#4

Applying Cognitive Load Theory Scientifically and Practically

MIS561 Data Visualization
Special Topic

Recap: Cognitive load theory

Cognitive load

- The amount of information that working memory can hold at one time.
- Cognitive Load Theory was developed by John Sweller (1988).

Processing that takes up mental resources but doesn't help the audience understand the information. This is something we want to avoid.

How do we <u>**measure**</u> cognitive load?

How our Brain Works – Concept 1

Default Mode Network (DMN)

- Brain area that deactivates while paying attention to external stimuli (not always)

- DMN is active while executing internal-goal-oriented tasks (e.g., using memory to complete the task)

- Turns off for External-goal-oriented task (e.g., relying on visual perception)

Source:
Fox et al. 2005
Lanzoni et al. 2020
Murphy et al. 2019
Smallwood et al. 2021

How our Brain Works – Concept 2

Dual Process Theory

- A widely accepted model in psychology – explains how human thoughts can be broken down into System I and System 2

- System I is intuitive, immediate, effortless, and fast.

- System 2 is conscious, analytical, slow, deliberate.

- System 2 process requires cognitive resources as it is used when reflectively evaluate the task or output generated by System I response.

How do these concepts apply to the real world?

There are numerous ways!

1. You can categorize the types of tasks based on DMN and DPT (example on the next slide).

2. Use various measuring devices to infer users' mind (e.g., emotion).

3. Predict user behaviors

4. Identify areas where the users' are likely to feel "friction" – Similar to identifying clutters

Types of Tasks and how it relates to Data Visualization

Types of Tasks	DMN activation	DPT
Complex, External	Low	System 2 reliant
Simple, External	Low	System 1 reliant
Internally focused	High	System 2 reliant (magnitude varies)

Avoid!

Visual / Motor Cortex – Easy to Comprehend

Combining the theories together… (Kim et al. Forthcoming)

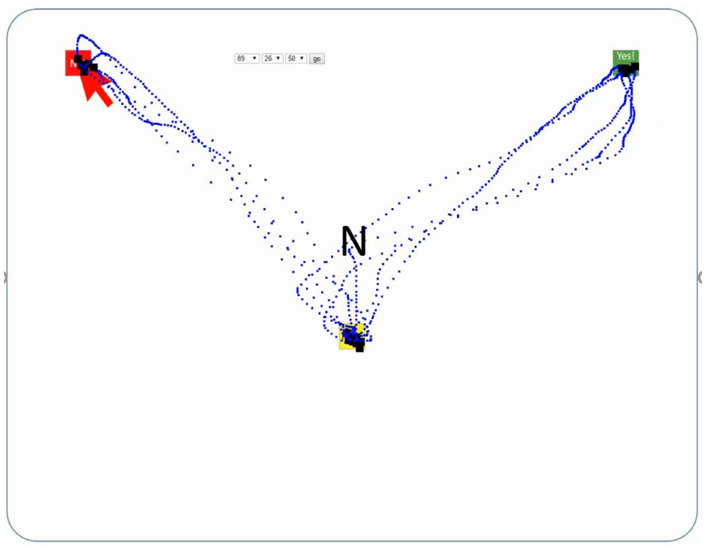
Motor learning, which refers to a set of processes aimed at learning and refining new skills through continuous practice, explains how humans become proficient in executing various motor movements, including typing on a keyboard (Filippi et al. 2018; Nieuwboer et al. 2009). Such skill acquisition process becomes less deliberate and effortful over time as they become more automatized (Shiffrin and Schneider 1977).

This applies to all instances where you may use your hand to interact with a computing device (e.g., computer mice, keyboards, mobile devices, etc.).

Also, over time, some things become routine tasks – converting to simple, externally focused task (e.g., answering identity questions).

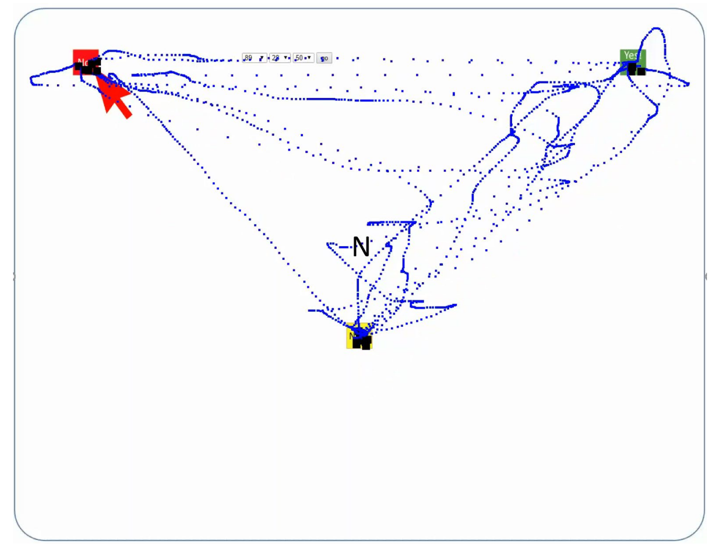
Low and High Cognitive Load (stream of 10 iterations)

