

# The Science of Product Development

Bringing Causal Inference to Conversion and Retention Metrics

David Robinson, Director of Data Science at Contentsquare  
2024 NYR Conference



When a company designs a product, they  
want it to be easy to use

Some are designed better than others!



Source: [The Uncomfortable](#) by Katerina Kamprani

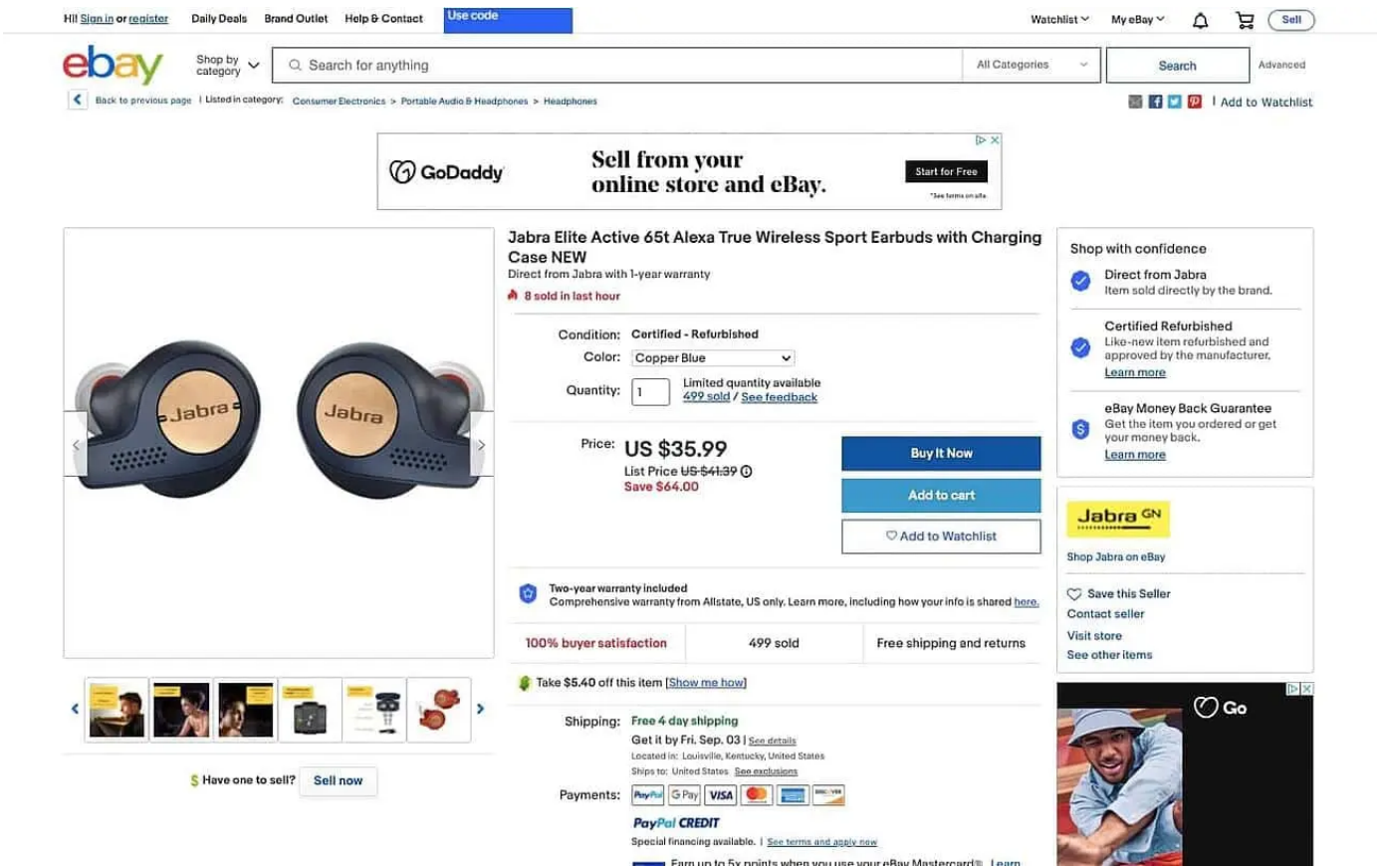
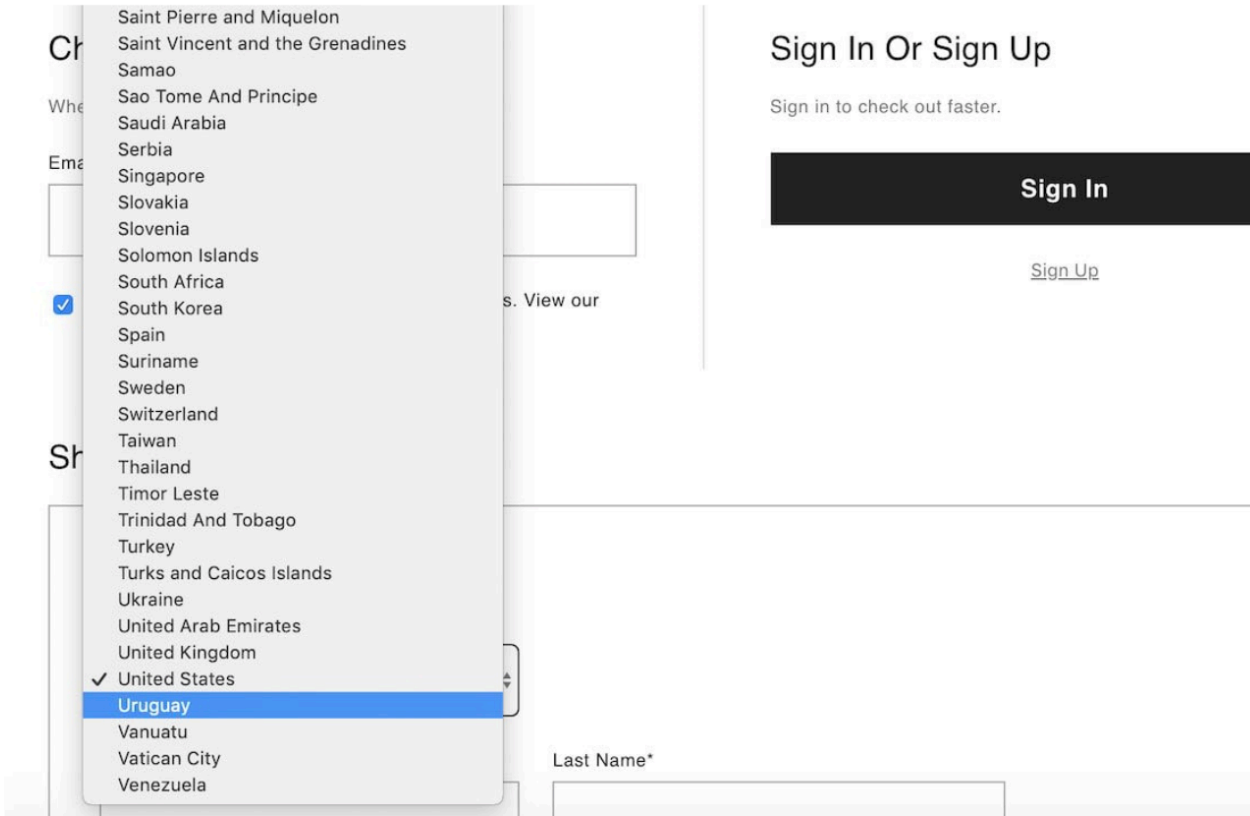
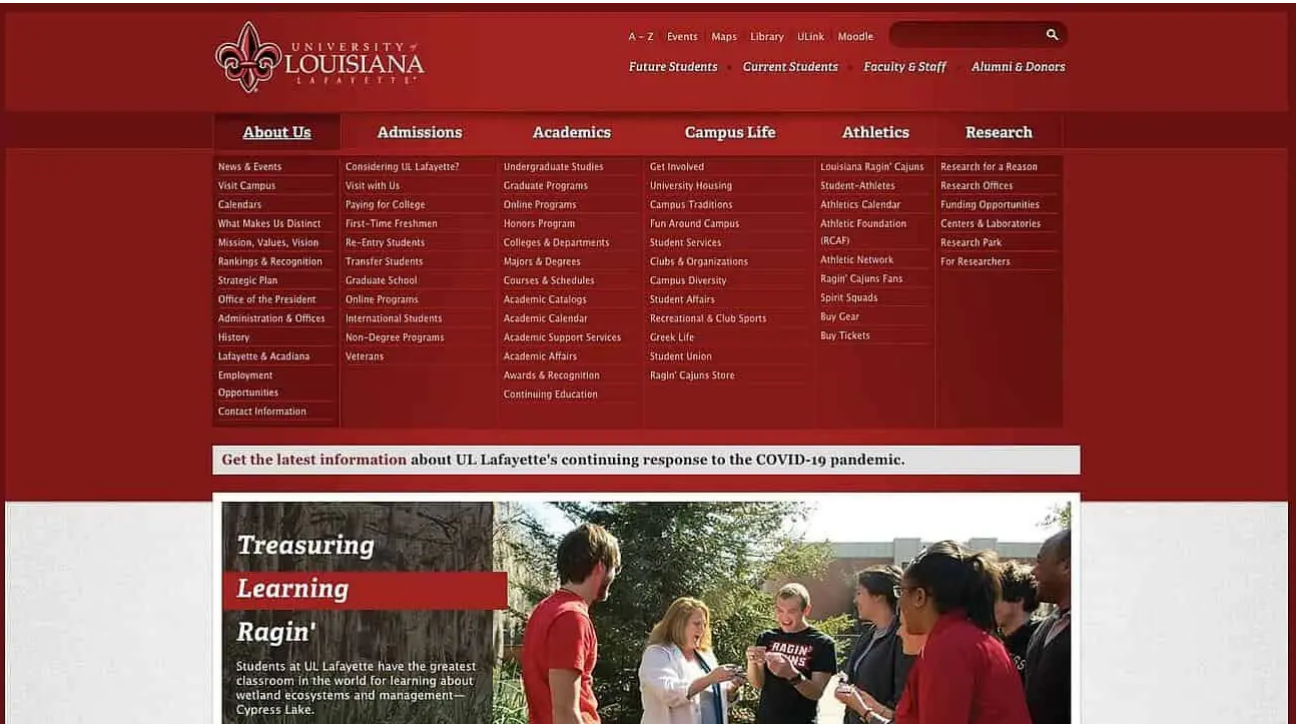
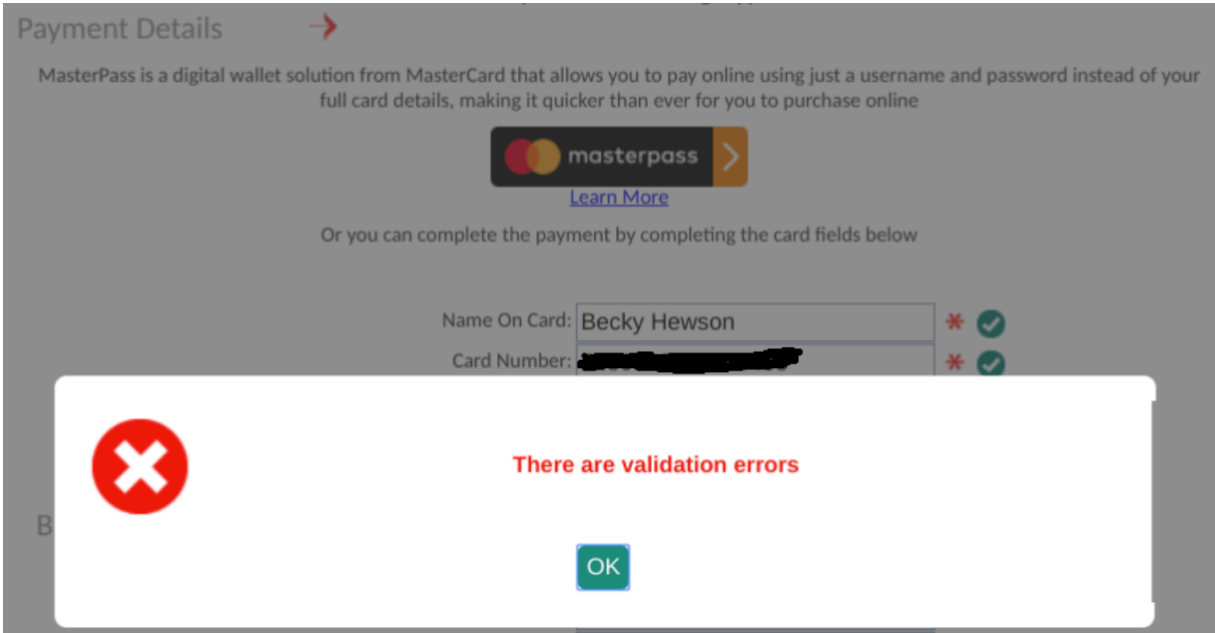
Digital products have an advantage that designers of physical products can only dream of

They can collect *data* on how every single customer is using the product: what they're viewing, what they're clicking, and where they're getting stuck.

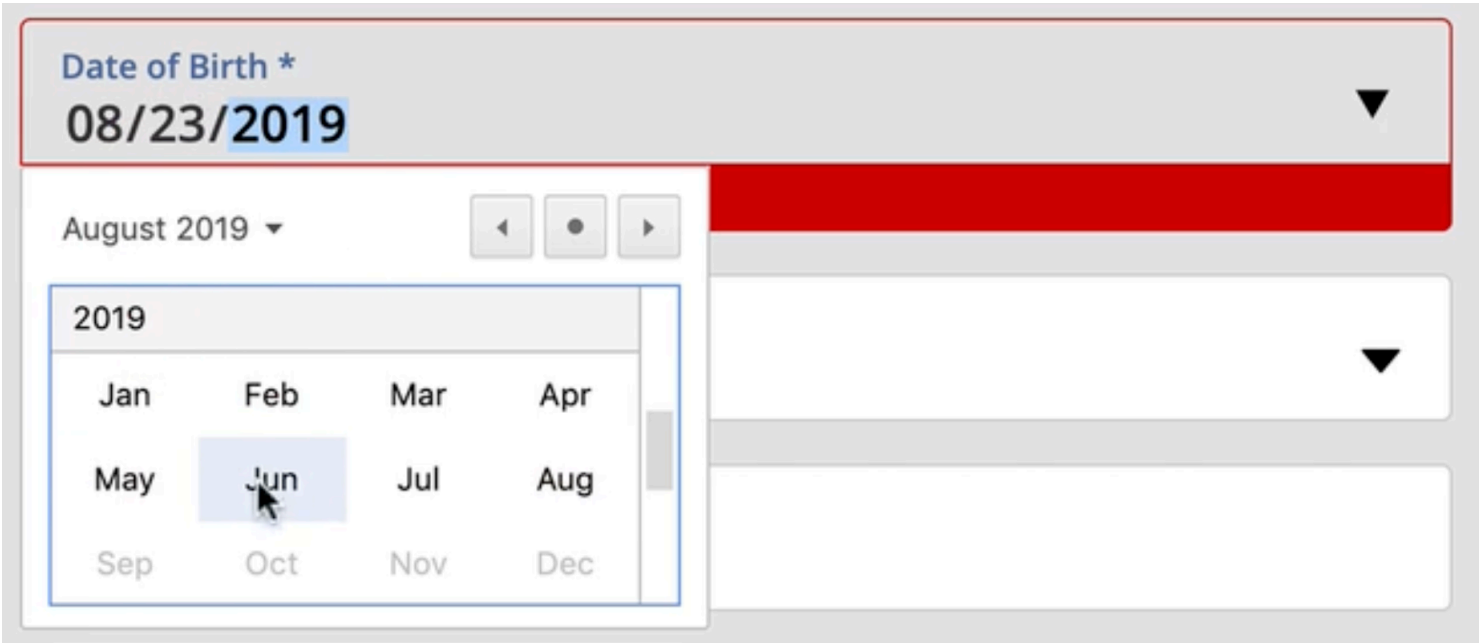


Digital products have an advantage that designers of physical products can only dream of

They can collect *data* on how every single customer is using the product: what they’re viewing, what they’re clicking, and where they’re getting stuck.



So what’s their excuse?





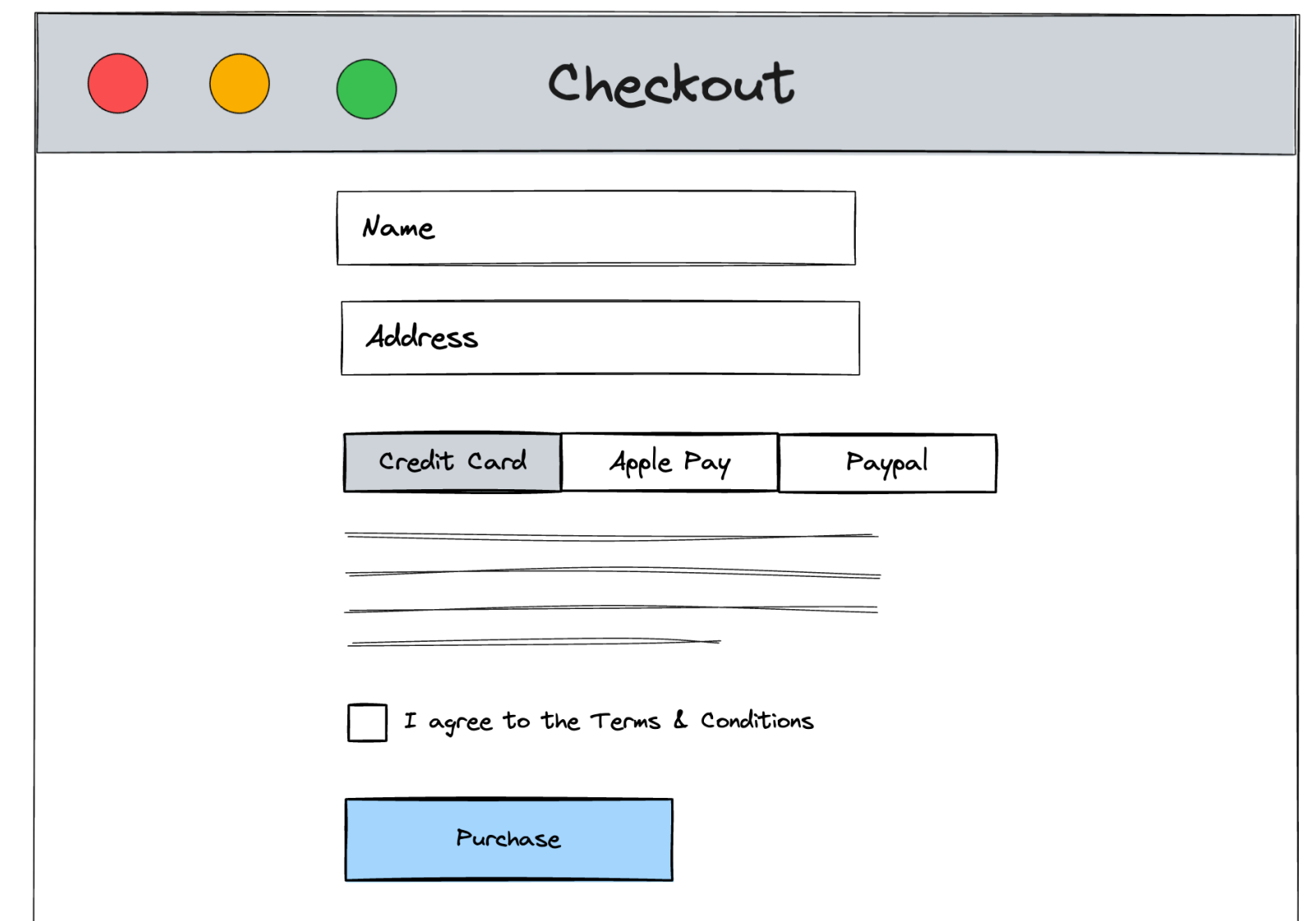
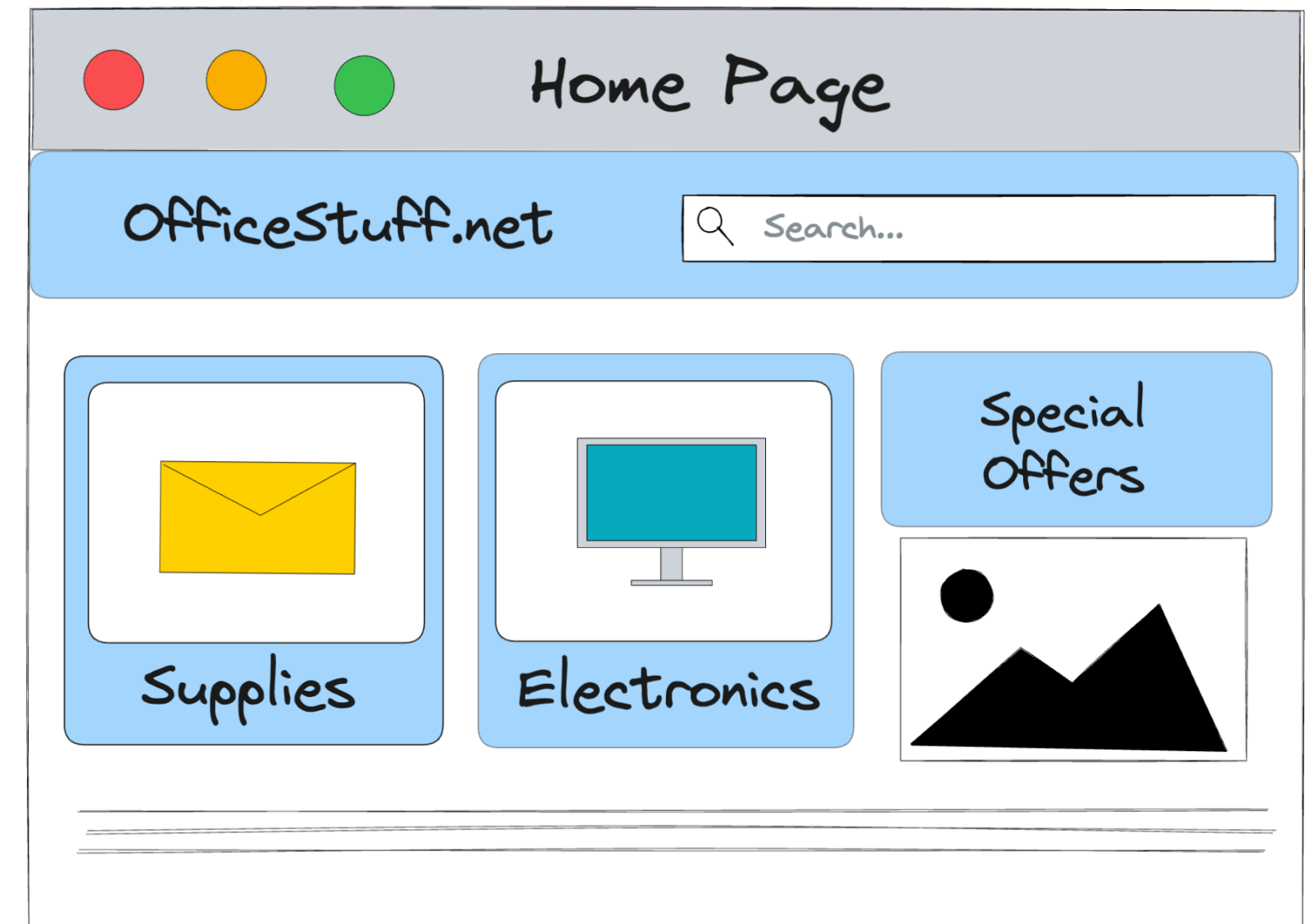
Land on /home  
Click "Special Offers"  
View /special-offers  
Click "Paperclips"  
View /paper-clips  
Click "Add to Cart"  
Click "Check Out"  
View /checkout  
Click "Save for Later"  
Drop Off

