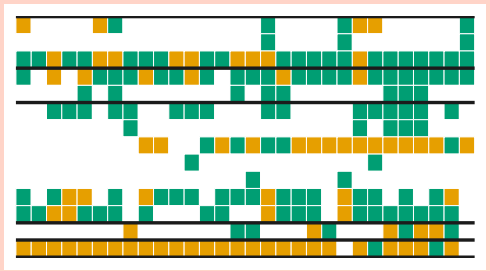
Provide additional information about 2FA

Give step-wise setup instructions

Give option-specific information

Warn about risks of 2FA deactivation (only Cluster 4)

Clustering: Non-conditional factors



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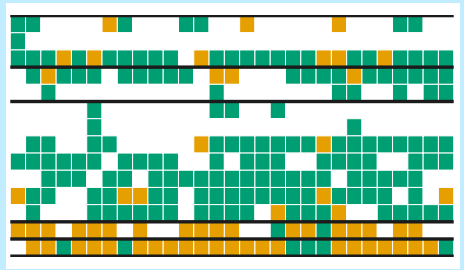

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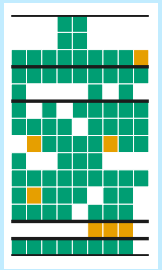

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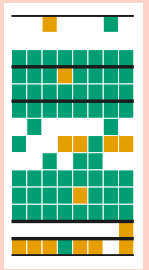

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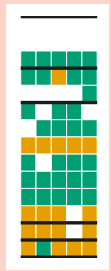
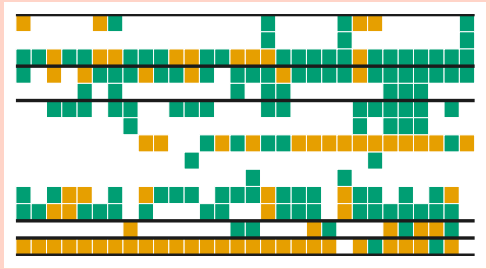


Cluster 6 (n = 5)

Allow multiple 2FA options to be activated simultaneously

Clustering: Non-conditional factors



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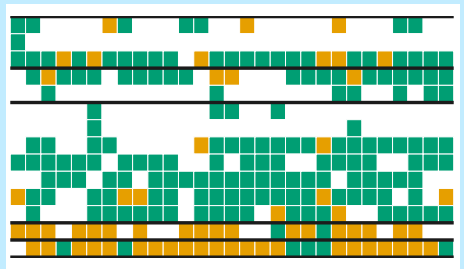
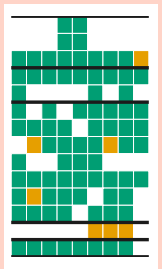


Cluster 2 (n = 29)

Offer device remembrance

Cluster 3 (n = 4)



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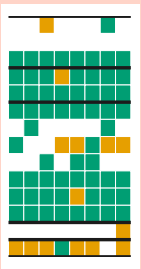
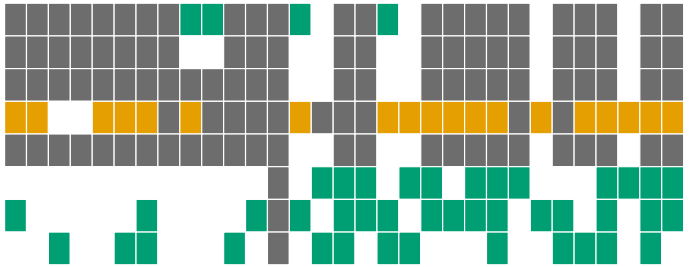


Cluster 5 (n = 8)

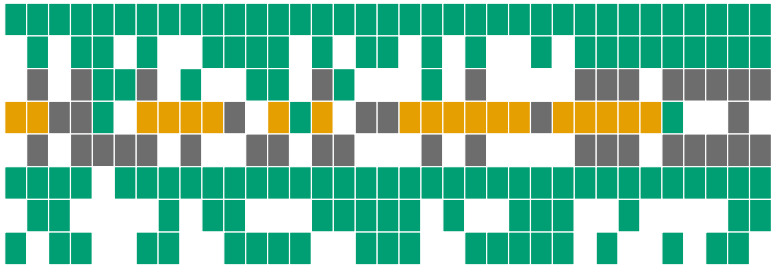
Cluster 6 (n = 5)

Sub-Clustering: Conditional factors



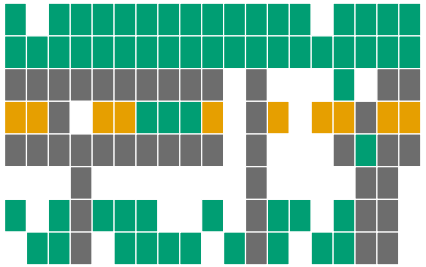
Subcluster 1 (n = 31)

No selection of multiple 2FA options or enforce a specific option



Subcluster 2 (n = 35)