Is N the number 5?
99.5% accuracy



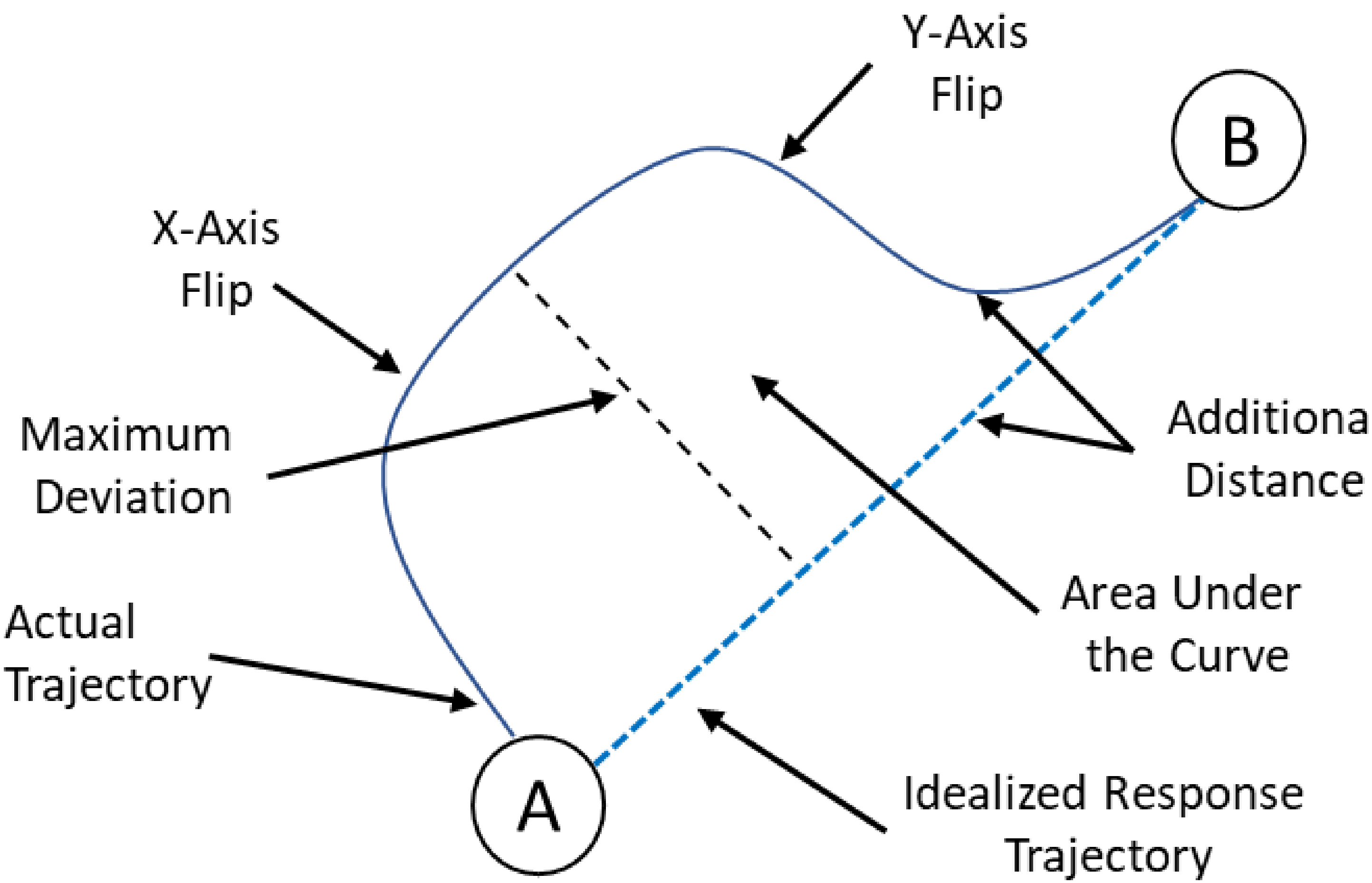
Low: 21 seconds

Is the current number N, higher or lower than the sum of the previous two numbers?
81.3% accuracy



High: 38 seconds

Transforming Mouse Cursor Movements to Metrics



Empirical Evidence – Computer Mice (Kim et al. 2022)

Observing mouse cursor movements as people answer demographics question, personality test questions, and "difficult to answer" questions.