Land on /home  
Click "Special Offers"  
View /special-offers  
Click Back  
Click "Search"  
Enter "Headphones"  
Click - Sort by Price  
Click - Sort by Category  
Drop Off

Land on /promo  
Click "50% Off Special Offers"  
View /special-offers  
Click Back  
Click - Sign In  
Click "Search"  
Enter "Keyboard"  
Click - Sort by Price  
Click - Filter by Price  
Click - Mechanical Keyboard  
View /products/mechanical-keyboard  
Click - "Buy (One Click)"  
Purchase

Land on /home  
Click "Browse"  
View /categories  
View /recent  
Click Back  
Drop Off

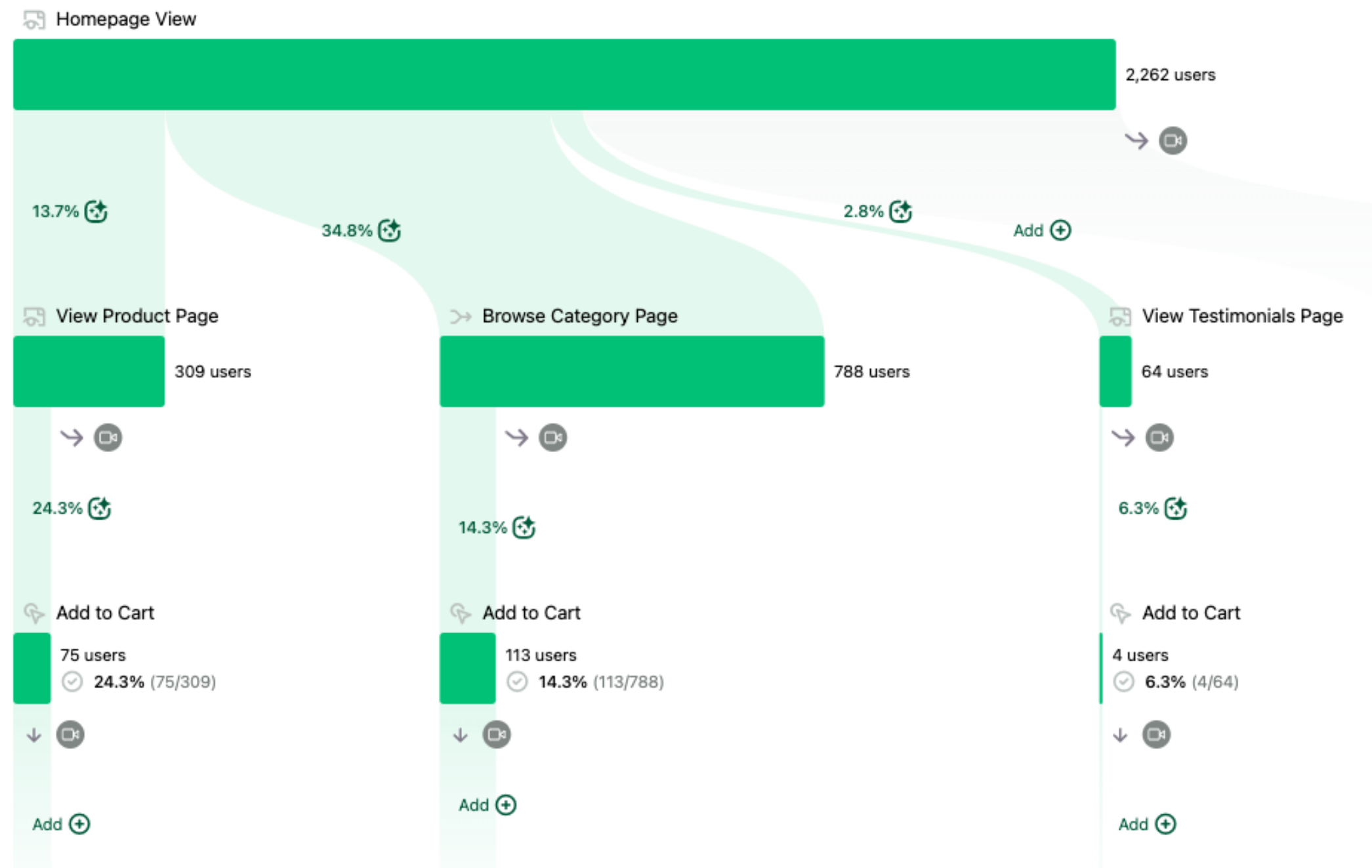
View /home  
Click "Supplies"  
View /supplies  
Click "Paper"  
View /products/paper  
Click "Add to Cart"  
View /supplies  
Click "Scissors"  
View /products/scissors  
Click Back  
Click "Premium Scissors"  
View /products/scissors  
Click "Add to Cart"  
View - Checkout  
Click - Enter Name  
Click - Enter Credit Card  
Validation Error  
Click - Enter Credit Card  
Click - Check Terms & Conditions  
Purchase



What statistical tools can turn  
sequences of events into **product  
insights and improvements?**

Date range **Past 7 days** within **a single session**  
**Update results**

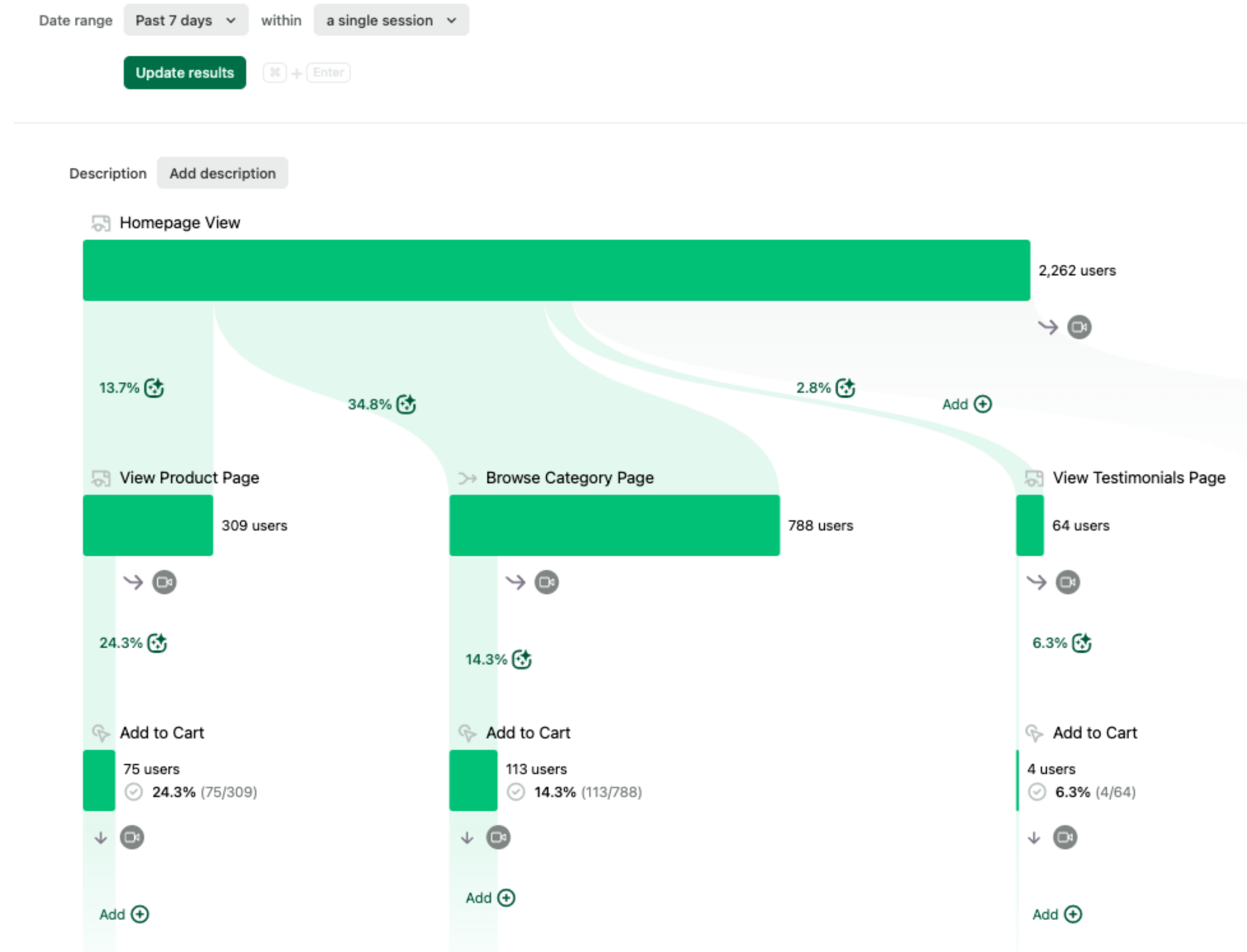
Description **Add description**



We developed these principles at  
Heap to power the Journeys product  
(launched 2022)





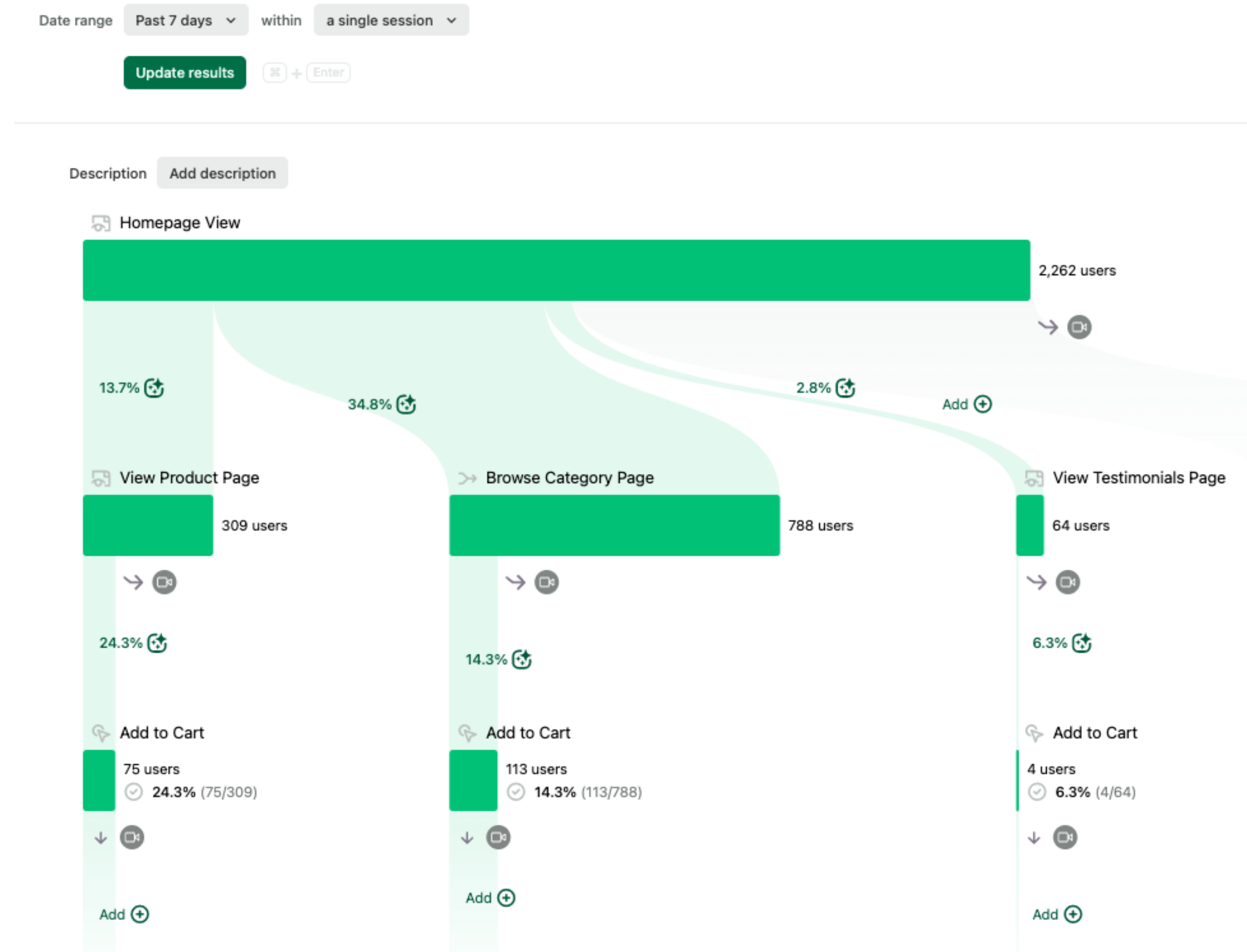


Today, I'm focused more on the theory: on the "missing science" of analyzing and improving products

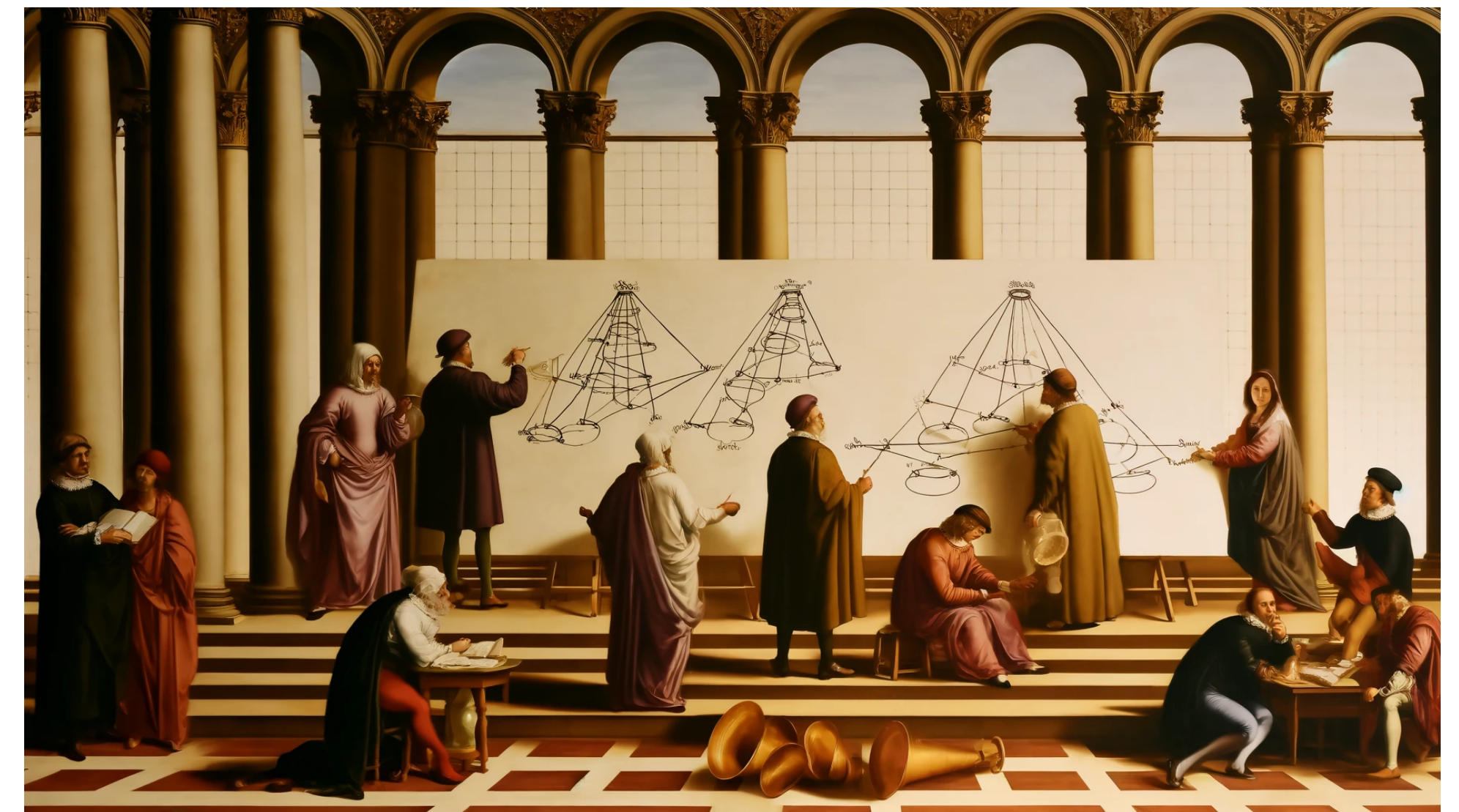


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Today, I'm focused more on the theory: on the "missing science" of analyzing and improving products



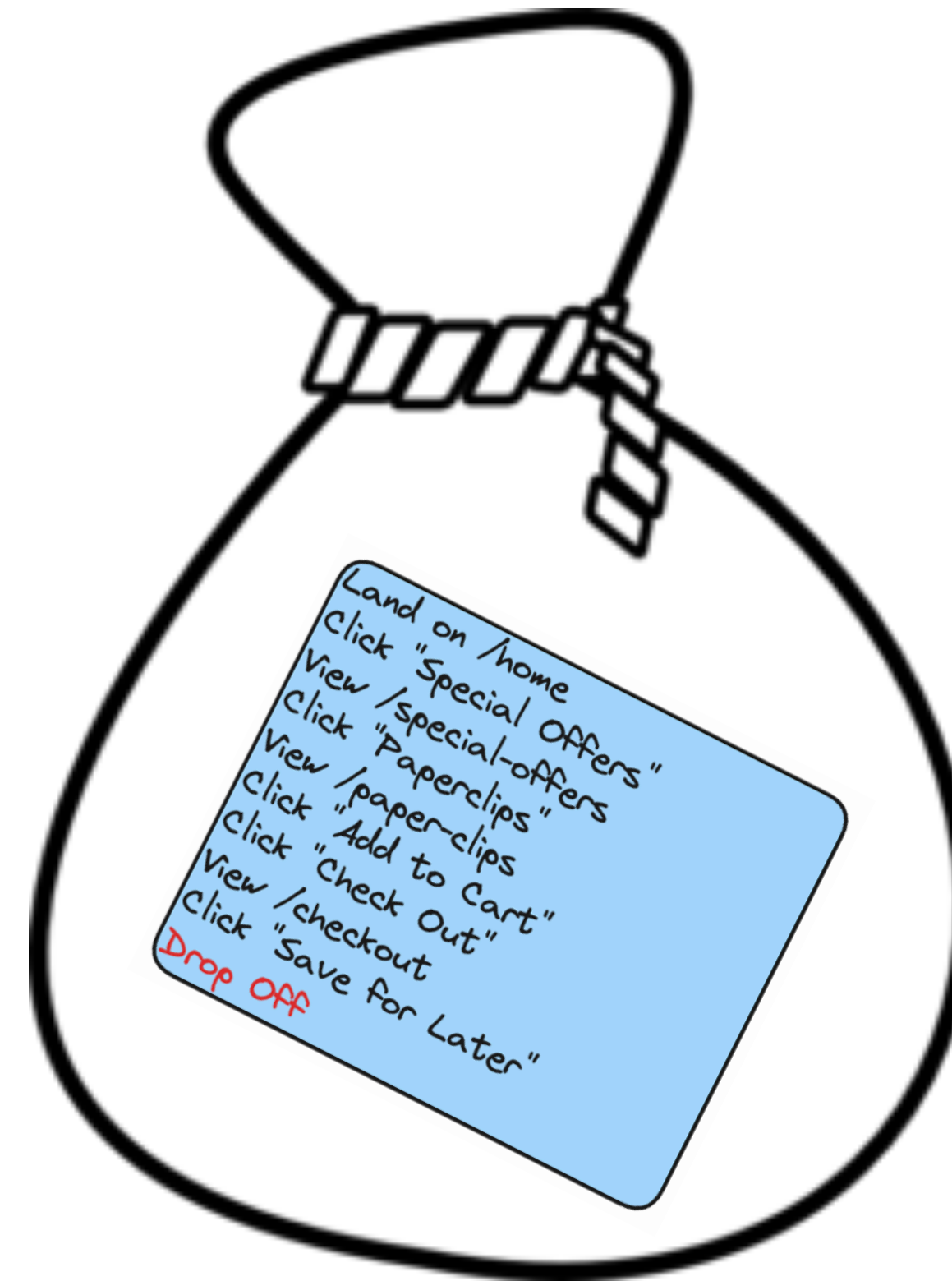
We developed these principles at Heap to power the Journeys product (launched 2022)





# Correlations

The “bag of clicks” model



# The “bag of clicks” model

Land on /home  
Click "Special Offers"  
View /special-offers  
Click "Paperclips"  
View /paper-clips  
Click "Add to Cart"  
Click "Check Out"  
View /checkout  
Click "Save for Later"  
Drop Off

Land on /home  
Click "Special Offers"  
View /special-offers  
Click Back  
Click "Search"  
Enter "Headphones"  
Click - Sort by Price  
Click - Sort by Category  
Drop Off

Land on /promo  
Click "50% Off Special Offers"  
View /special-offers  
Click Back  
Click - Sign In  
Click "Search"  
Enter "Keyboard"  
Click - Sort by Price  
Click - Filter by Price  
Click - Mechanical Keyboard  
View /products/mechanical-keyboard  
Click - "Buy (One Click)"  
Purchase

Land on /home  
Click "Browse"  
View /categories  
View /recent  
Click Back  
Drop Off

View /home  
Click "Supplies"  
View /supplies  
Click "Paper"  
View /products/paper  
Click "Add to Cart"  
View /supplies  
Click "Scissors"  
View /products/scissors  
Click Back  
Click "Premium Scissors"  
View /products/scissors  
Click "Add to Cart"  
View - Checkout  
Click - Enter Name  
Click - Enter Credit Card  
Validation Error  
Click - Enter Credit Card  
Click - Check Terms & Conditions  
Purchase



# The “bag of clicks” model

Land on /home  
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Click "Browse"  
View /categories  
View /recent  
Click Back  
Drop Off

View /home  
Click "Supplies"  
View /supplies  
Click "Paper"  
View /products/paper  
Click "Add to Cart"  
View /supplies  
Click "Scissors"  
View /products/scissors  
Click Back  
Click "Premium Scissors"  
View /products/scissors  
Click "Add to Cart"  
View - Checkout  
Click - Enter Name  
Click - Enter Credit Card  
Validation Error  
Click - Enter Credit Card  
Click - Check Terms & Conditions  
Purchase



user_id	viewed_home	clicked_search	clicked_read_reviews	clicked_learn_more	...yada yada...	purchased
187180	0	1	1	0	...	1
662863	0	0	0	0	...	1
684172	1	1	1	0	...	0
261982	1	1	0	0	...	0
579325	1	1	1	1	...	0
829755	1	1	0	1	...	0
454574	1	1	0	0	...	0
216105	1	1	1	1	...	1
181215	0	1	0	0	...	0
996510	1	1	0	0	...	0
379967	1	1	0	0	...	0
511056	1	1	0	1	...	0
948165	1	1	1	0	...	0
575719	1	1	0	1	...	0
356383	1	1	1	0	...	0
582609	1	1	1	0	...	0
988781	1	0	0	1	...	0

# The “bag of clicks” model

Land on /home  
Click "Special Offers"  
View /special-offers  
Click "Paperclips"  
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View /categories  
View /recent  
Click Back  
Drop Off