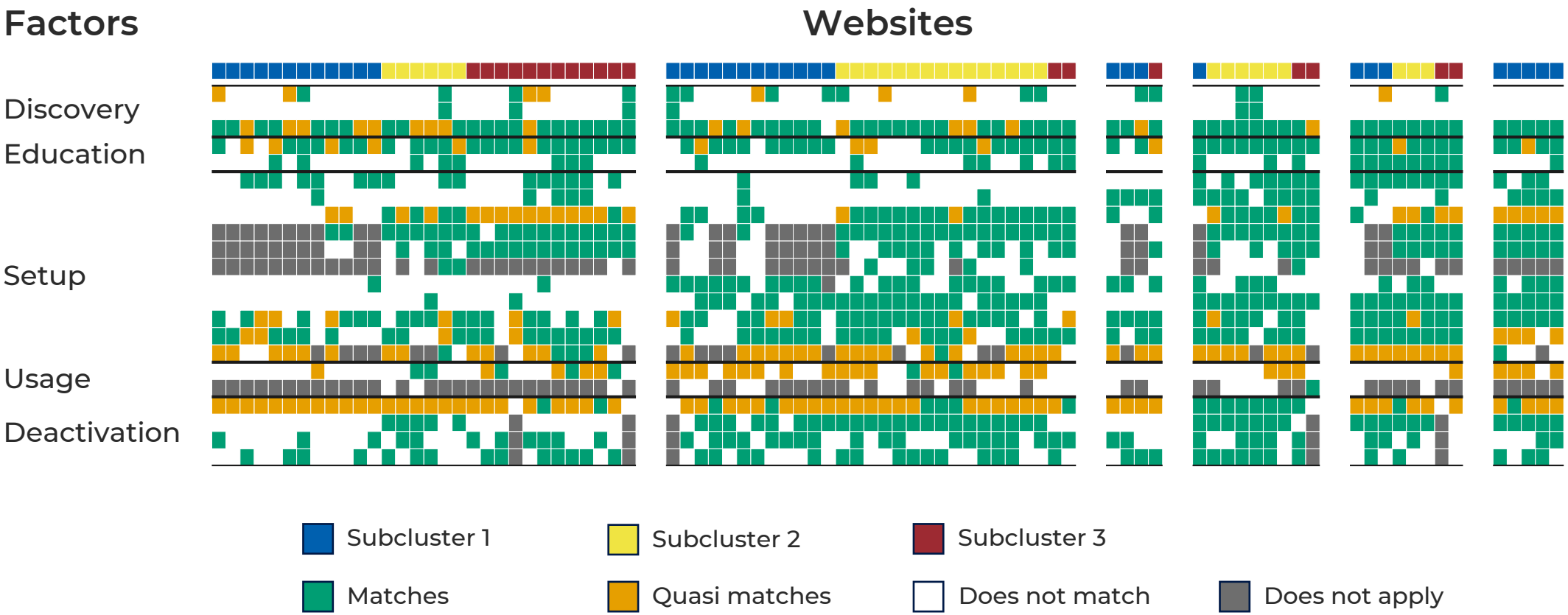
Verify 2FA deactivation



Subcluster 3 (n = 19)

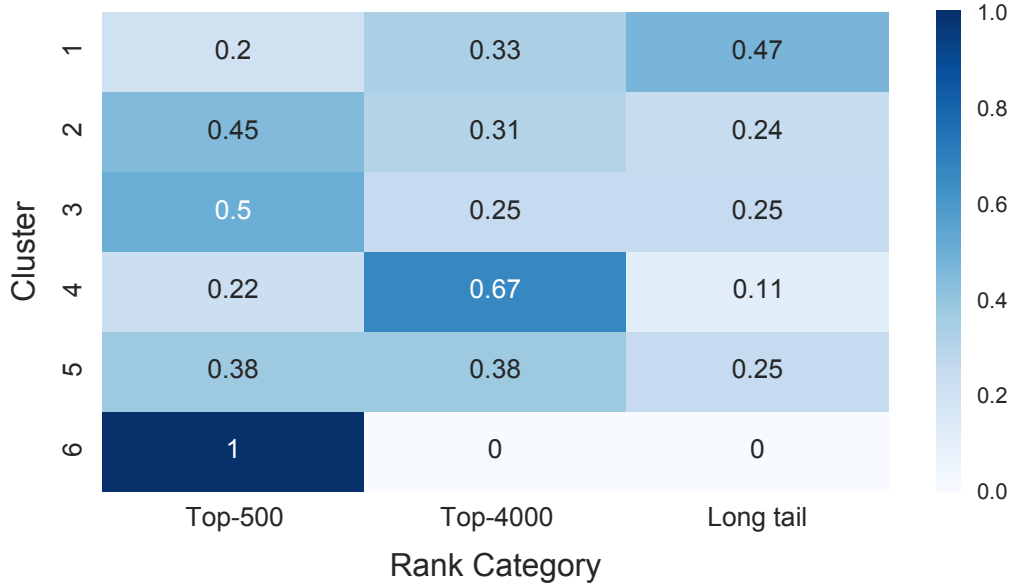
Do not enforce specific 2FA options

Combined Clusters



Website Cluster versus Website Rank

- Divide websites by their Tranco rank in 3 equal-sized groups: *Top-500*, *Top-4000*, *Long tail*
- Normalized contingency table for cluster versus rank:



- Fisher's exact test ($p = 0.04388$) shows statistically signifcant association

Opinionated Separation of Comparison Factors

- Expert evaluation of our comparison factors to separate them by relevance: *Security*, *Usability*, *Both*, *None*

- Four disjoint sets of factors:
  Non-conditional-UX (7 factors), *Non-conditional-Security* (6 factors),
  Conditional-UX (5 factors), *Conditional-Security* (3 factors)

- Repeated consistency analysis and clustering
  - Pairwise Hamming distances: **no** better consistency across all websites
  - Clustering based on Silhouette coefficients: **more** diverse strategies

Qualitative Data Analysis

Consistent Lack of Informing and Educating Users

Only a minority of websites provided additional information (“learn more”)

Most websites immediately start the 2FA setup process without informing users about the benefits/drawbacks of 2FA

Only 1/3 of the websites provided step-by-step setup instructions but almost all confirm a successful setup

Qualitative Data Analysis

Mixed Strategies for Device Remembrance

<50% of the websites support device remembrance

These websites describe this feature in different ways

≈2/3 offer the feature as opt-*in*, ≈1/5 offer as opt-*out*, ≈1/5 unsolicitedly places remembrance cookie (during login or even setup)