Simple externally Focused Task (System 1) – demographics questions

Internally focused task (System 2) – answering difficult questions

Hypothesis – Mouse cursor speed is going to slow down when people are answering difficult questions.

Empirical Evidence – Computer Mice (Kim et al. 2022)

FLNS – Feature level normalized speed score
SLNS – Subject level normalized speed score

Red dots indicate speed data points for hard questions

Key Research Questions / Answers - Keyboard

1. *Do people type real identity info with greater fluency than a synthetic identity?*

2. *For authentic user, do they type their name fields with greater fluency than other identity fields (e.g., address, city, email address)?*

3. *For synthetic users, what differences (if any) occur for different identity fields?*

Between comparison: Yes. HUGE differences (not interesting).

Within comparison: Yes, and this too appears to be robust (exclude numbers).

Within comparison: Enter most common name with higher fidelity – e.g., western cultures (**Joe** Valacich); eastern (Xiaofei **Wang**).

Within: All other fields are the same.

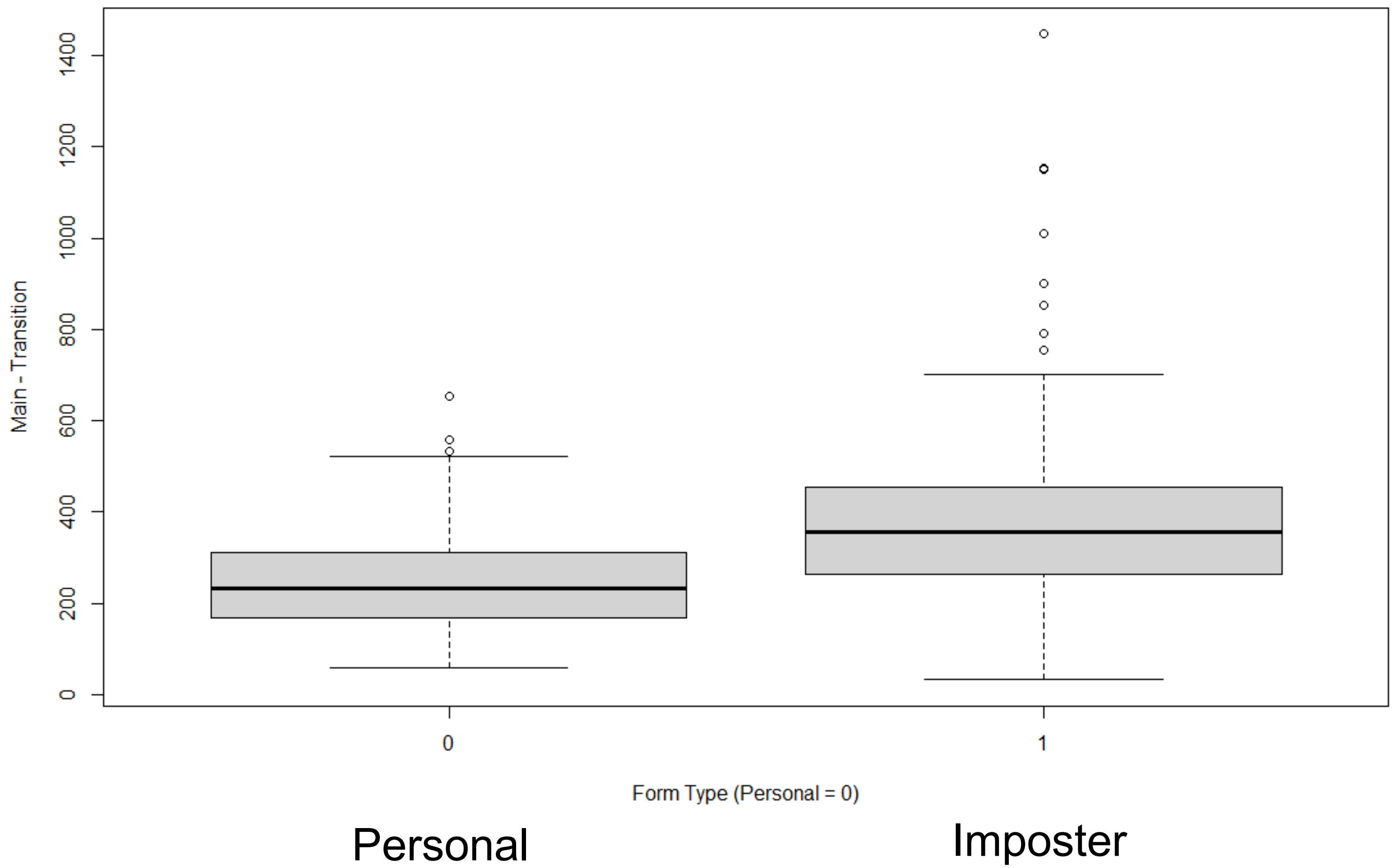
Kim et al. Forthcoming

How do we measure the differences in user behaviors when typing their personal vs. imposter information?

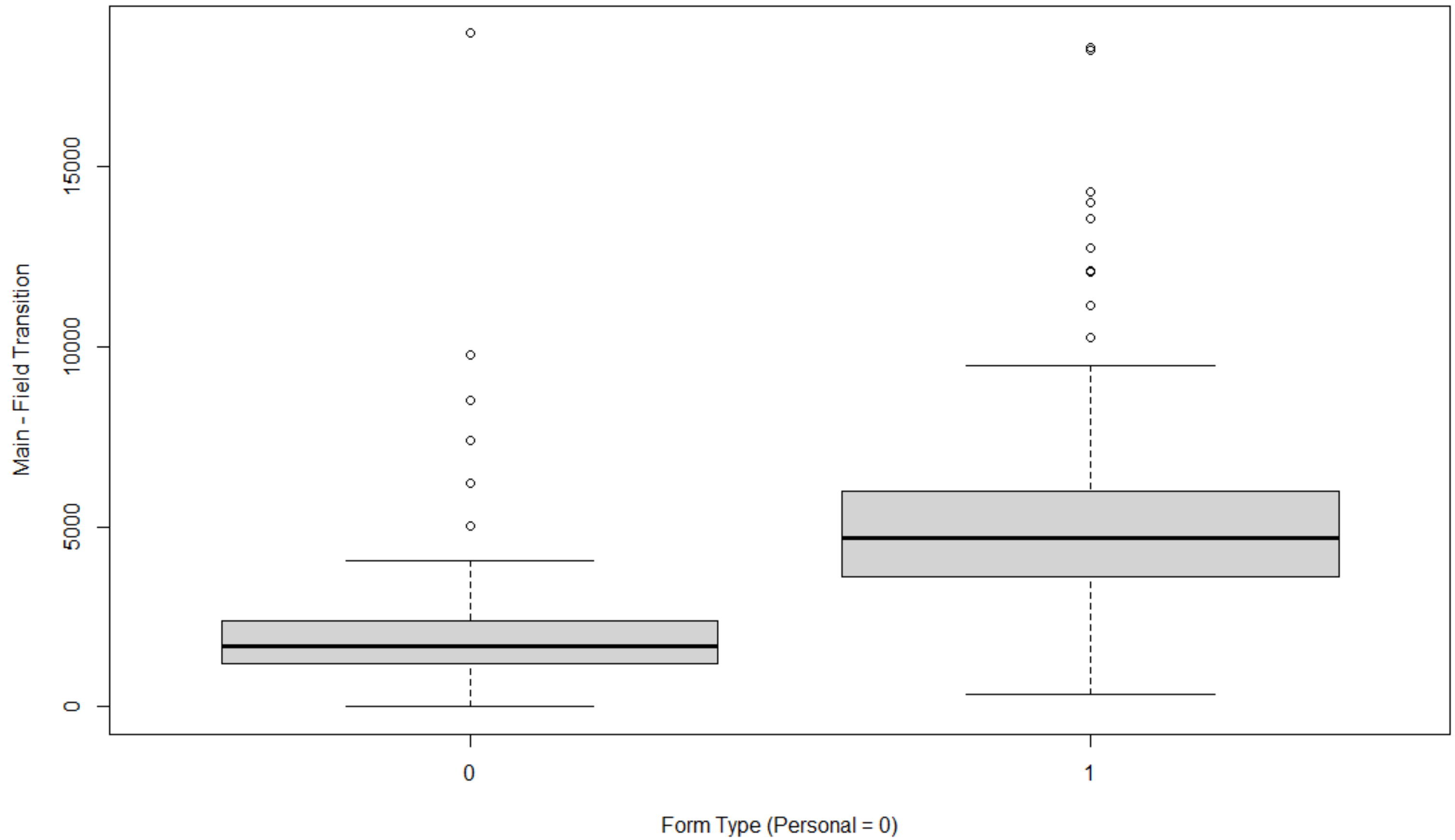
Recalling identity information (Simple External Task)
- Pre-exposure to similar forms (Task similarity)
- Muscle memory (Typing your own name)
- Familiarity with the information