View /home  
Click "Supplies"  
View /supplies  
Click "Paper"  
View /products/paper  
Click "Add to Cart"  
View /supplies  
Click "Scissors"  
View /products/scissors  
Click Back  
Click "Premium Scissors"  
View /products/scissors  
Click "Add to Cart"  
View - Checkout  
Click - Enter Name  
Click - Enter Credit Card  
Validation Error  
Click - Enter Credit Card  
Click - Check Terms & Conditions  
Purchase



“Users viewed these pages and did these clicks...”

user_id	viewed_home	clicked_search	clicked_read_reviews	clicked_learn_more	...yada yada...	purchased
187180	0	1	1	0	...	1
662863	0	0	0	0	...	1
684172	1	1	1	0	...	0
261982	1	1	0	0	...	0
579325	1	1	1	1	...	0
829755	1	1	0	1	...	0
454574	1	1	0	0	...	0
216105	1	1	1	1	...	1
181215	0	1	0	0	...	0
996510	1	1	0	0	...	0
379967	1	1	0	0	...	0
511056	1	1	0	1	...	0
948165	1	1	1	0	...	0
575719	1	1	0	1	...	0
356383	1	1	1	0	...	0
582609	1	1	1	0	...	0
988781	1	0	0	1	...	0

“...which of those led to purchases?”



user_id ↕	viewed_home ↕	clicked_search ↕	clicked_read_reviews ↕	clicked_learn_more ↕	...yada yada... ↕	purchased ↕
187180	0	1	1	0	...	1
662863	0	0	0	0	...	1
684172	1	1	1	0	...	0
261982	1	1	0	0	...	0
579325	1	1	1	1	...	0
829755	1	1	0	1	...	0
454574	1	1	0	0	...	0
216105	1	1	1	1	...	1
181215	0	1	0	0	...	0
996510	1	1	0	0	...	0
379967	1	1	0	0	...	0
511056	1	1	0	1	...	0
948165	1	1	1	0	...	0
575719	1	1	0	1	...	0
356383	1	1	1	0	...	0
582609	1	1	1	0	...	0
988781	1	0	0	1	...	0
857058	1	1	0	0	...	0
498438	1	1	0	0	...	0
470140	1	0	1	0	...	0
714748	1	0	0	1	...	0
624947	1	1	1	1	...	0
524455	1	0	0	1	...	1

$$y_i = \beta_1 x_{i1} + \beta_2 x_{i2} + \cdots + \beta_p x_{ip} + \varepsilon_i$$

user_id ↕	viewed_home ↕	clicked_search ↕	clicked_read_reviews ↕	clicked_learn_more ↕	...yada yada... ↕	purchased ↕
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379967	1	1	0	0	...	0
511056	1	1	0	1	...	0
948165	1	1	1	0	...	0
575719	1	1	0	1	...	0
356383	1	1	1	0	...	0
582609	1	1	1	0	...	0
988781	1	0	0	1	...	0
857058	1	1	0	0	...	0
498438	1	1	0	0	...	0
470140	1	0	1	0	...	0
714748	1	0	0	1	...	0
624947	1	1	1	1	...	0
524455	1	0	0	1	...	1

$$y_i = \beta_1 x_{i1} + \beta_2 x_{i2} + \dots + \beta_p x_{ip} + \varepsilon_i$$

Checkout

Name

Address

Credit Card

Apple Pay

Paypal

☐

I agree to Terms & Conditions

Purchase

user_id ↕	viewed_home ↕	clicked_search ↕	clicked_read_reviews ↕	clicked_learn_more ↕	...yada yada... ↕	purchased ↕
187180	0	1	1	0	...	1
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261982	1	1	0	0	...	0
579325	1	1	1	1	...	0
829755	1	1	0	1	...	0
454574	1	1	0	0	...	0
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996510	1	1	0	0	...	0
379967	1	1	0	0	...	0
511056	1	1	0	1	...	0
948165	1	1	1	0	...	0
575719	1	1	0	1	...	0
356383	1	1	1	0	...	0
582609	1	1	1	0	...	0
988781	1	0	0	1	...	0
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498438	1	1	0	0	...	0
470140	1	0	1	0	...	0
714748	1	0	0	1	...	0
624947	1	1	1	1	...	0
524455	1	0	0	1	...	1

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Checkout

Name

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Credit Card

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Paypal

☐

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Purchase

This click has a 100% correlation with purchasing!



user_id ↕	viewed_home ↕	clicked_search ↕	clicked_read_reviews ↕	clicked_learn_more ↕	...yada yada... ↕	purchased ↕
187180	0	1	1	0	...	1
662863	0	0	0	0	...	1
684172	1	1	1	0	...	0
261982	1	1	0	0	...	0
579325	1	1	1	1	...	0
829755	1	1	0	1	...	0
454574	1	1	0	0	...	0
216105	1	1	1	1	...	1
181215	0	1	0	0	...	0
996510	1	1	0	0	...	0
379967	1	1	0	0	...	0
511056	1	1	0	1	...	0
948165	1	1	1	0	...	0
575719	1	1	0	1	...	0
356383	1	1	1	0	...	0
582609	1	1	1	0	...	0
988781	1	0	0	1	...	0
857058	1	1	0	0	...	0
498438	1	1	0	0	...	0
470140	1	0	1	0	...	0
714748	1	0	0	1	...	0
624947	1	1	1	1	...	0
524455	1	0	0	1	...	1

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Checkout

Name

Address

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☐

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user_id ↕	viewed_home ↕	clicked_search ↕	clicked_read_reviews ↕	clicked_learn_more ↕	...yada yada... ↕	purchased ↕
187180	0	1	1	0	...	1
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261982	1	1	0	0	...	0
579325	1	1	1	1	...	0
829755	1	1	0	1	...	0
454574	1	1	0	0	...	0
216105	1	1	1	1	...	1
181215	0	1	0	0	...	0
996510	1	1	0	0	...	0
379967	1	1	0	0	...	0
511056	1	1	0	1	...	0
948165	1	1	1	0	...	0
575719	1	1	0	1	...	0
356383	1	1	1	0	...	0
582609	1	1	1	0	...	0
988781	1	0	0	1	...	0
857058	1	1	0	0	...	0
498438	1	1	0	0	...	0
470140	1	0	1	0	...	0
714748	1	0	0	1	...	0
624947	1	1	1	1	...	0
524455	1	0	0	1	...	1

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Checkout

Name

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Credit Card

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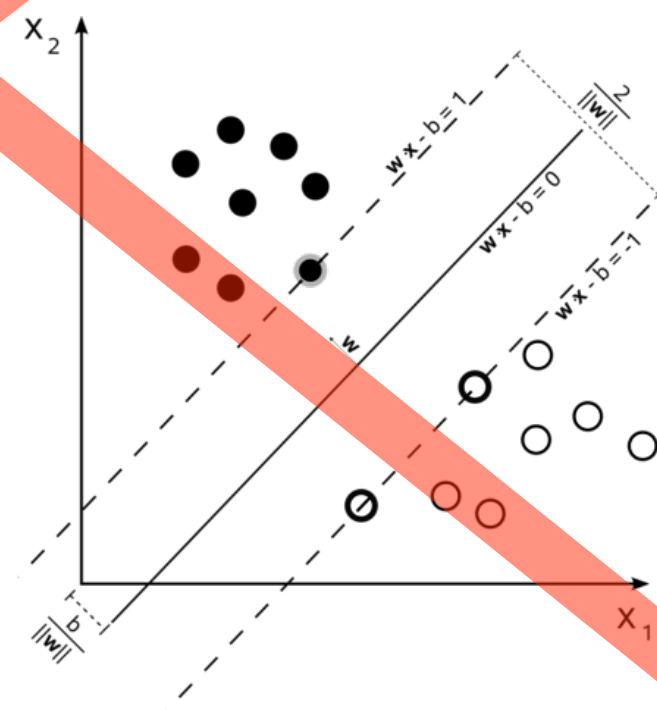
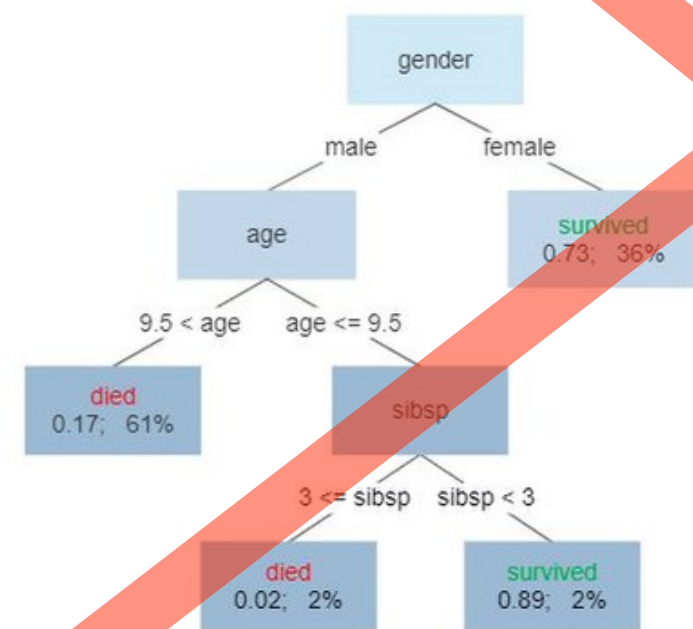
This click has a 99% correlation with purchasing!

I agree to Terms & Conditions

Purchase

The most important problems facing product builders  
aren't predictive, they're **causal**

$$y_i = \beta_1 x_{i1} + \beta_2 x_{i2} + \cdots + \beta_p x_{ip} + \varepsilon_i$$

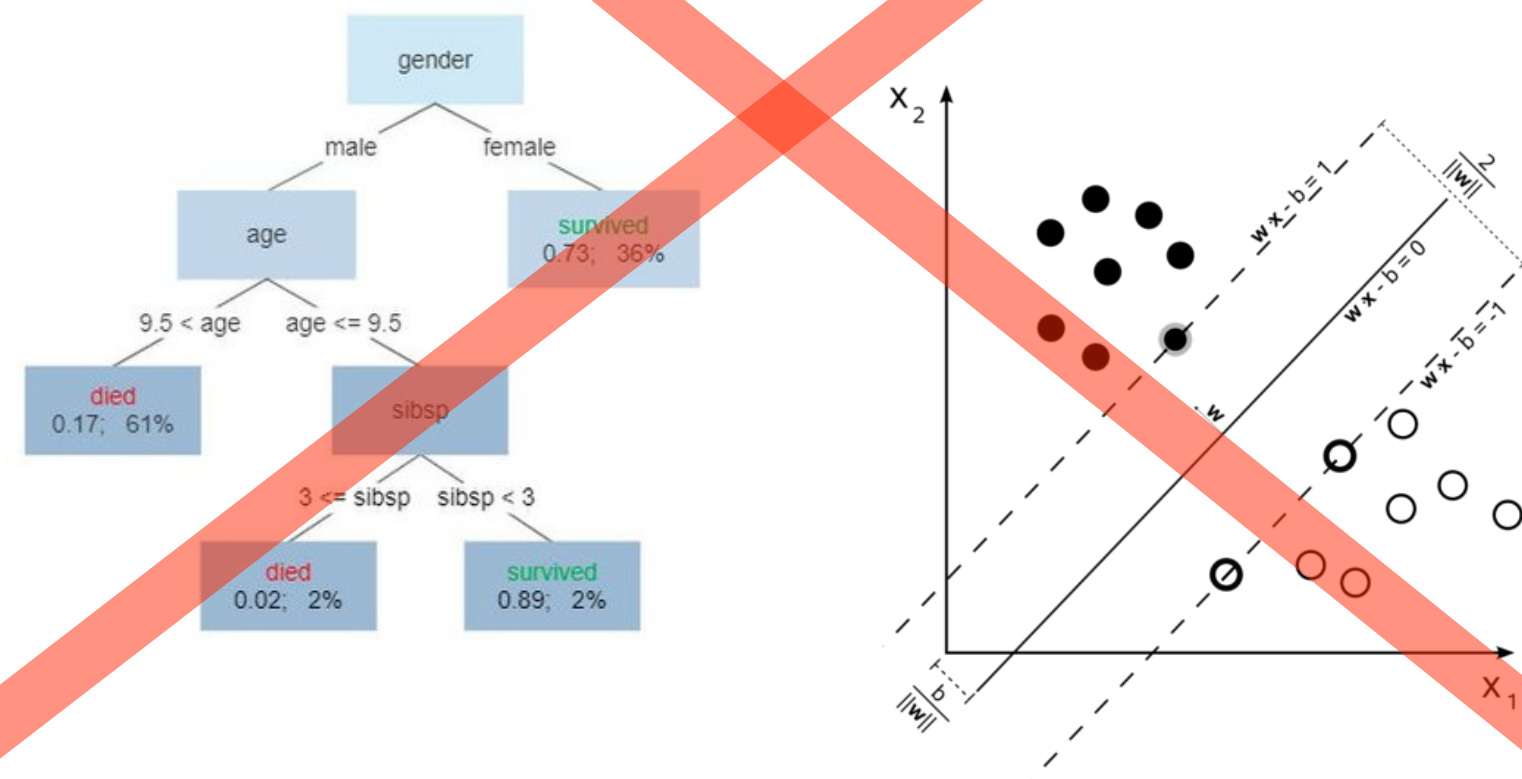


**Prediction**

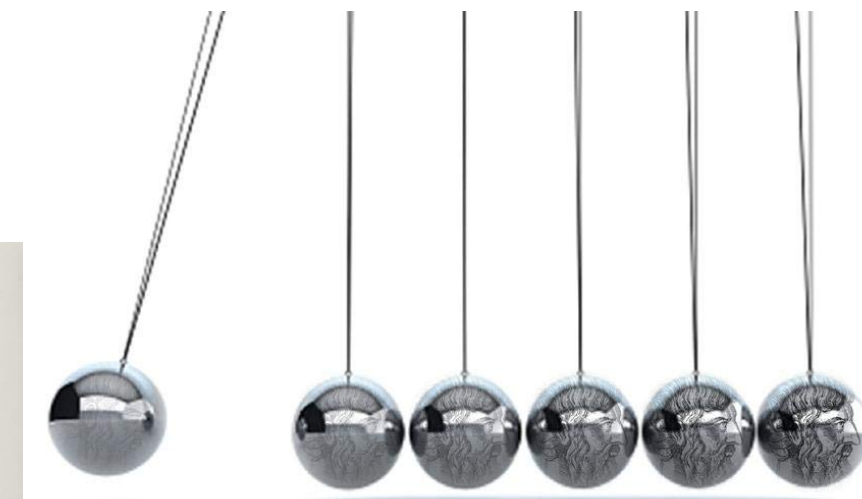
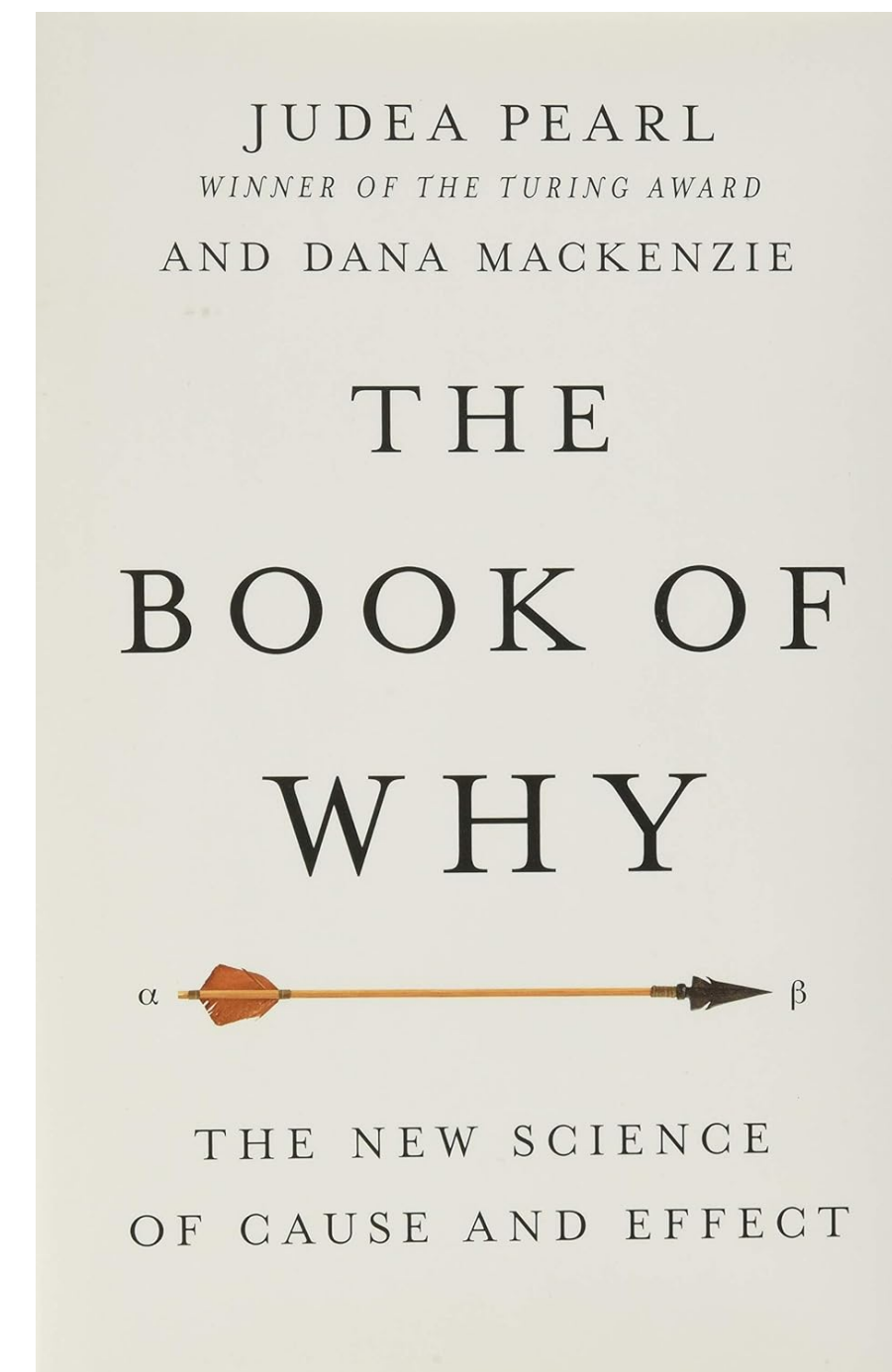


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**Prediction**

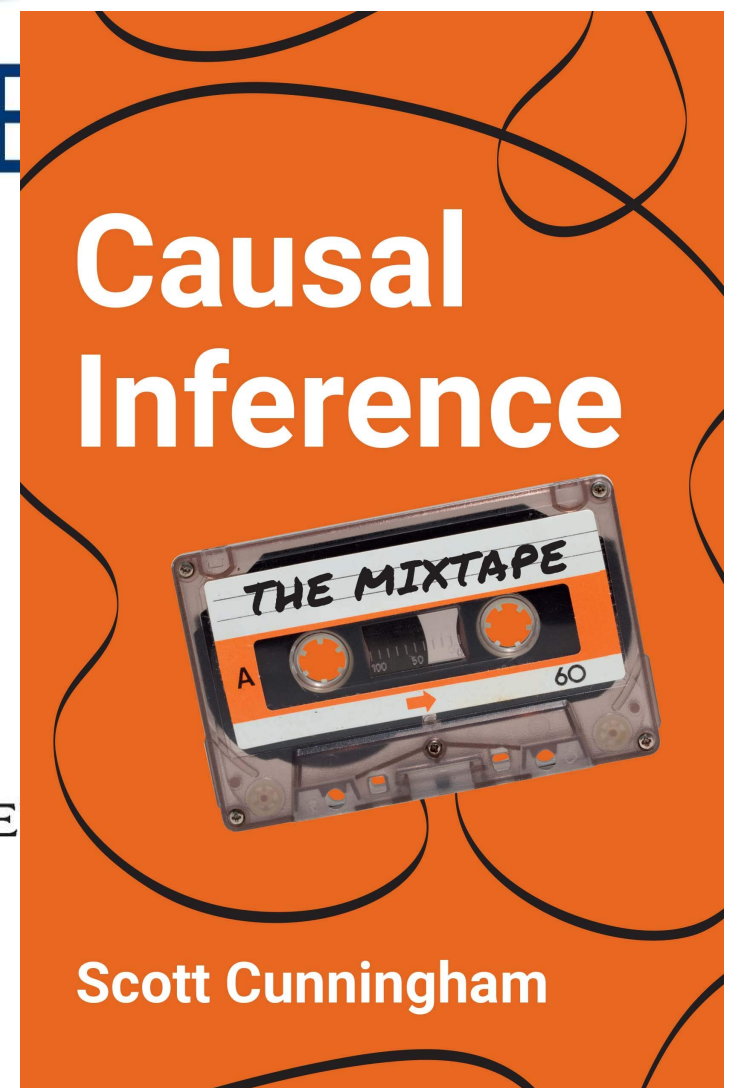


**CAUSAL INFERENCE  
IN STATISTICS**  
A Primer

Judea Pearl  
Madelyn Glymour  
Nicholas P. Jewell



WILEY



**Intervention**

Maybe it *is* actually true that making the purchase button bigger would improve the conversion rate. How can we determine that?

Maybe it *is* actually true that making the purchase button bigger would improve the conversion rate. How can we determine that?

A/B Test!

Name

Address

Credit Card

Apple Pay

Paypal

☐ I agree to Terms & Conditions

Purchase

Control

Name

Address

Credit Card

Apple Pay

Paypal

☐ I agree to Terms & Conditions

Purchase

Experiment



A/B tests are the gold standard for determining the impact of an intervention

Name

Address

Credit Card

Apple Pay

Paypal

☐ I agree to Terms & Conditions

Purchase

Control

Name

Address

Credit Card

Apple Pay

Paypal

☐ I agree to Terms & Conditions

Purchase

Experiment

# A/B tests are the gold standard for determining the impact of an intervention

Name

Address

Credit Card

Apple Pay

Paypal

☐ I agree to Terms & Conditions

Purchase

Control

Name

Address

Credit Card

Apple Pay

Paypal

☐ I agree to Terms & Conditions

Purchase

Experiment

- It's no surprise it works: they're randomized controlled trials (RCTs), which scientists have studied for a century!

# A/B tests are the gold standard for determining the impact of an intervention

Name

Address

Credit Card Apple Pay Paypal

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

☐ I agree to Terms & Conditions

Purchase

Control

Name

Address

Credit Card Apple Pay Paypal

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

☐ I agree to Terms & Conditions

Purchase

Experiment

- It's no surprise it works: they're randomized controlled trials (RCTs), which scientists have studied for a century!
- But...