Typing imposter information (Complex External Task)
- Using more brain resources to comprehend study information
- Low Muscle memory
- Low familiarity with the information

Average key transition time when entering identity information (Kim et al. Forthcoming)



Average field transition time when entering identity information



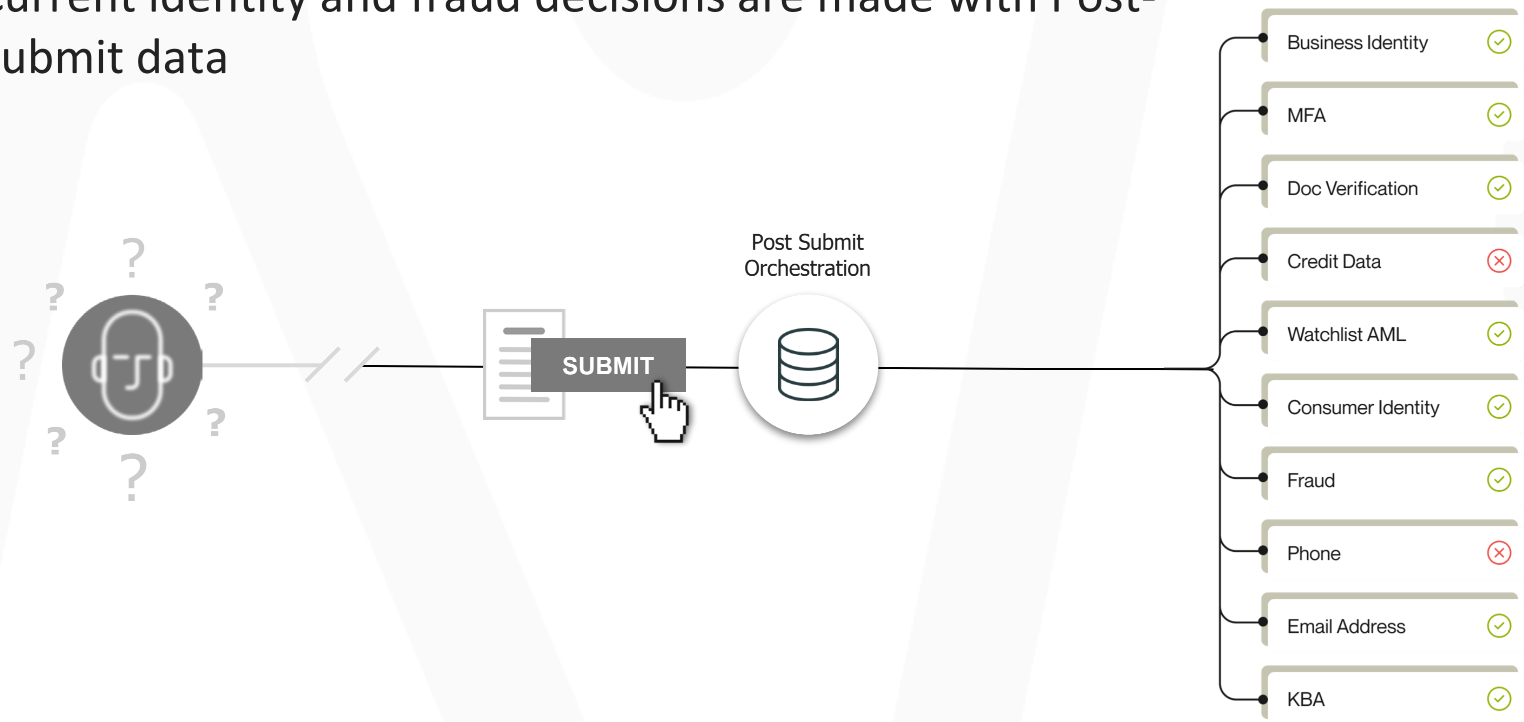
Personal

Imposter

94.9% Accuracy!

Fraudsters will be able to “prep” so need diverse range of follow-up questions (i.e., more than age and more than city / state).

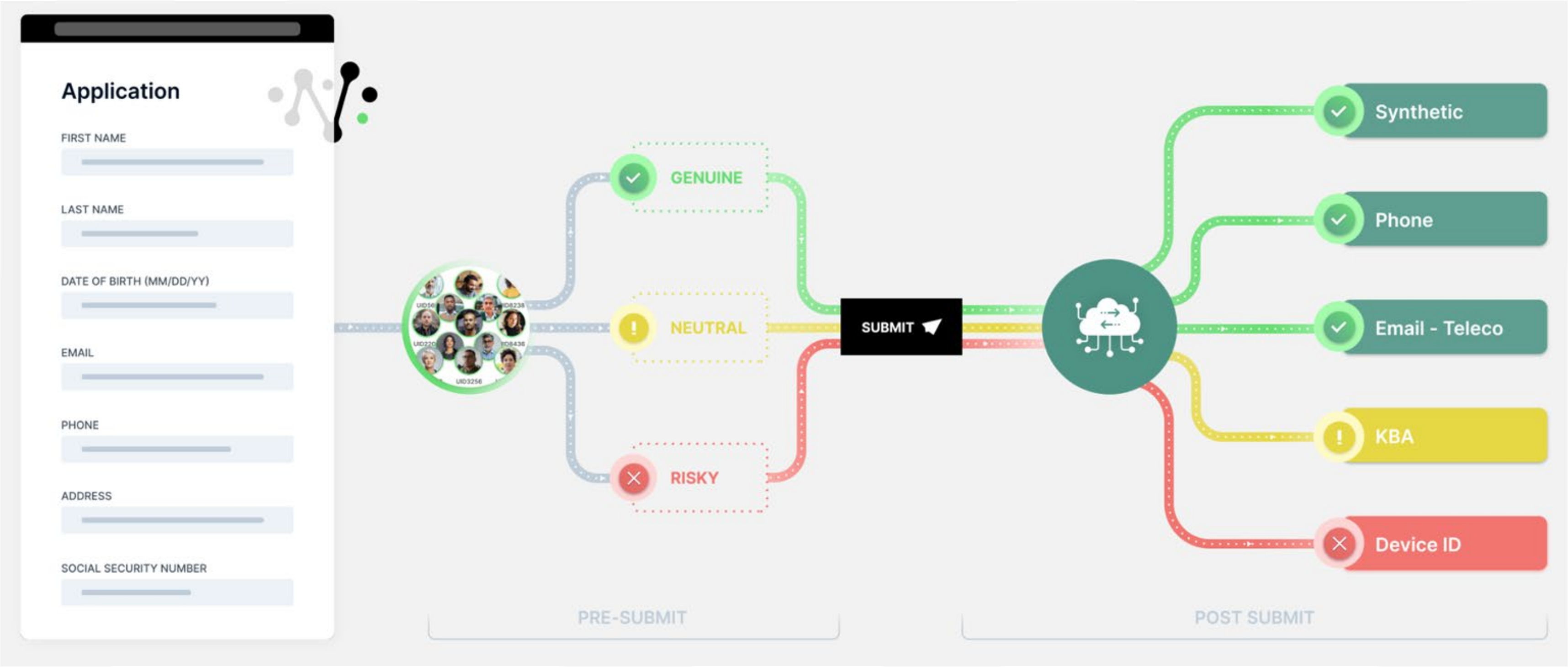
Current identity and fraud decisions are made with Post-Submit data



- **Current fraud / identity stacks are rigid and use rigid post submit data that is easily purchased by fraudsters**
- **Heavier friction verification solutions often times have a miserable customer experience and low conversion rate**

Pre-submit data enhances all other data

Maximize the identity investments you've already made using pre-submit



How does this apply to Data Visualization?