# A/B tests are the gold standard for determining the impact of an intervention

<div><input type="text" value="Name"/></div>	<div><input type="text" value="Name"/></div>
<div><input type="text" value="Address"/></div>	<div><input type="text" value="Address"/></div>
<div><div>Credit Card</div><div>Apple Pay</div><div>Paypal</div></div>	<div><div>Credit Card</div><div>Apple Pay</div><div>Paypal</div></div>
<div><div><div></div><div></div><div></div><div></div></div></div>	<div><div><div></div><div></div><div></div><div></div></div></div>
<div><input type="checkbox"/> I agree to Terms &amp; Conditions</div>	<div><input type="checkbox"/> I agree to Terms &amp; Conditions</div>
<div><div>Purchase</div></div>	<div><div>Purchase</div></div>
Control	Experiment

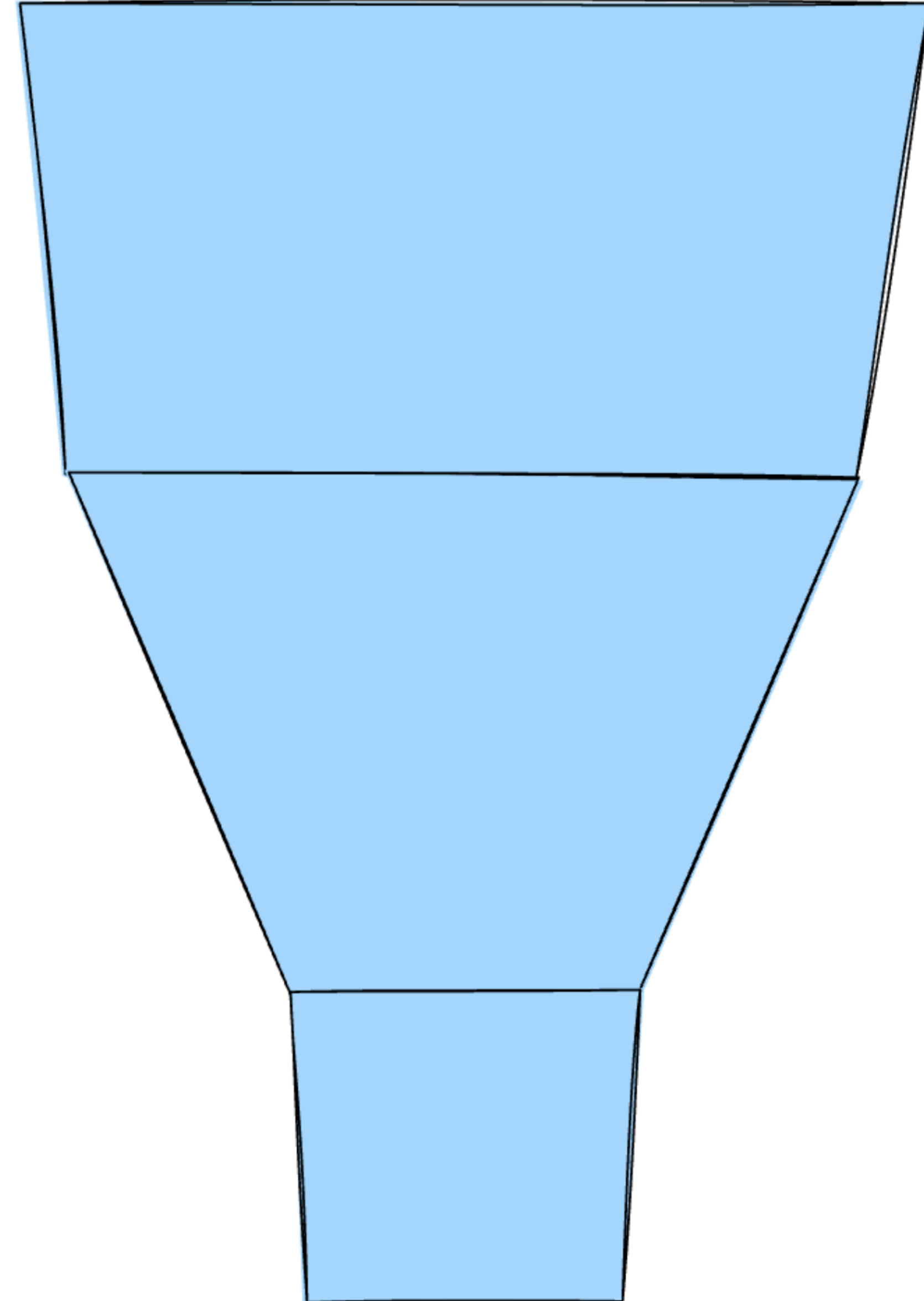
- It's no surprise it works: they're randomized controlled trials (RCTs), which scientists have studied for a century!
- But...
- they are **not** the only way to reason about causal effects

# A/B tests are the gold standard for determining the impact of an intervention

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Control	Experiment

- It's no surprise it works: they're randomized controlled trials (RCTs), which scientists have studied for a century!
- But...
  - they are **not** the only way to reason about causal effects
  - it does **not** mean that all observational data is useless

# Funnels



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Four horizontal lines representing input fields for card details.

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1000 users  
start the form



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Four horizontal lines representing input fields for card details.

600 users  
check the box



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594 users  
purchase



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60%



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Four horizontal lines representing a text input field

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99%



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95%

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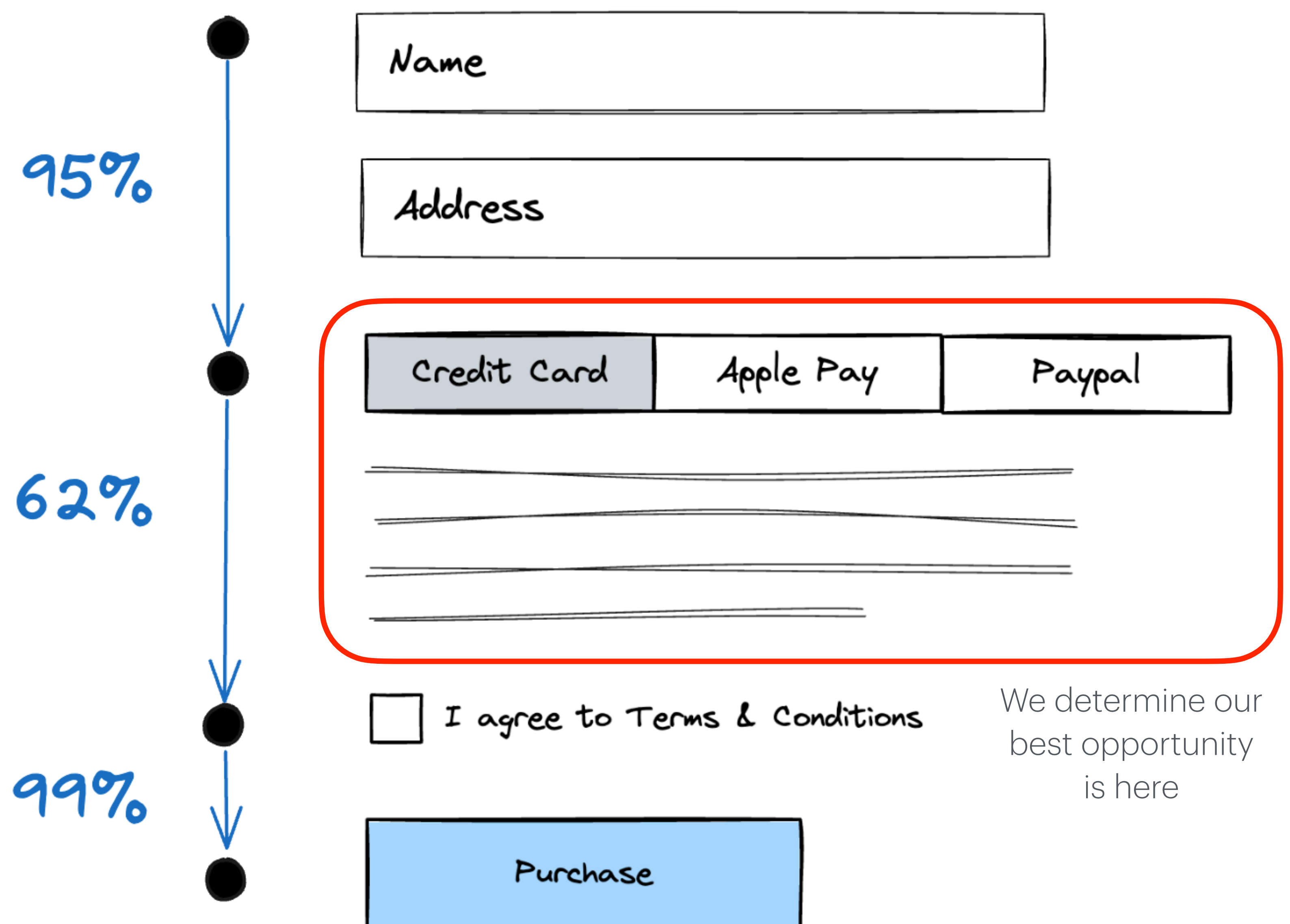
62%

99%

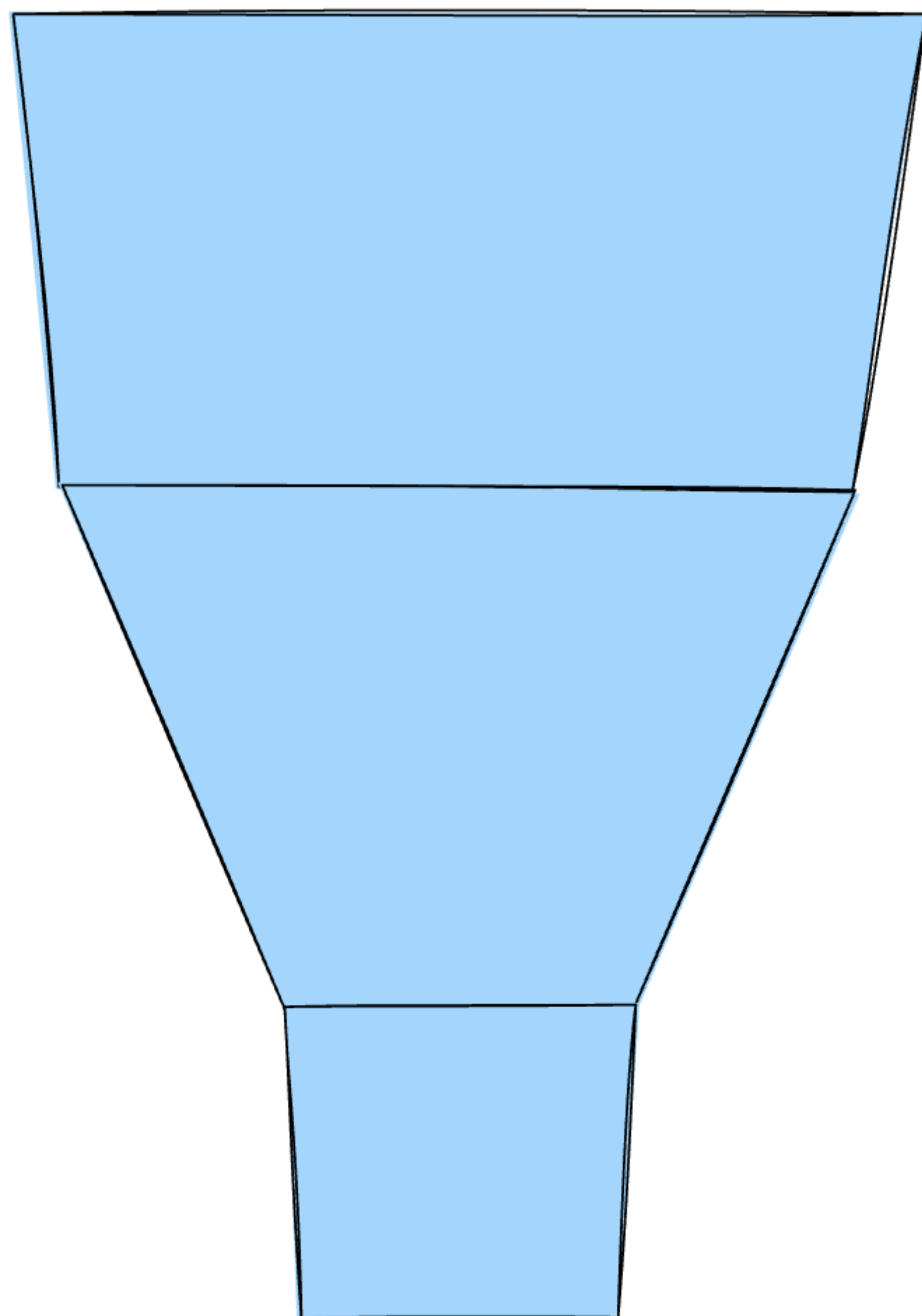
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We determine our best opportunity is here



95%

62%

99%

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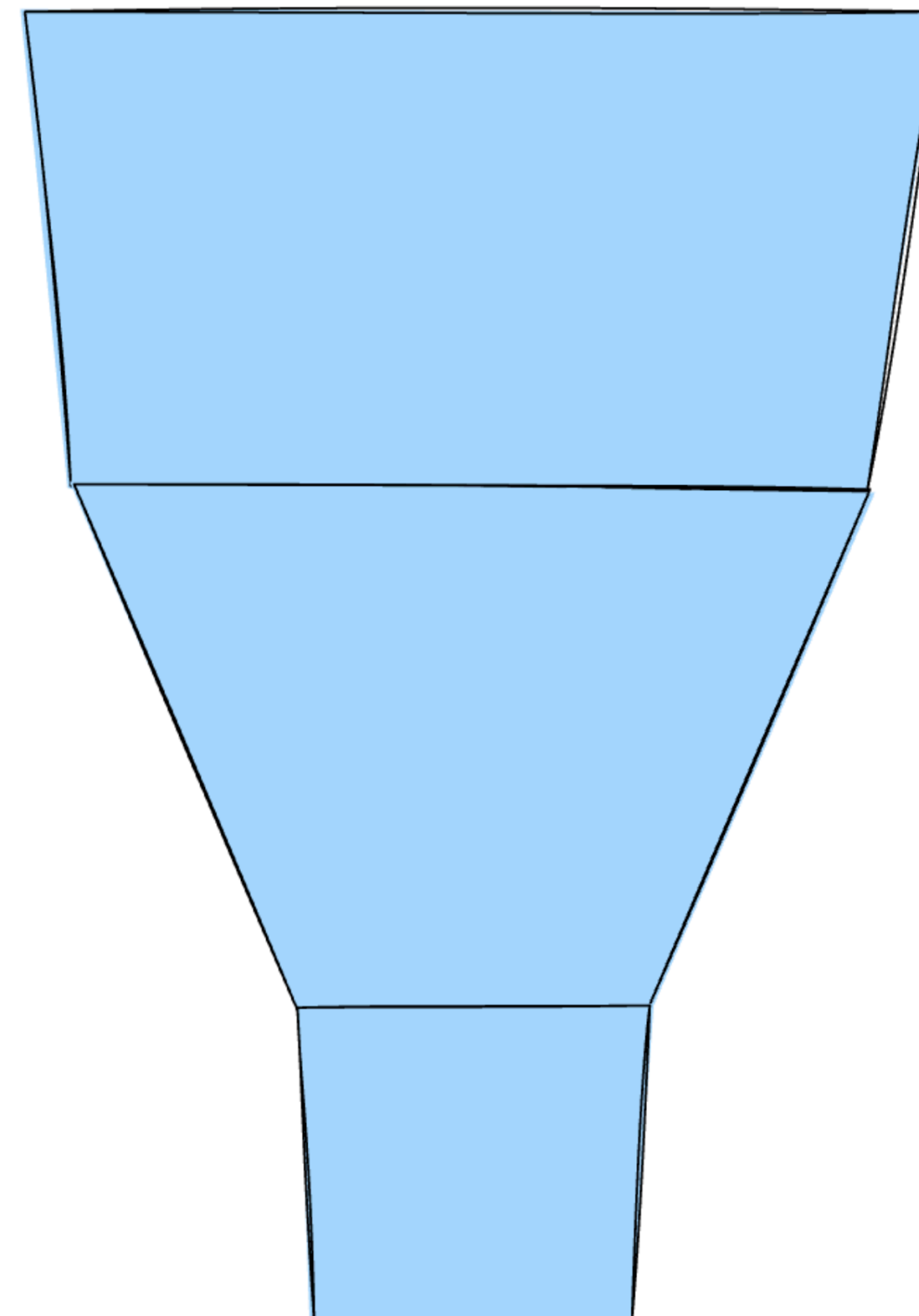
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We determine our  
best opportunity  
is here

# Why are we able to do causal reasoning with funnels?



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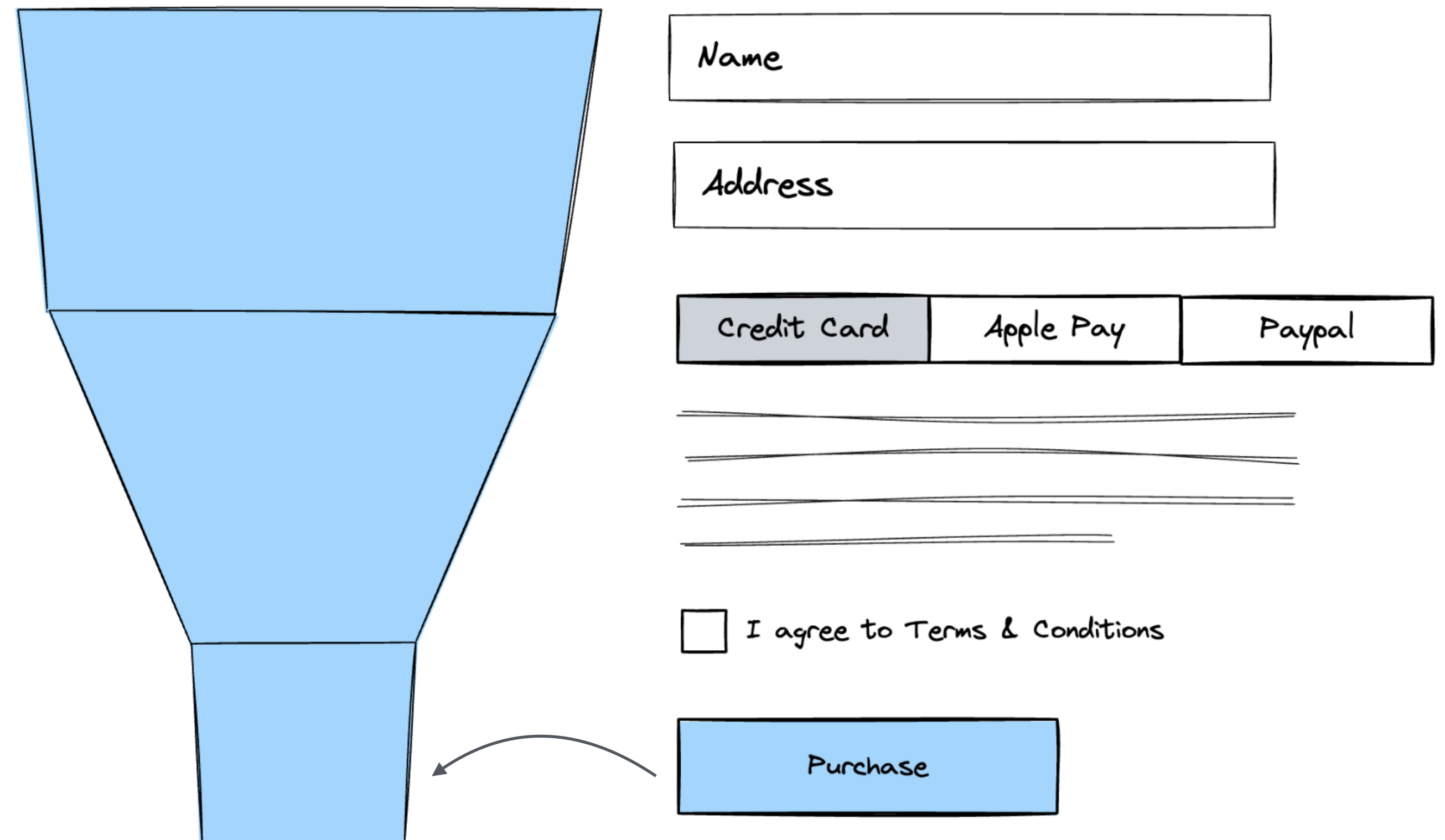
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# Why are we able to do causal reasoning with funnels?

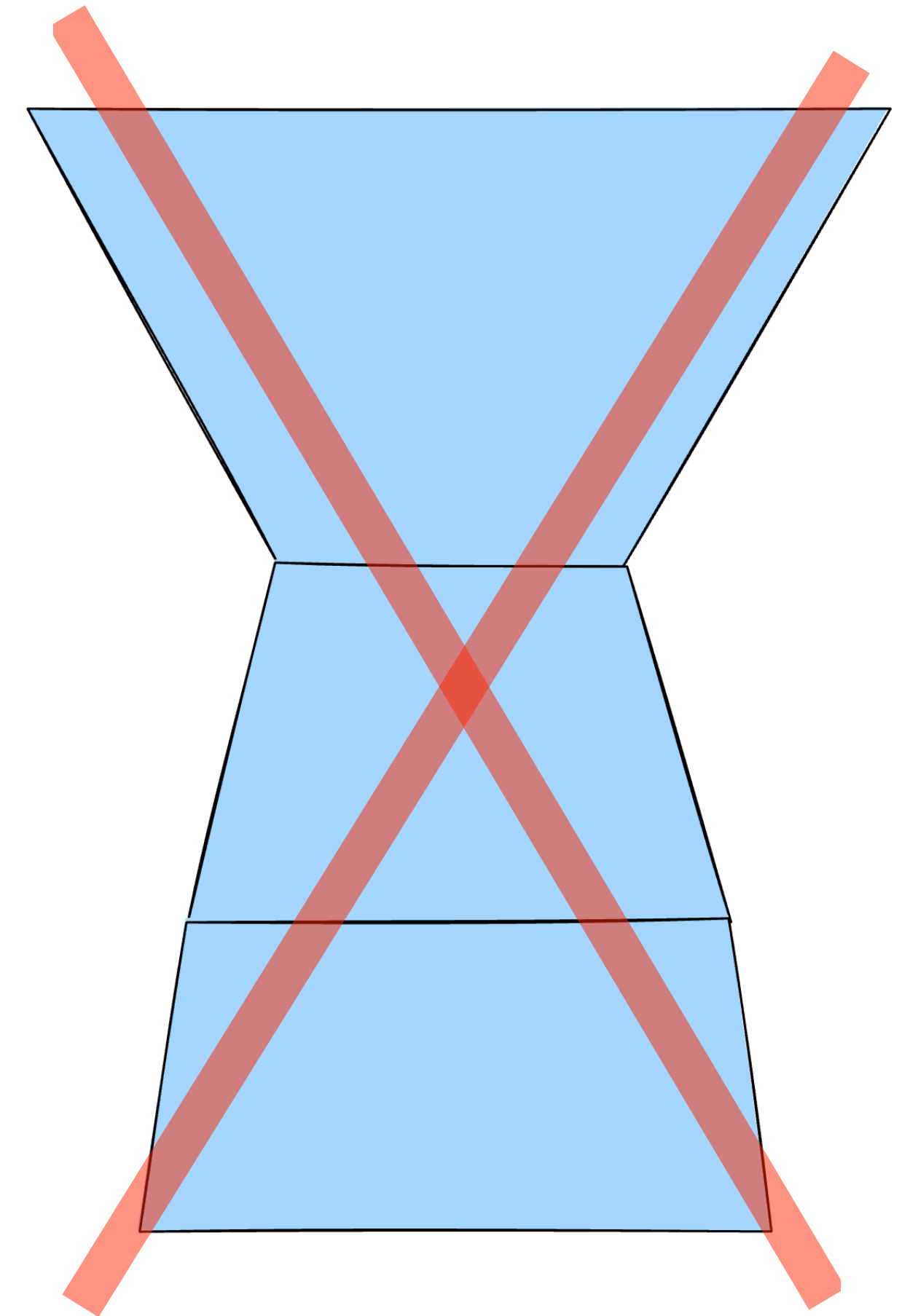
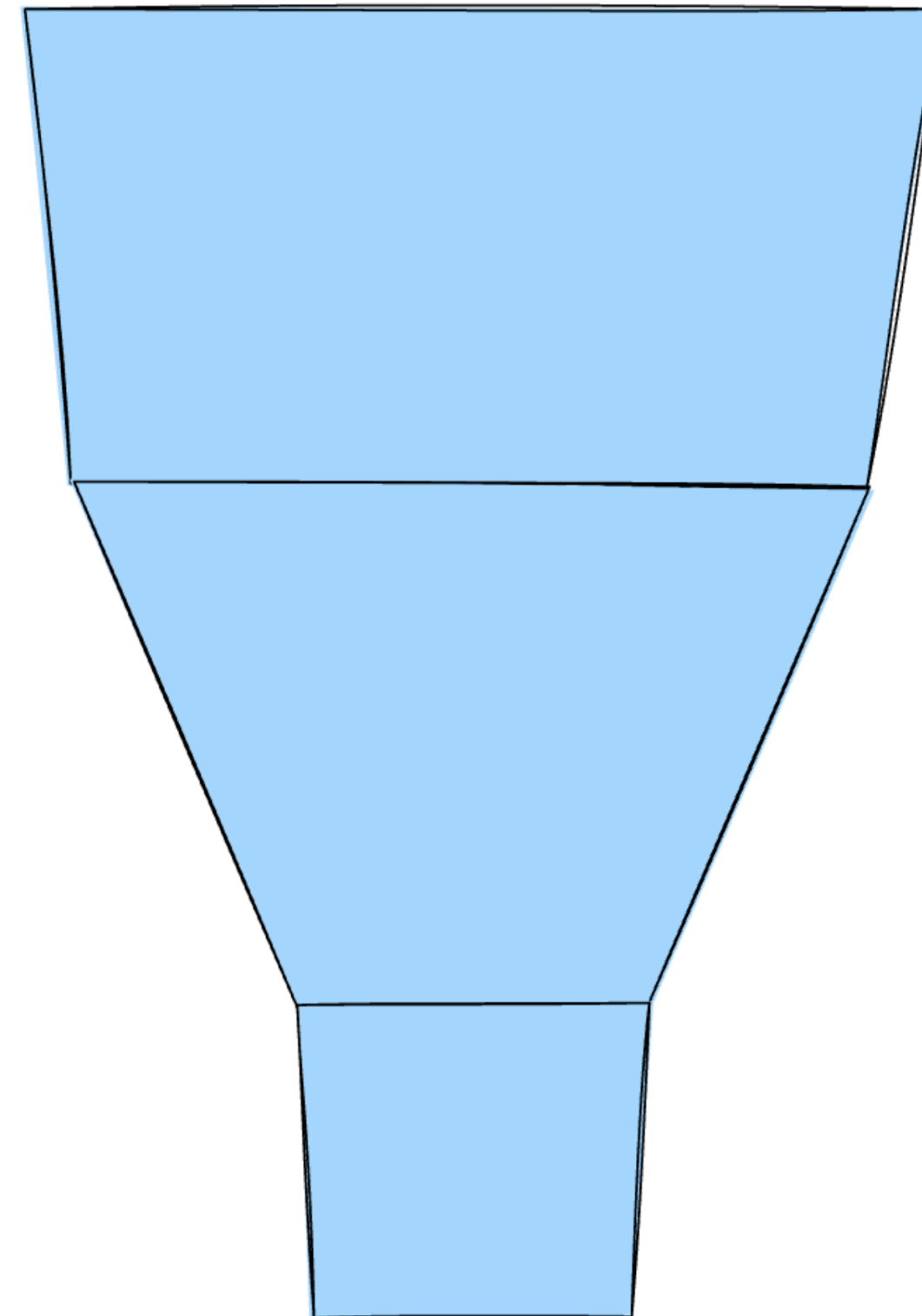
- **Locality:** We assume modifications to one part of a flow affect only that step in the funnel





# Why are we able to do causal reasoning with funnels?

- **Locality:** We expect modifications to one part of a flow to affect only that step in the funnel
- **Chronology:** Users are measured as they progress forward in the funnel; not if they skip steps



The weakness of a funnel is that it's **linear**

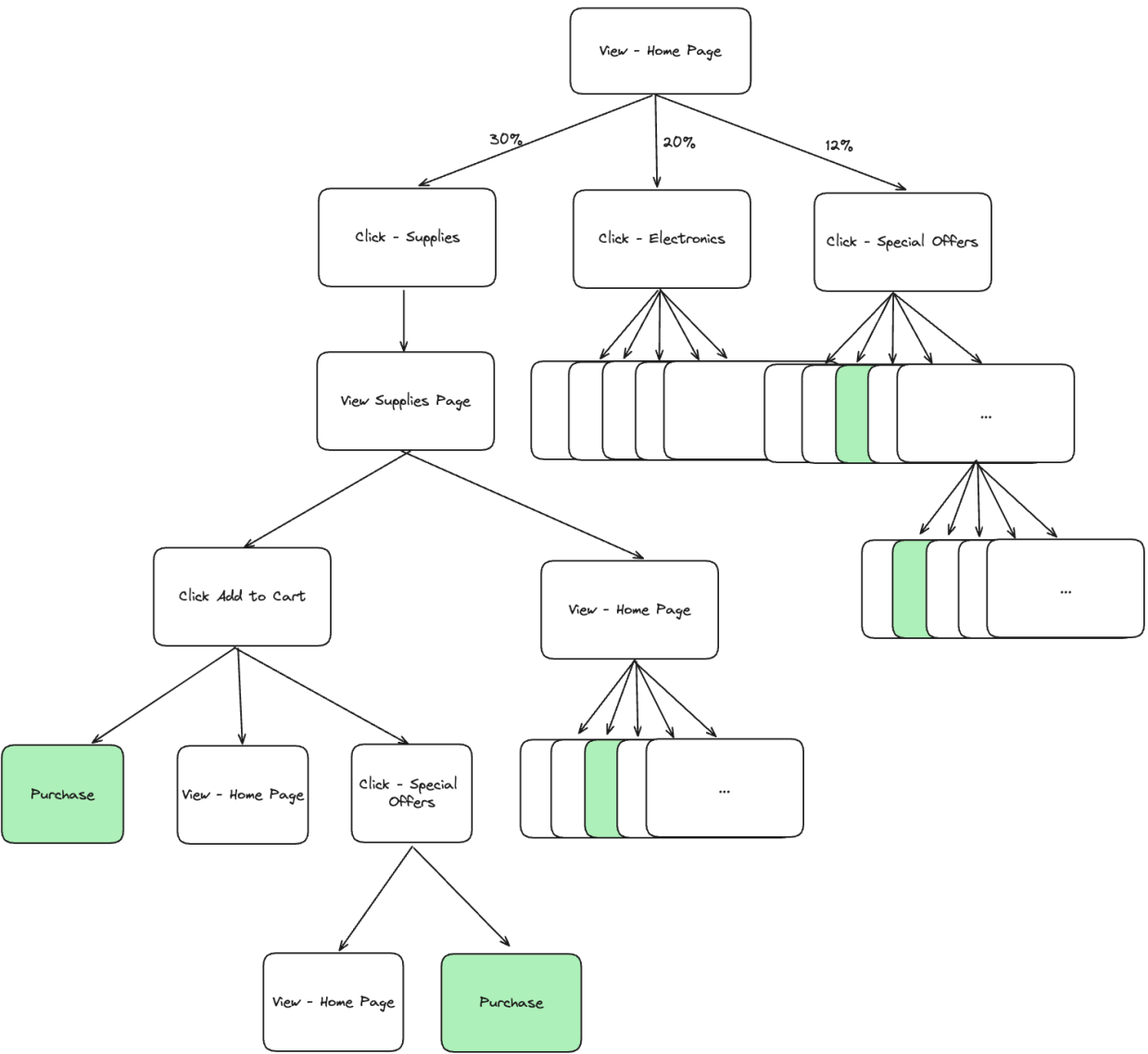
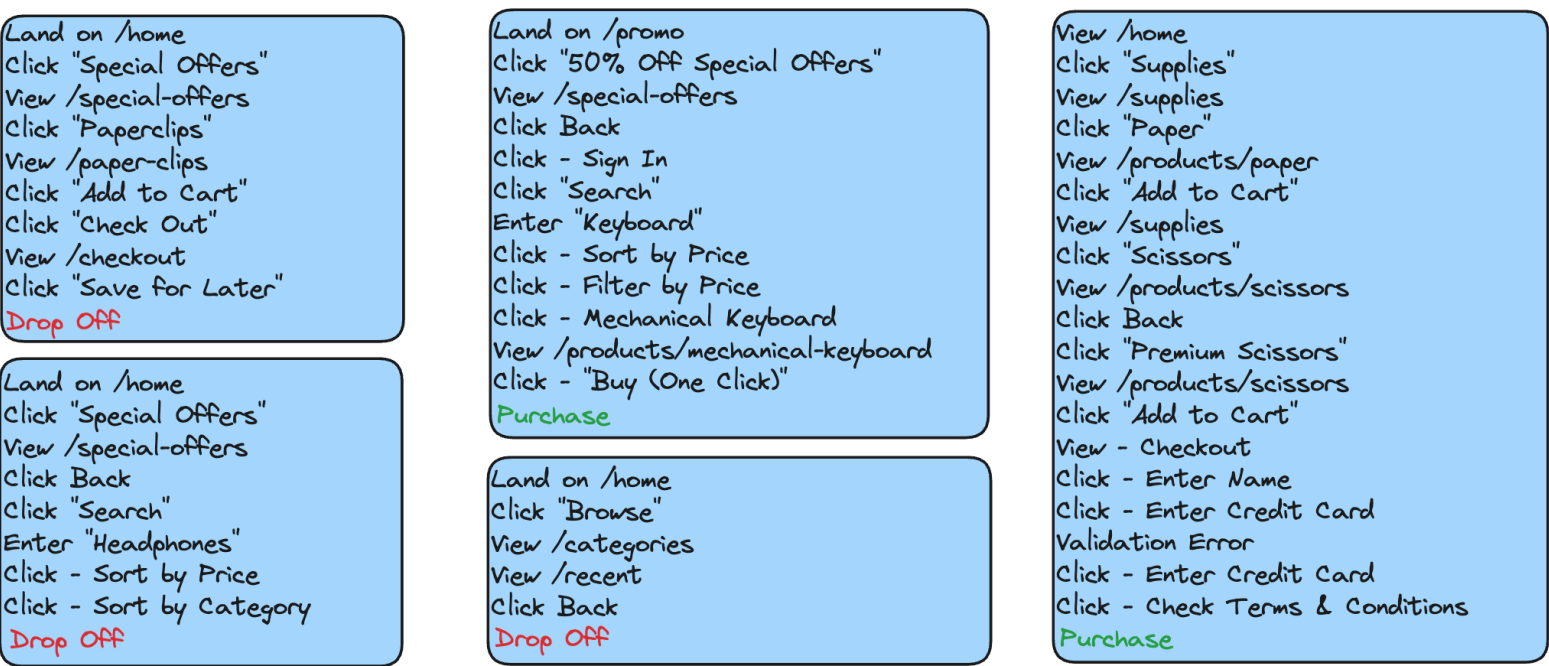
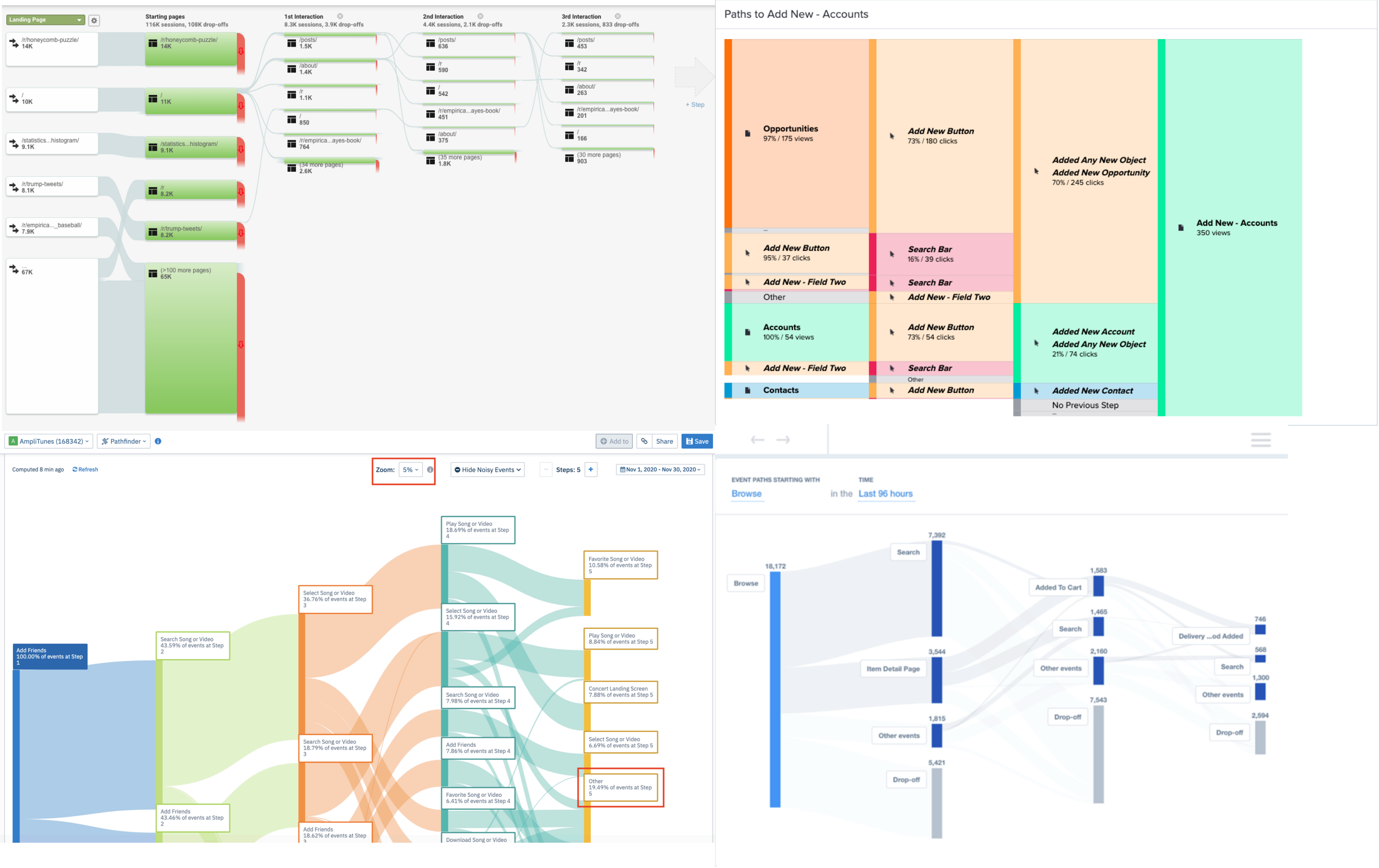
What a  
funnel sees



What the  
user did

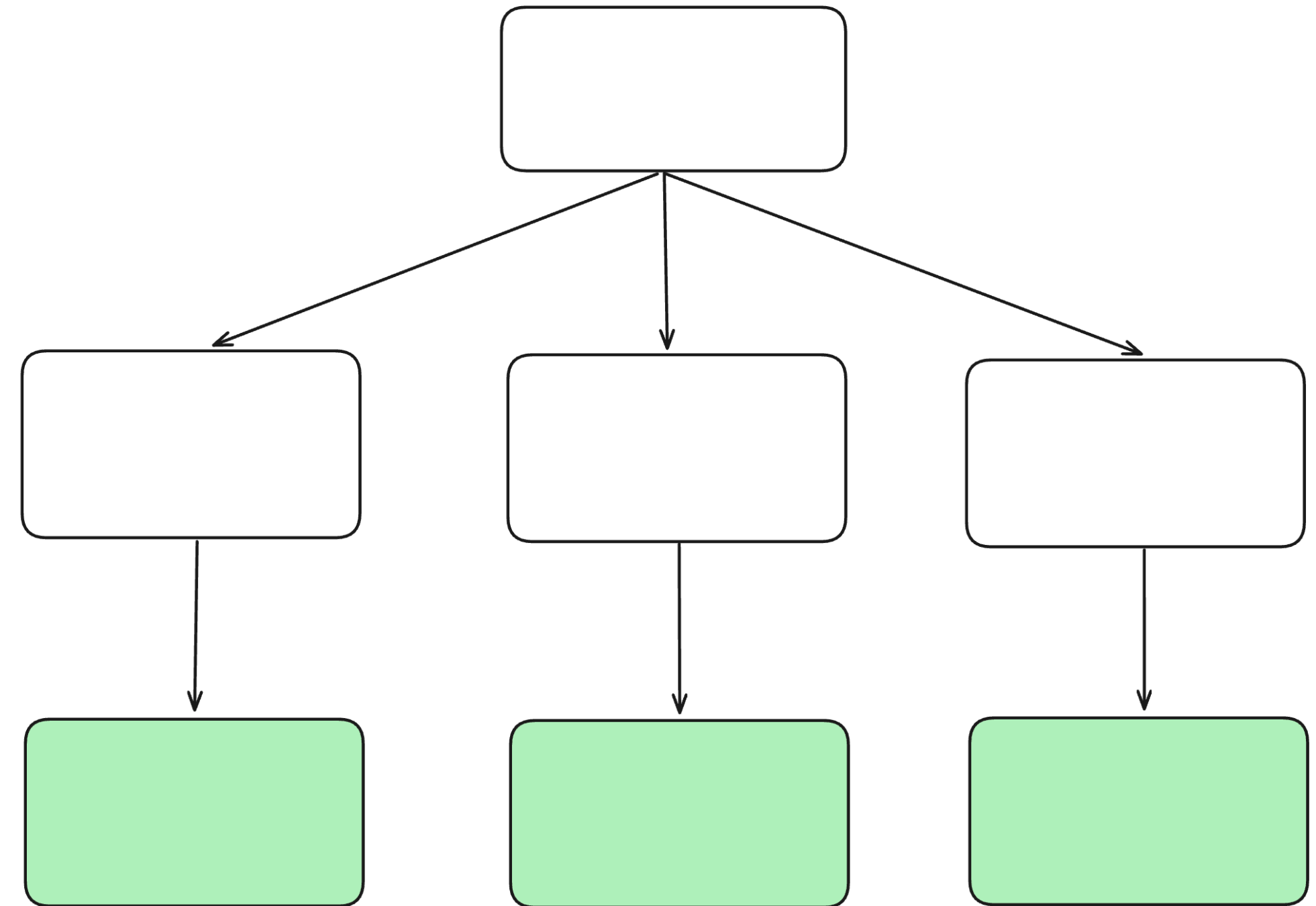


# Previous tools for measuring nonlinear sequences count consecutive actions



This leads to an explosion in state space: very difficult to draw conclusions

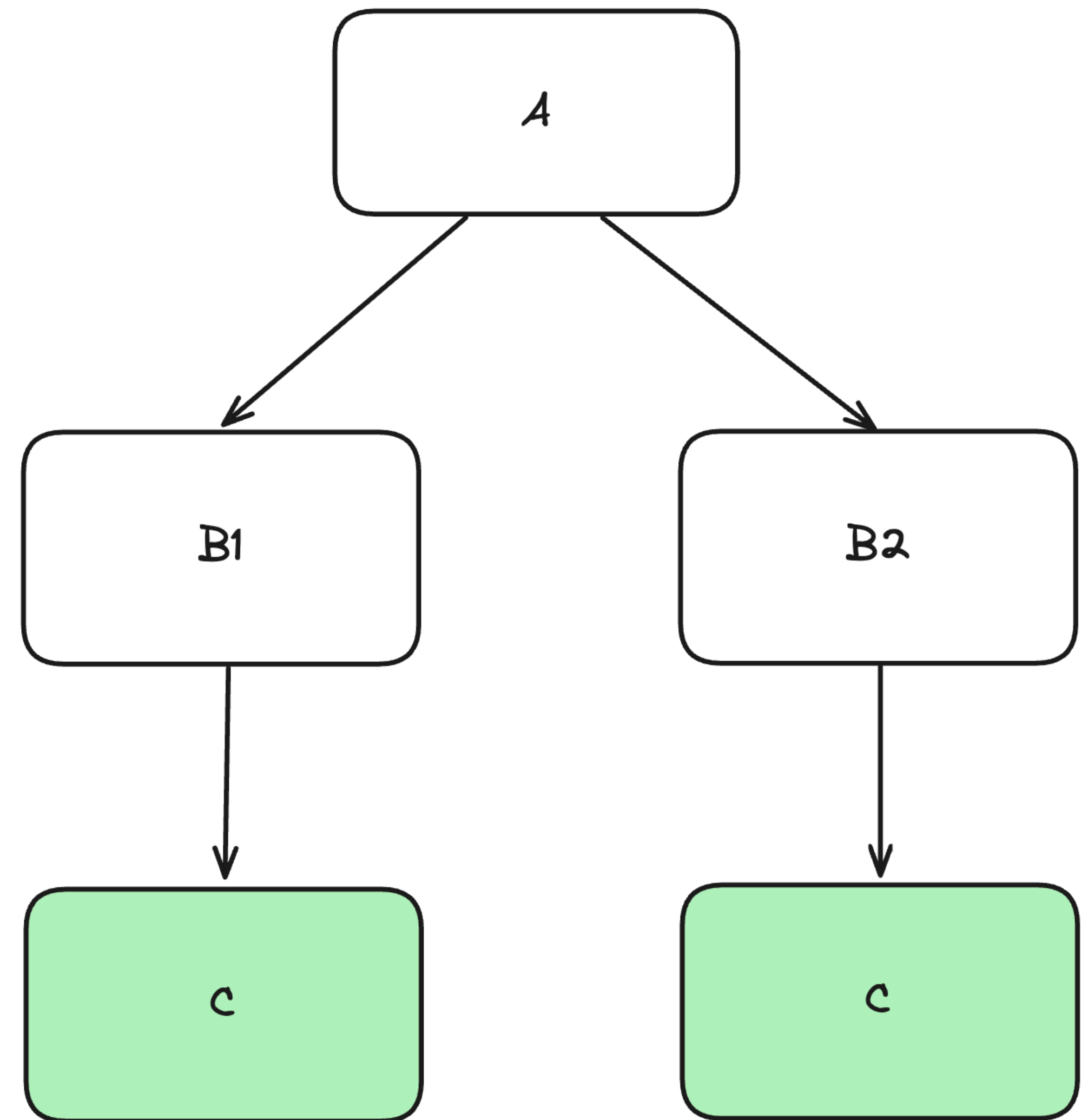
# Journeygrams





Journeygrams are a calculus that uses a directed rooted tree to quantify sequences of events