Visualizations including too many layers of complexity can hinder decision-making processes by limiting the cognitive capacity of users, therefore affecting their attention, recognition, and working memory (Calvo et al. 2022)

Main things to consider

1. Aesthetics might be worth considering if striving to create something memorable, but an attractive image cannot qualify as effective unless it accurately conveys something meaningful or credible
2. Consider these three elements:
   - Density – Amount of data being represented
   - Robustness – Representation of scientific confidence and consensus
   - Saliency – Relevance of information to user needs
3. Add interaction (User-Centered Design)
   - Involve users throughout the design process in order to create highly usable visualization tools.
   - Let the users decide what they want to see ☺

Source:
(Holmes 1984; Korasa 2013 ;Borkin et al. 2013; Calvo et al. 2022; Davis et al. 2020; Dong et al. 2008; Yucong et al. 2019)

Case Study: Project Ukko (Calvo et al. 2022)

Goal: Create new forms of representation for wind prediction

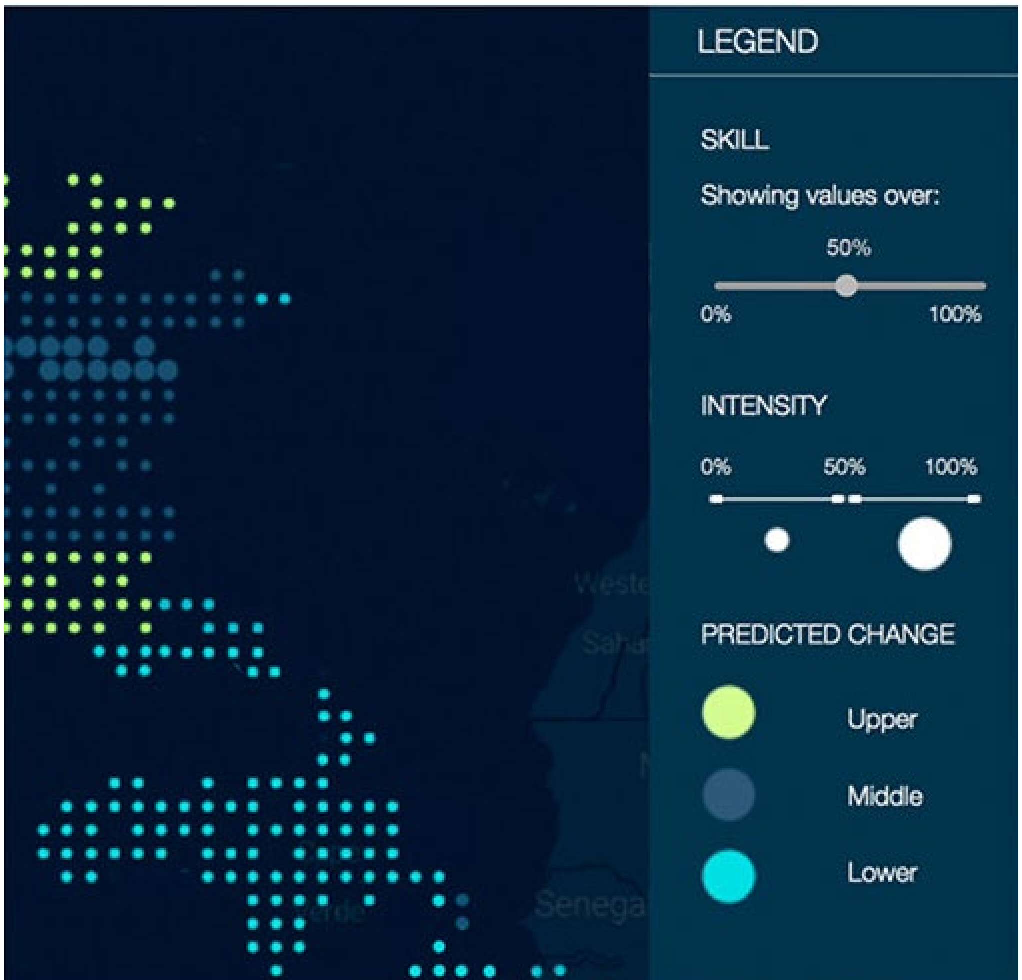
- Graphical components used:
- Glyph thickness (intensity of wind)
- Glyph inclination (predicted change in wind condition – high, normal, low)
- Opacity (quality of prediction)

Case Study: Project Ukko (Calvo et al. 2022)

Initial graph – what are your thoughts?

Case Study: Project Ukko (Calvo et al. 2022)

Revamped version – thoughts?