We **specify** the tree based on the causal hypotheses we're considering



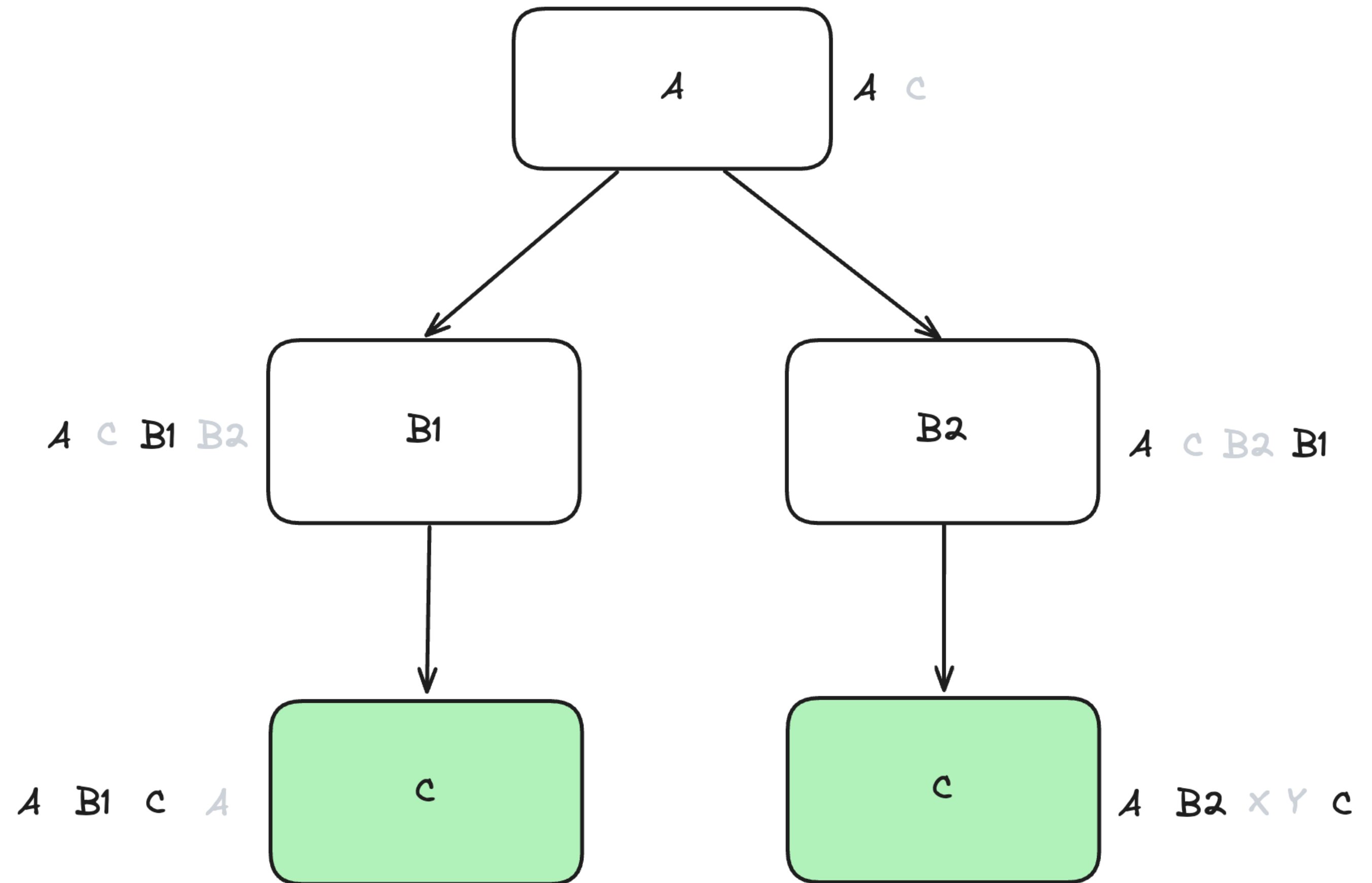
# How Journeygrams Work

Sequences **walk** the tree, transitioning to the next step when they see an event

When there's a fork, it follows the one that happens **first**

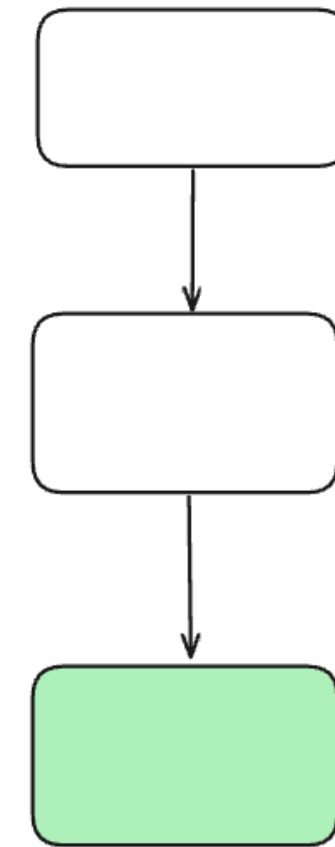
They **can't skip** steps

It **ignores** events other than the ones it is waiting for

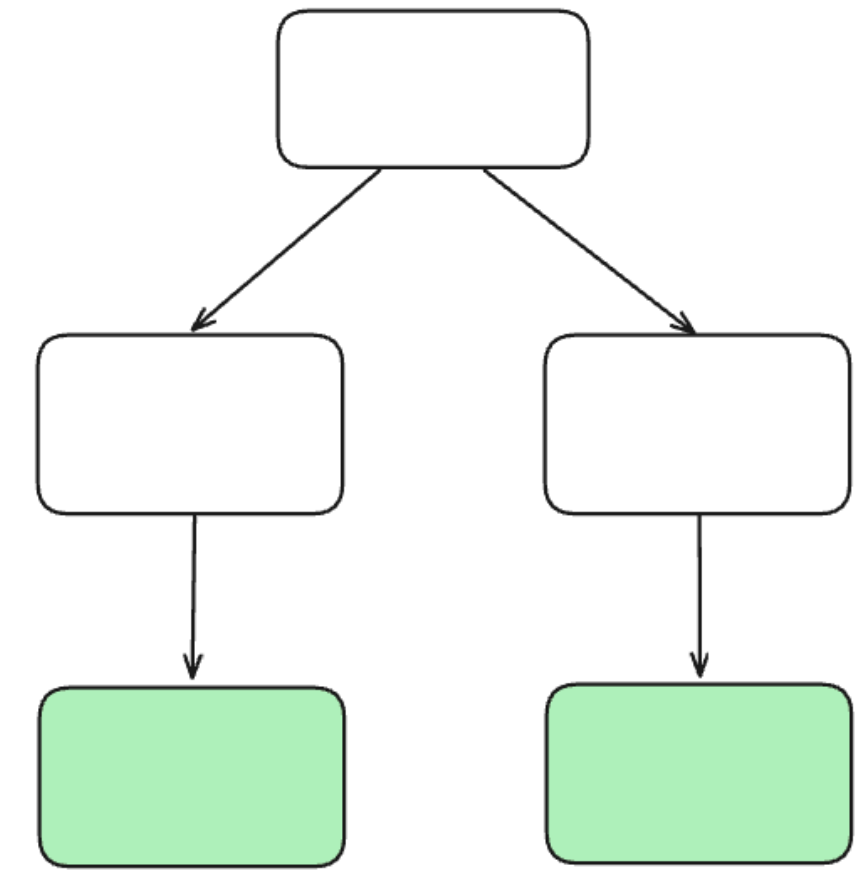


Funnels are a **special case** of journeygram

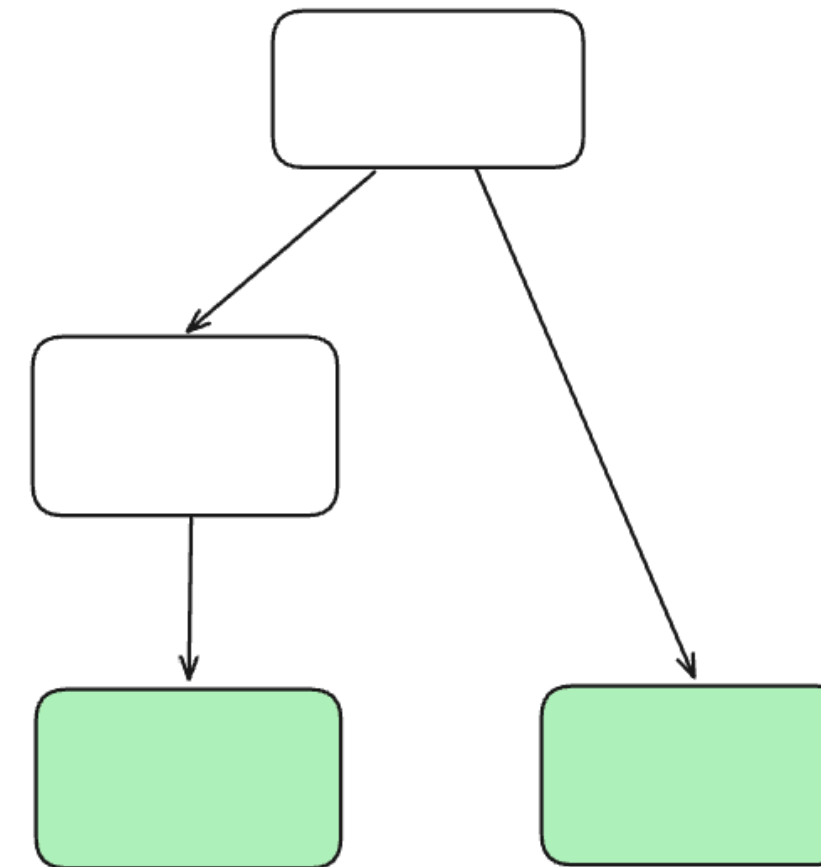
Other shapes let us extend the kinds of causal conclusions we intuitively draw from funnels



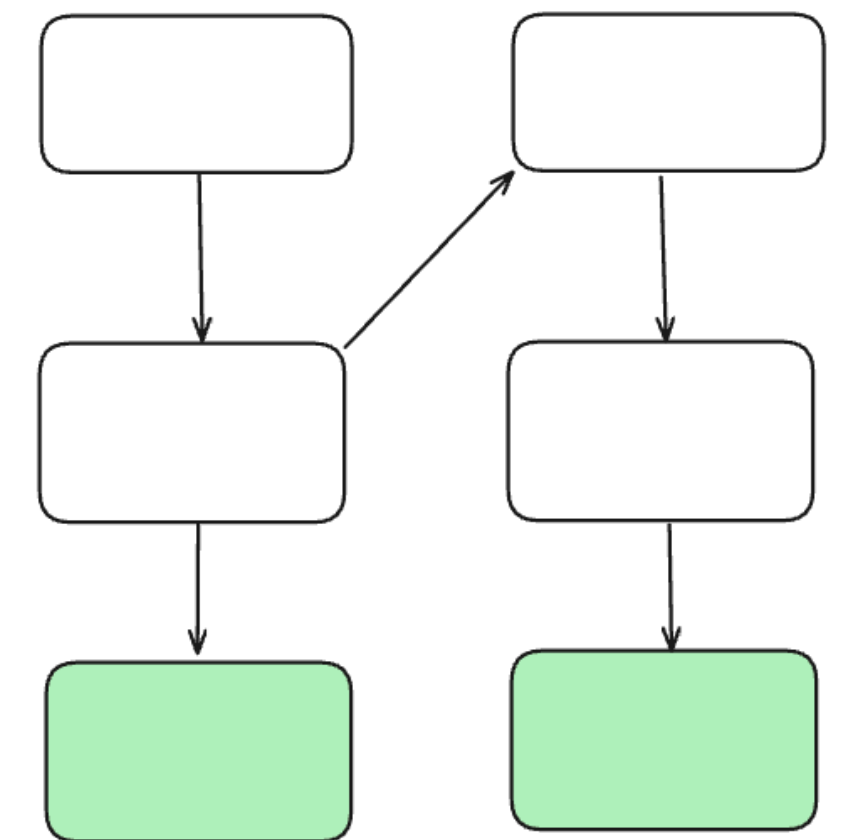
Funnel



Fork



Skippable Steps



Backtracking

If clicks happen at the same point in a journey, we *can* compare them

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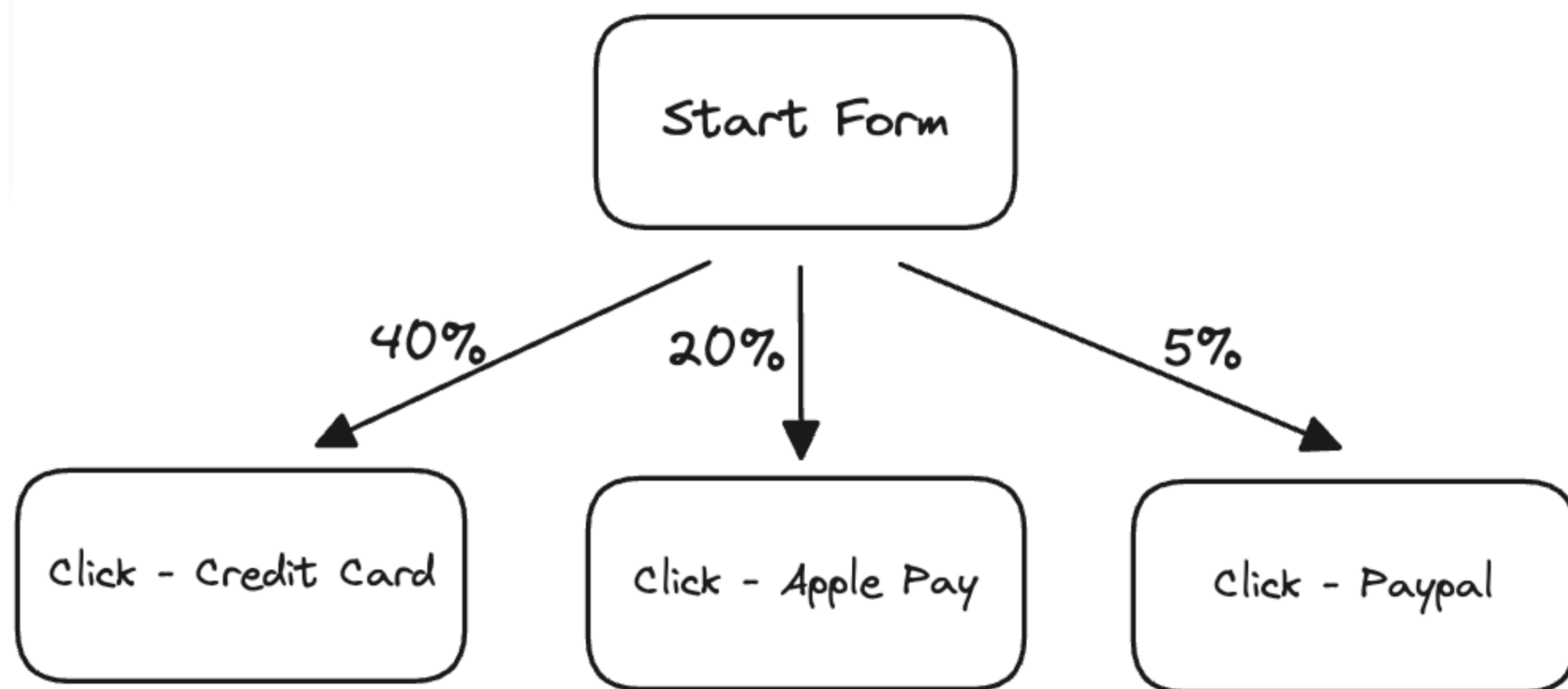
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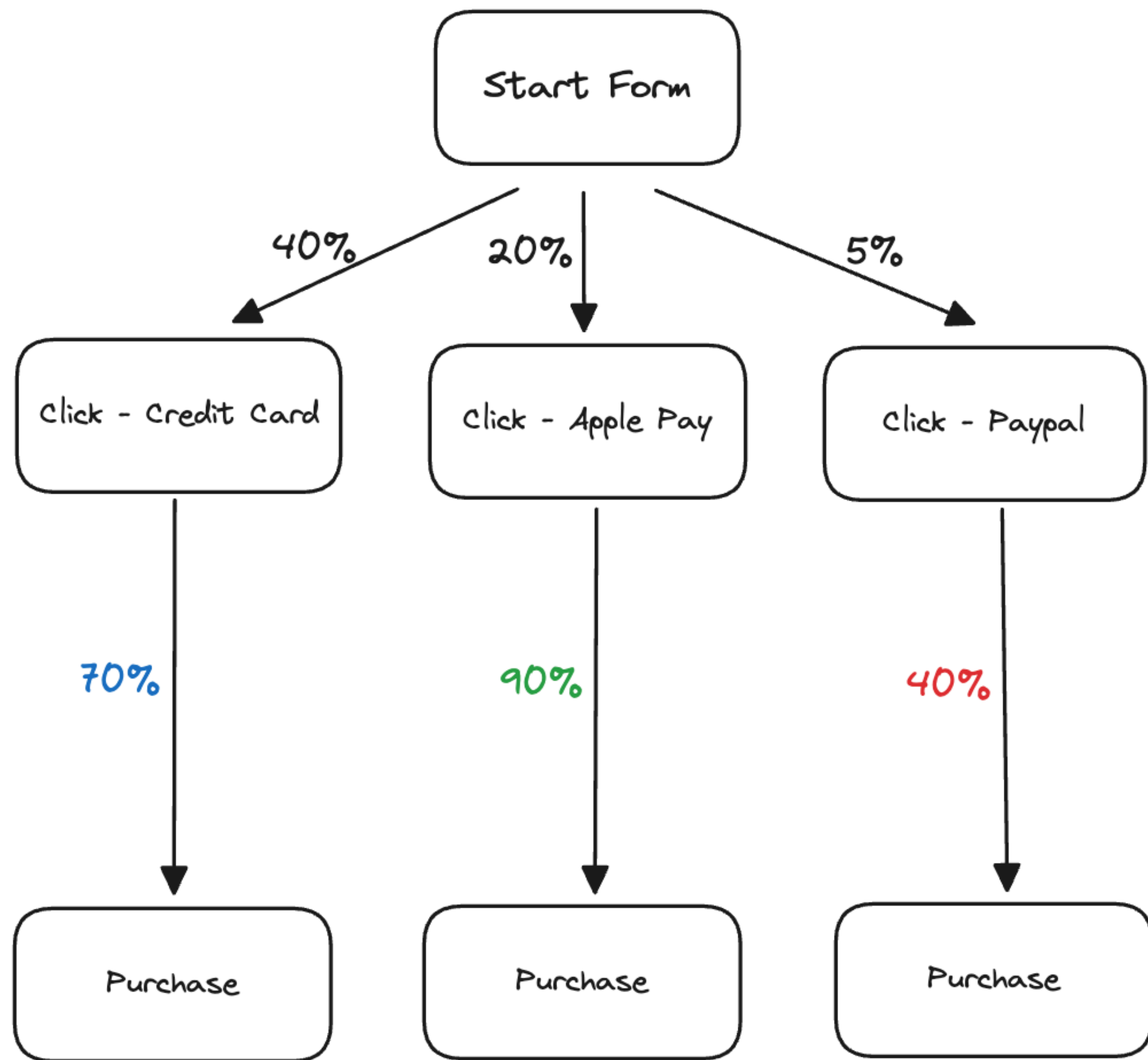
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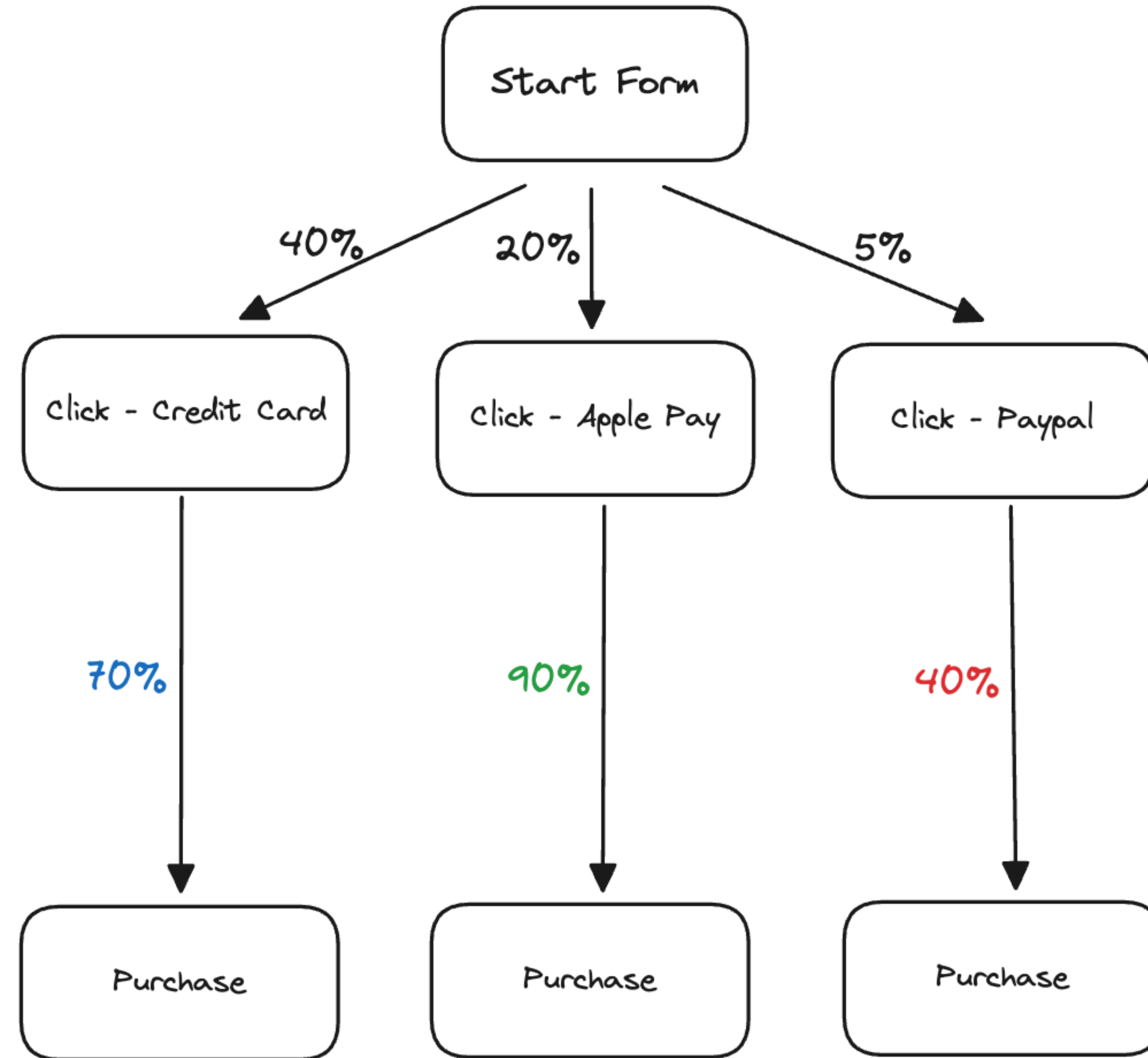
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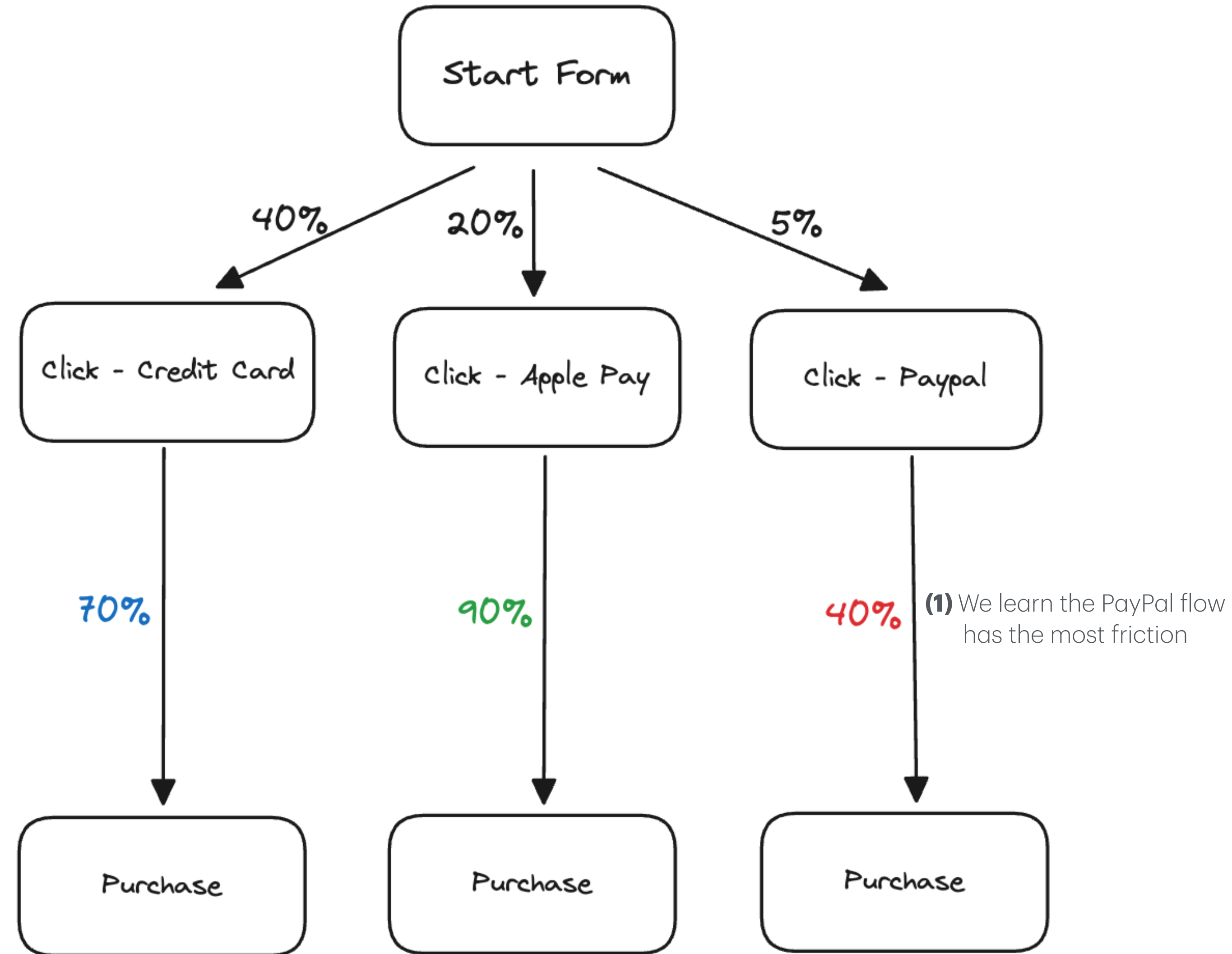
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In causal inference terms, we're *matching*



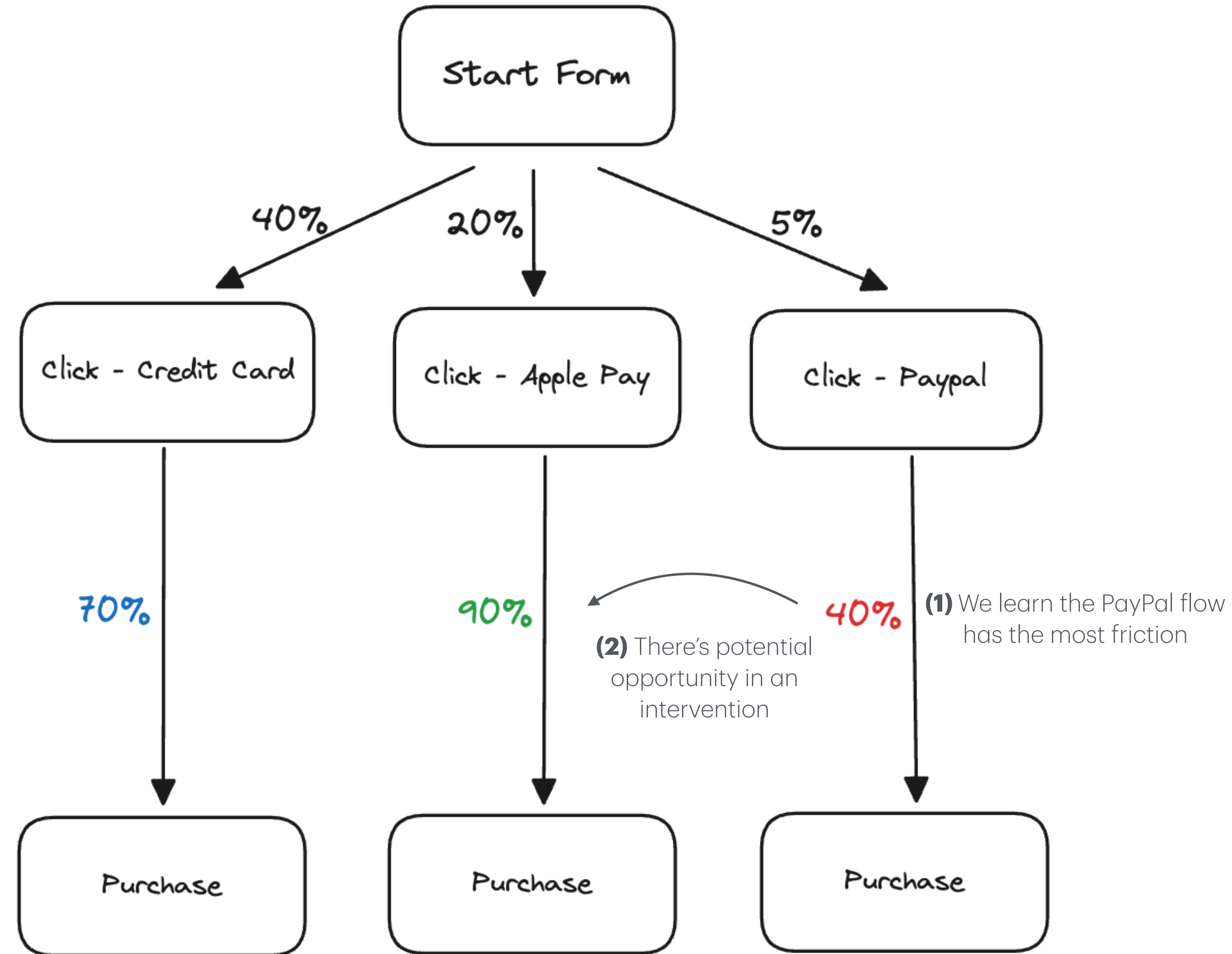
How do we use a journey to reason about causal effects?

In causal inference terms, we're *matching*



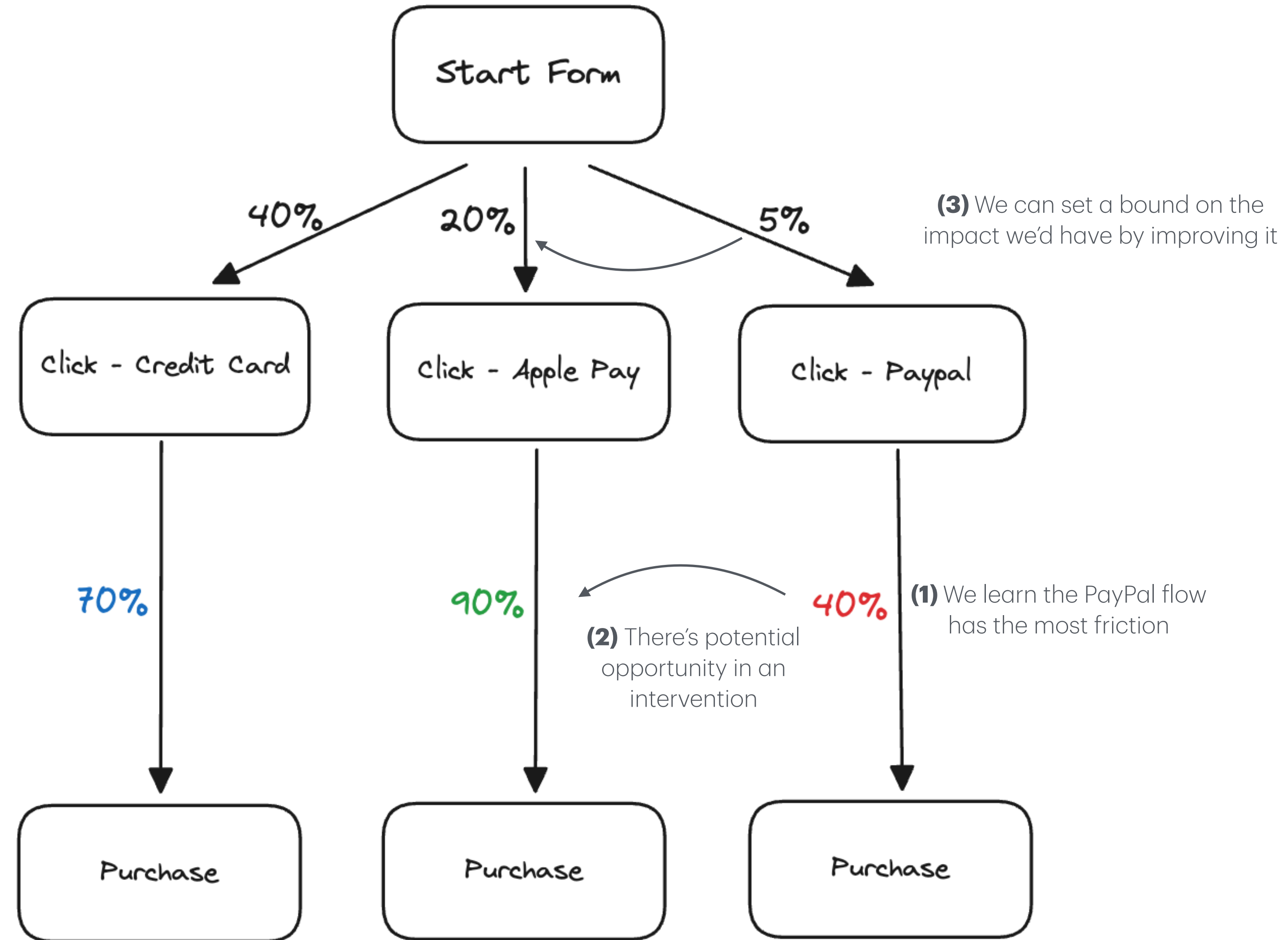
How do we use a journey to reason about causal effects?

In causal inference terms, we're *matching*



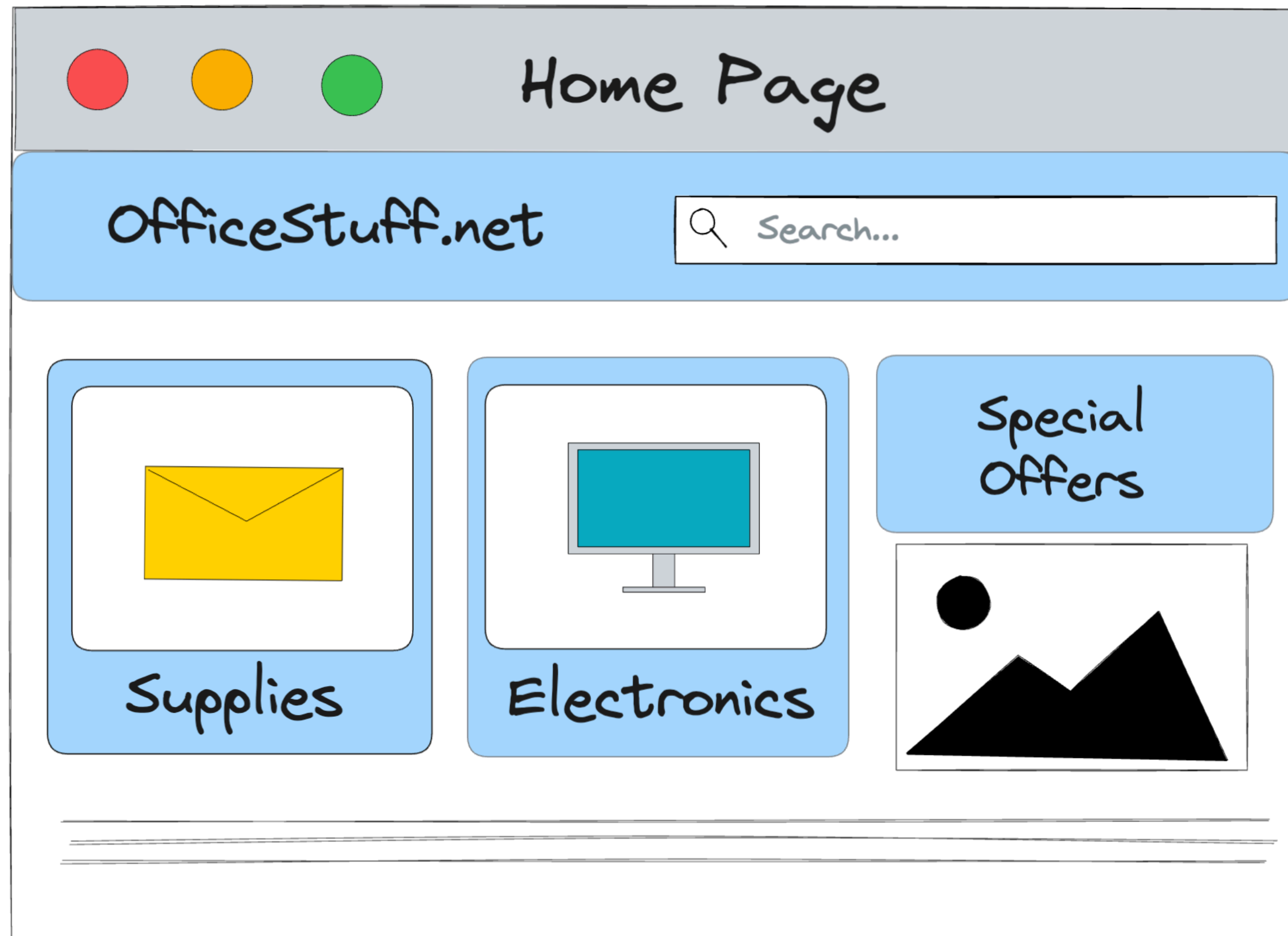
How do we use a journey to reason about causal effects?

In causal inference terms, we're *matching*



How do we use a journey to reason about causal effects?





Forks can measure larger goals, not just the UX within one page

Journeys: Skippable Steps

Name

Address

Credit Card

Apple Pay

Paypal

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☐ YES! Donate \$1 to "Save the Octopi"

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Purchase

Bad UI can cause users  
to miss important steps

Name

Address

Credit Card

Apple Pay

Paypal

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Bad UI can cause users  
to miss important steps

Name

Address



Error



We're sorry, something went wrong, and for some reason it's your job to figure out what

Create Card

Apple Pay

Paypal

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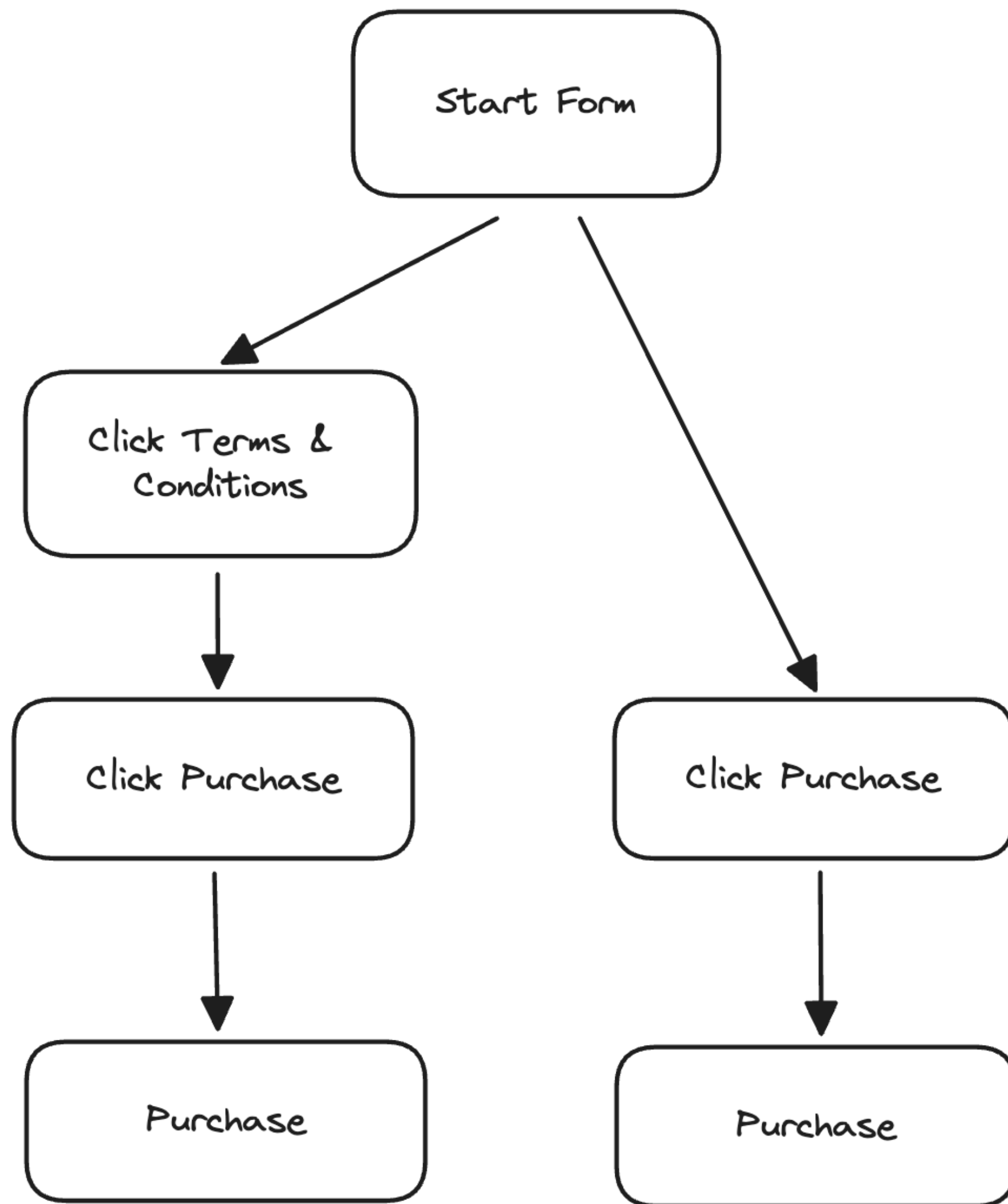
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Bad UI can cause users to miss important steps





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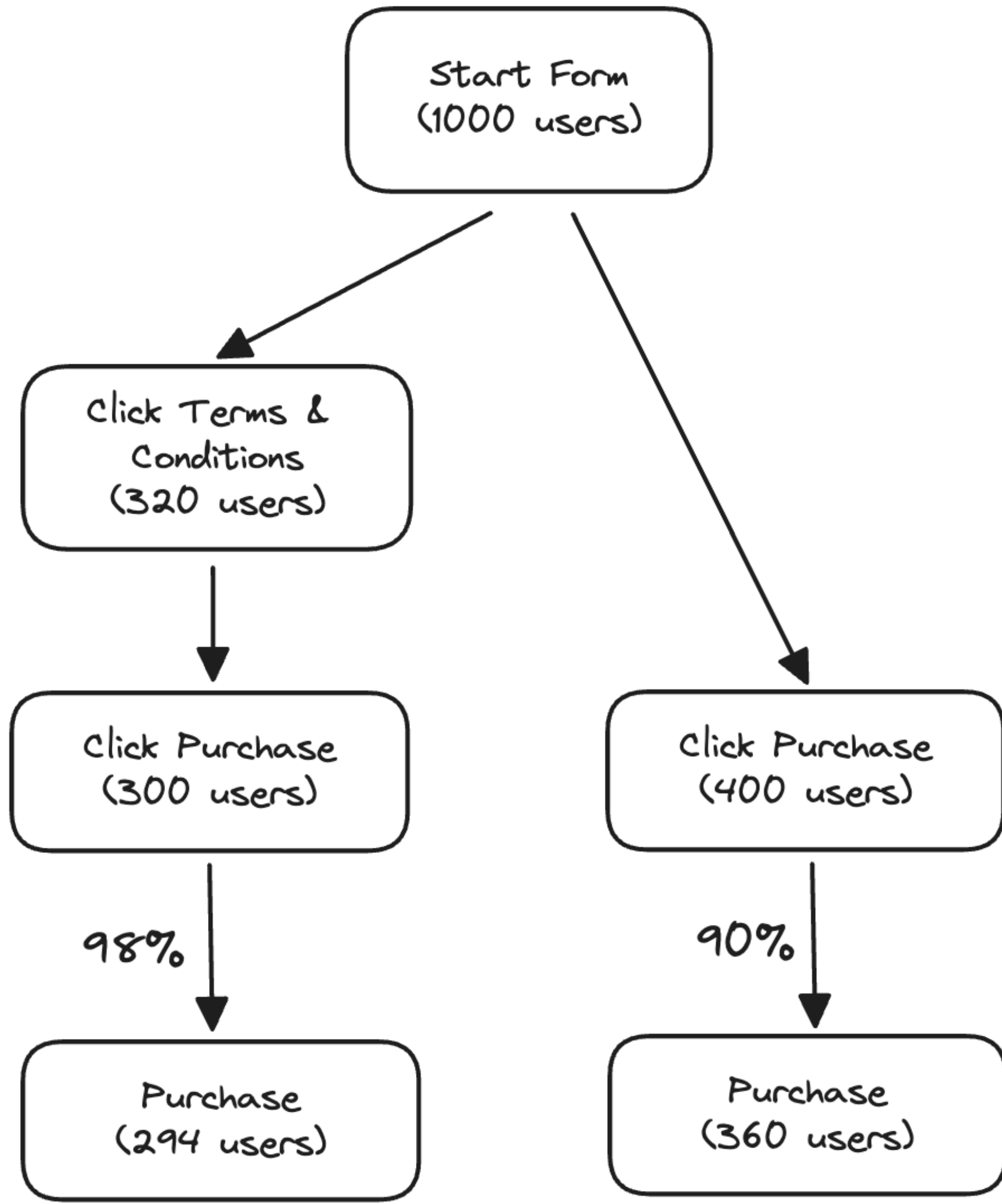
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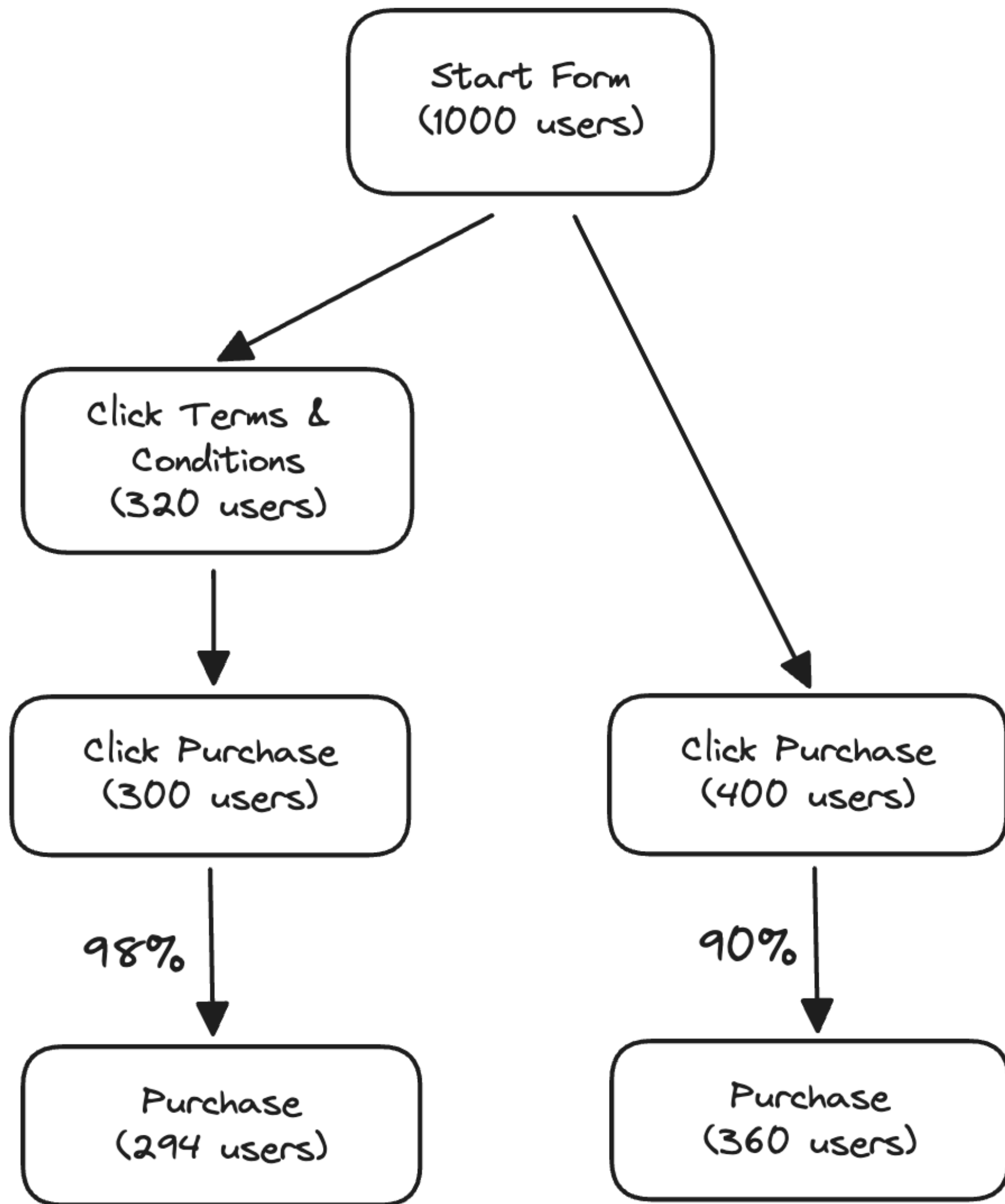
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Opportunity  
Size