Case Study: Project Ukko (Calvo et al. 2022)

Locate or identify an area on the map that is appropriate to the location of a wind power plant. The area must meet a series of conditions:

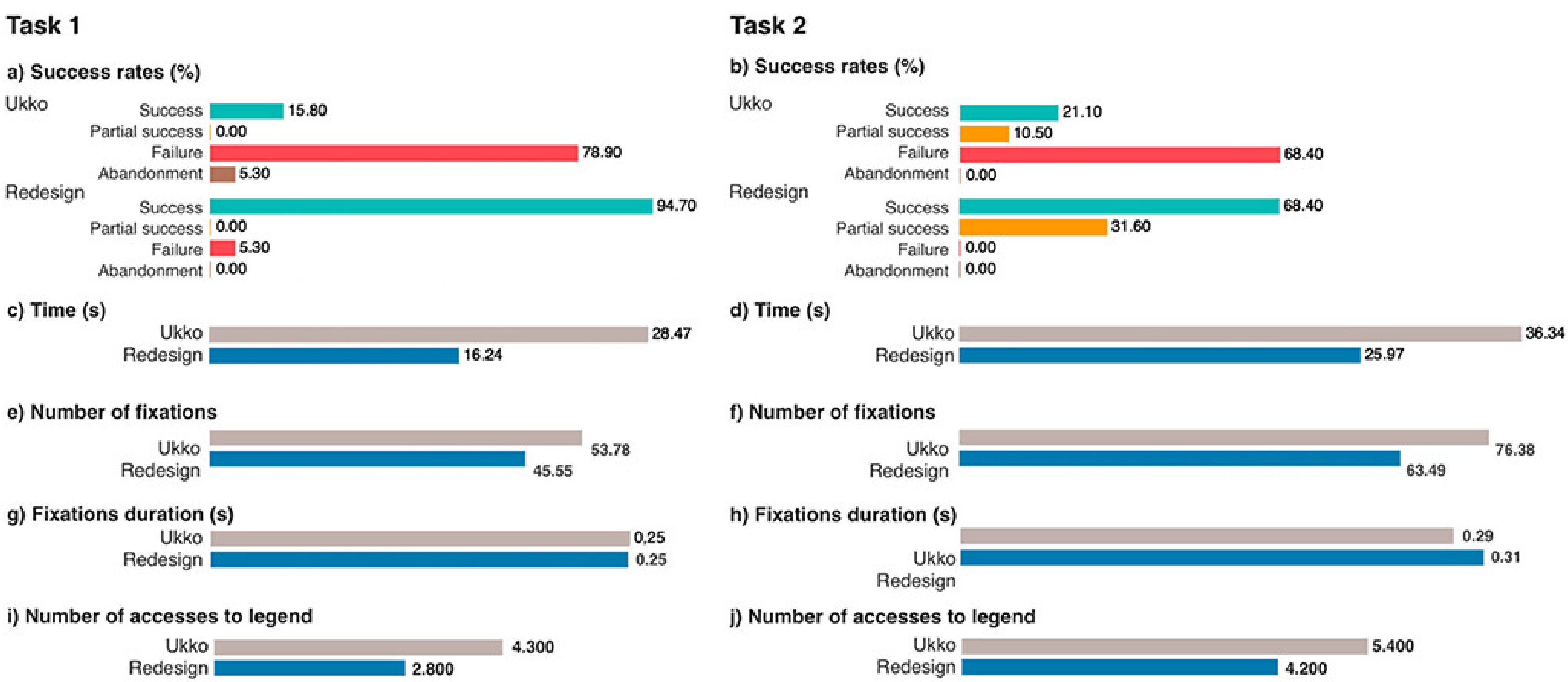
1. For Project Ukko, the suitable area should have a prediction skill over 50%, high or medium-high intensity, and an upper or mid-upper predicted change in wind speed.

2. For the redesigned version, the area should have a skill over 50%, intensity over 50%, and upper predicted change

Case Study: Project Ukko (Calvo et al. 2022)

Identify aloud the conditions that occur in the points included in the highlighted area on the map in terms of skill, intensity, and predicted change.

Case Study: Project Ukko (Calvo et al. 2022)



In Summary…

1. Cognitive Load is an important component of user experience that influences:
   - The emotions that the users feel towards the system that they use
   - Ability to comprehend information in a timely manner
   - Successful execution of the task

2. Various design approaches that involves users into the design process (e.g., User Centered Design) is particularly useful in reducing cognitive load.

3. Heightened cognitive load is “NOT” always a bad thing, and there are different ways to measure them for practical reasons.