$$400 * (.98 - .9) = 32 \text{ users}$$

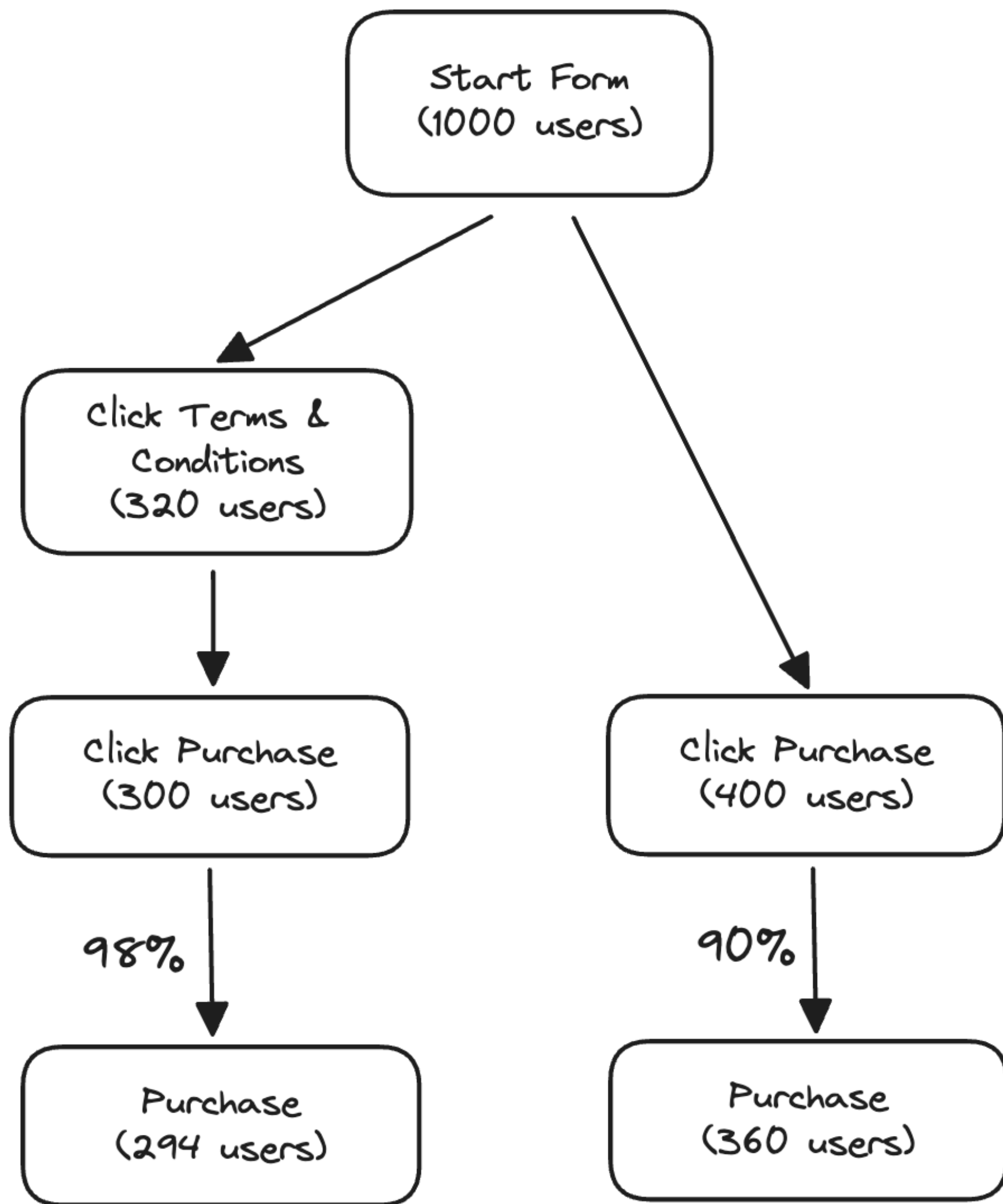
Name

Address

Credit Card Apple Pay Paypal

☐ YES! Sign me up for hourly emails  
☐ YES! Donate \$1 to "Save the Octopi"  
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Purchase



Opportunity  
Size

$$400 * (.98 - .9) = 32 \text{ users}$$

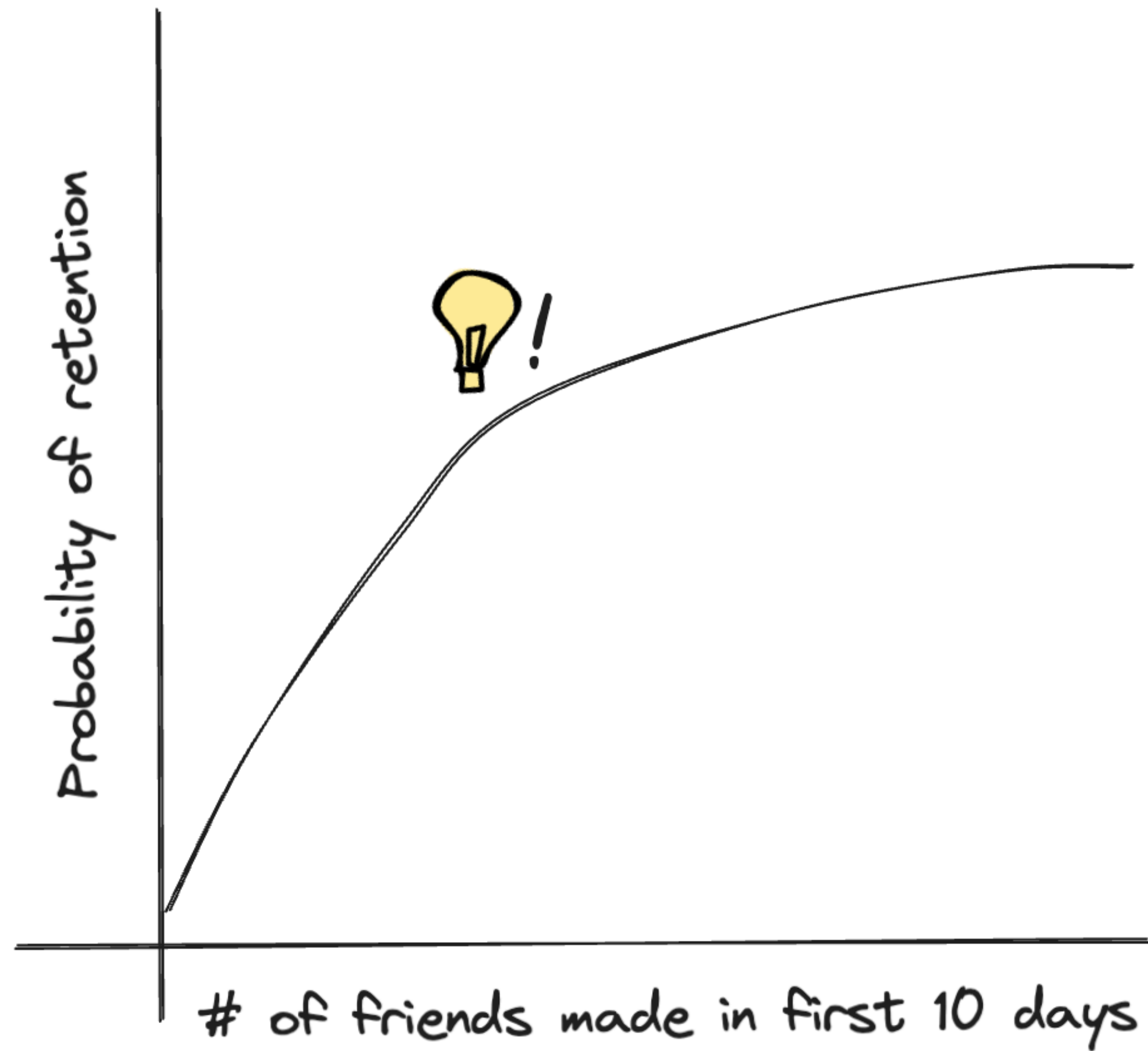
This information is *lost* in a bag-of-clicks approach

user_id	viewed_home	clicked_search	clicked_read_reviews	clicked_learn_more	...yada yada...	purchased
187180	0	1	1	0	...	1
662863	0	0	0	0	...	1
684172	1	1	1	0	...	0
261982	1	1	0	0	...	0
579325	1	1	1	1	...	0
829755	1	1	0	1	...	0
454574	1	1	0	0	...	0
216105	1	1	1	1	...	1
181215	0	1	0	0	...	0
996510	1	1	0	0	...	0
379967	1	1	0	0	...	0
511056	1	1	0	1	...	0
948165	1	1	1	0	...	0
575719	1	1	0	1	...	0
356383	1	1	1	0	...	0
582609	1	1	1	0	...	0
988781	1	0	0	1	...	0
857058	1	1	0	0	...	0
498438	1	1	0	0	...	0
470140	1	0	1	0	...	0
714748	1	0	0	1	...	0
624947	1	1	1	1	...	0
524455	1	0	0	1	...	1

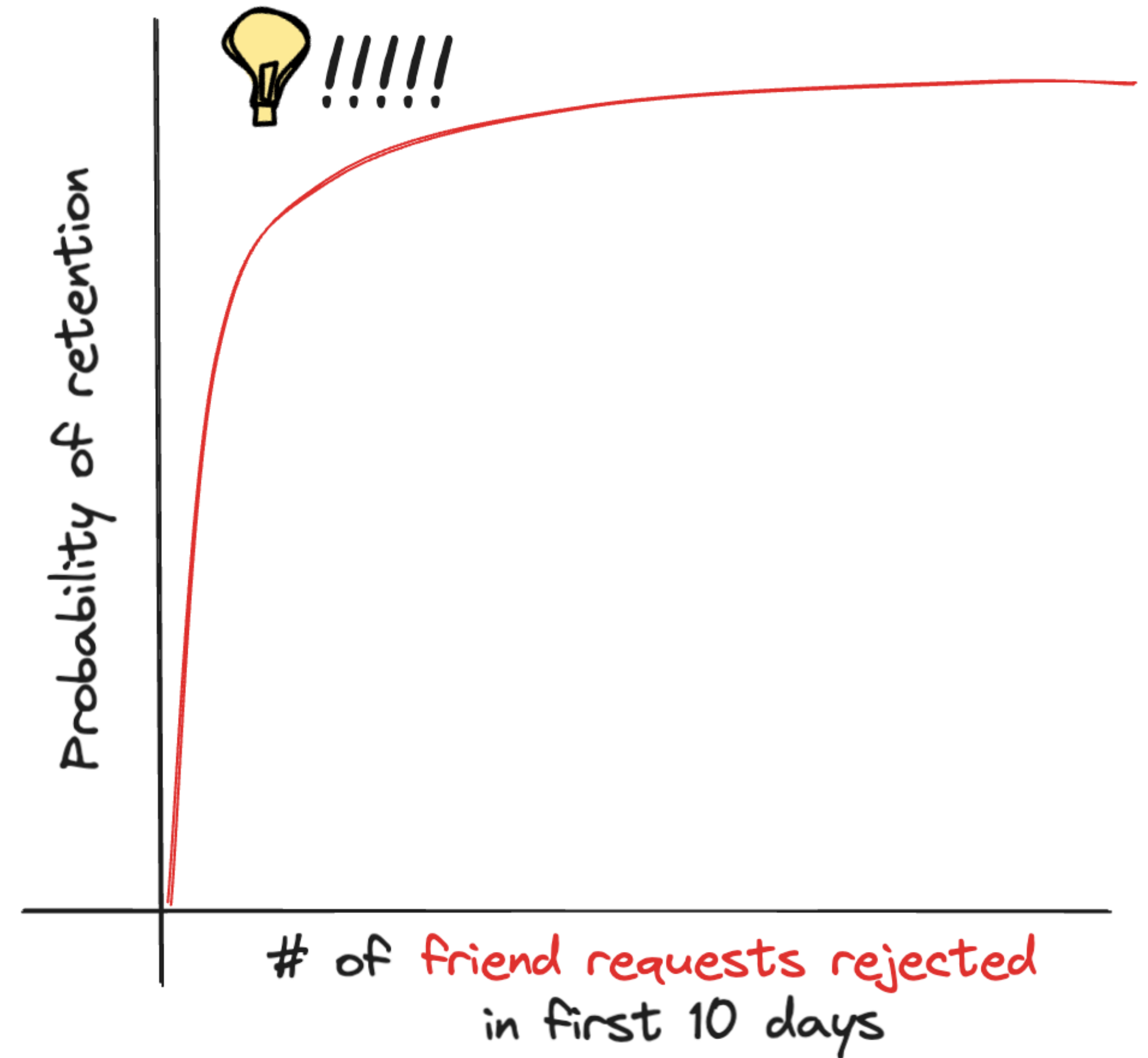
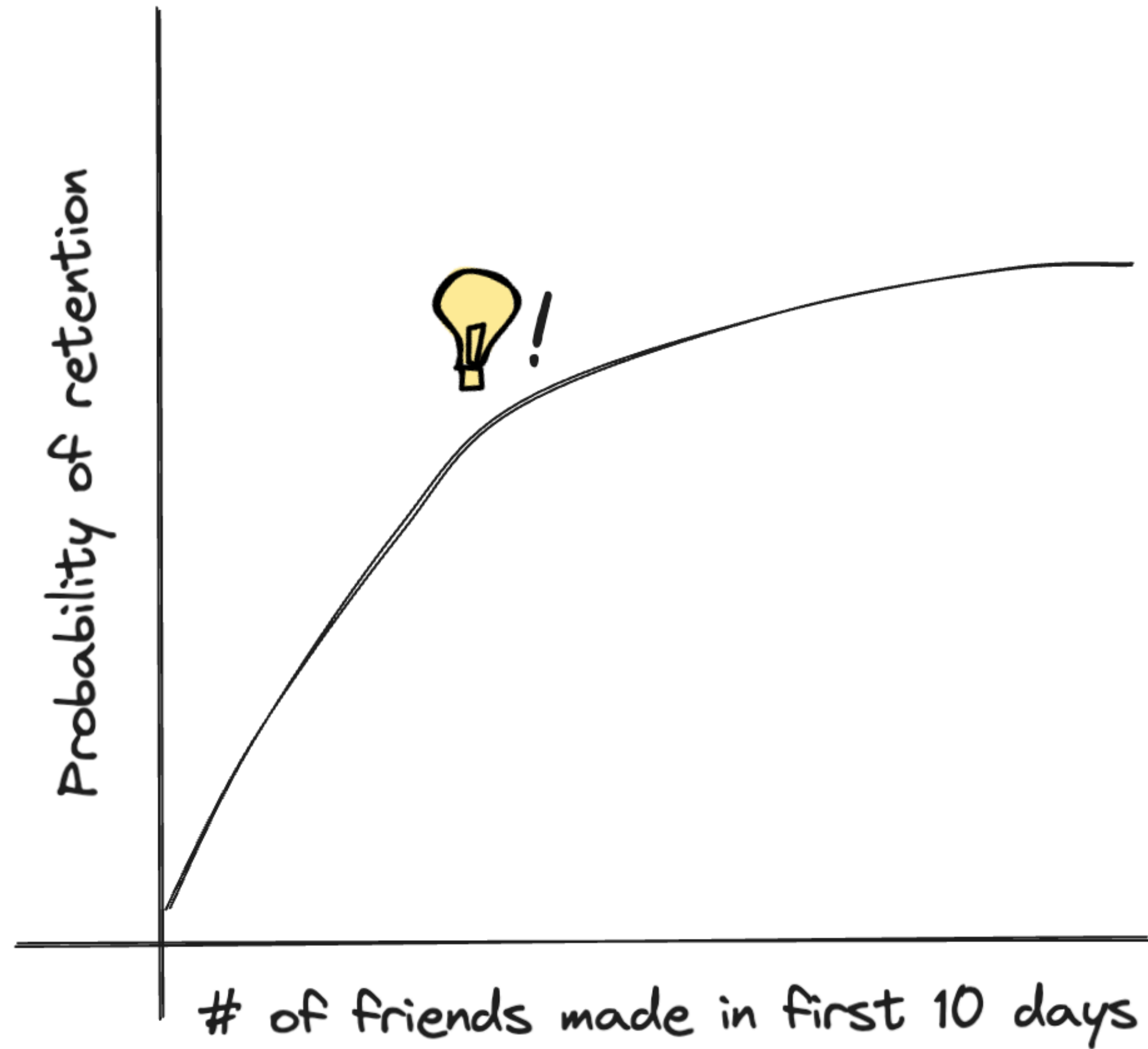
Retention



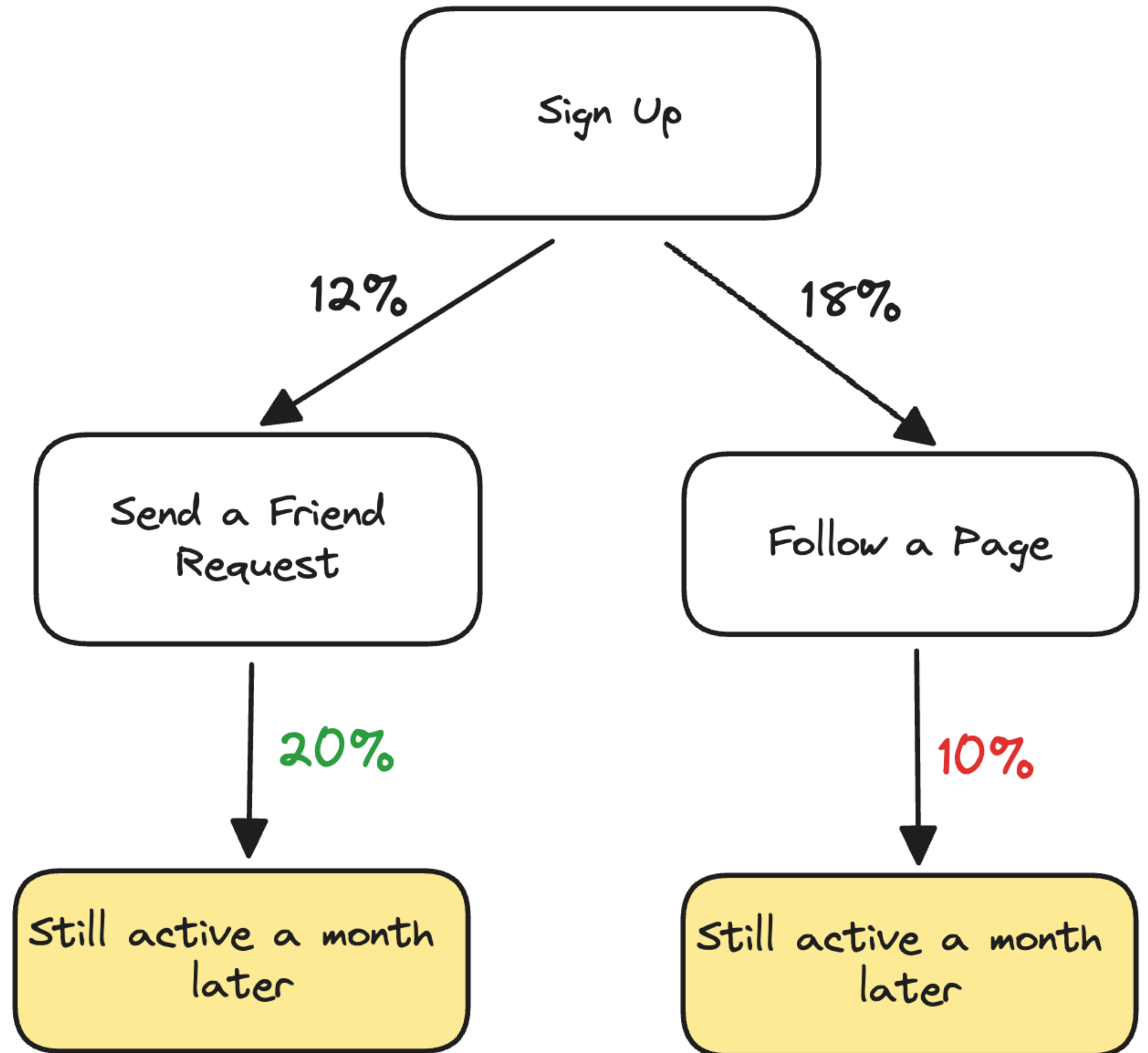
# Facebook's "aha" moment



# Facebook's "aha" moment?



What I'd rather see- find two actions that represent the same moment in a journey, and compare them



# Conclusion





“After growing wildly for years, the field of computing appears to be reaching its infancy.”

John Pierce, Bell Labs

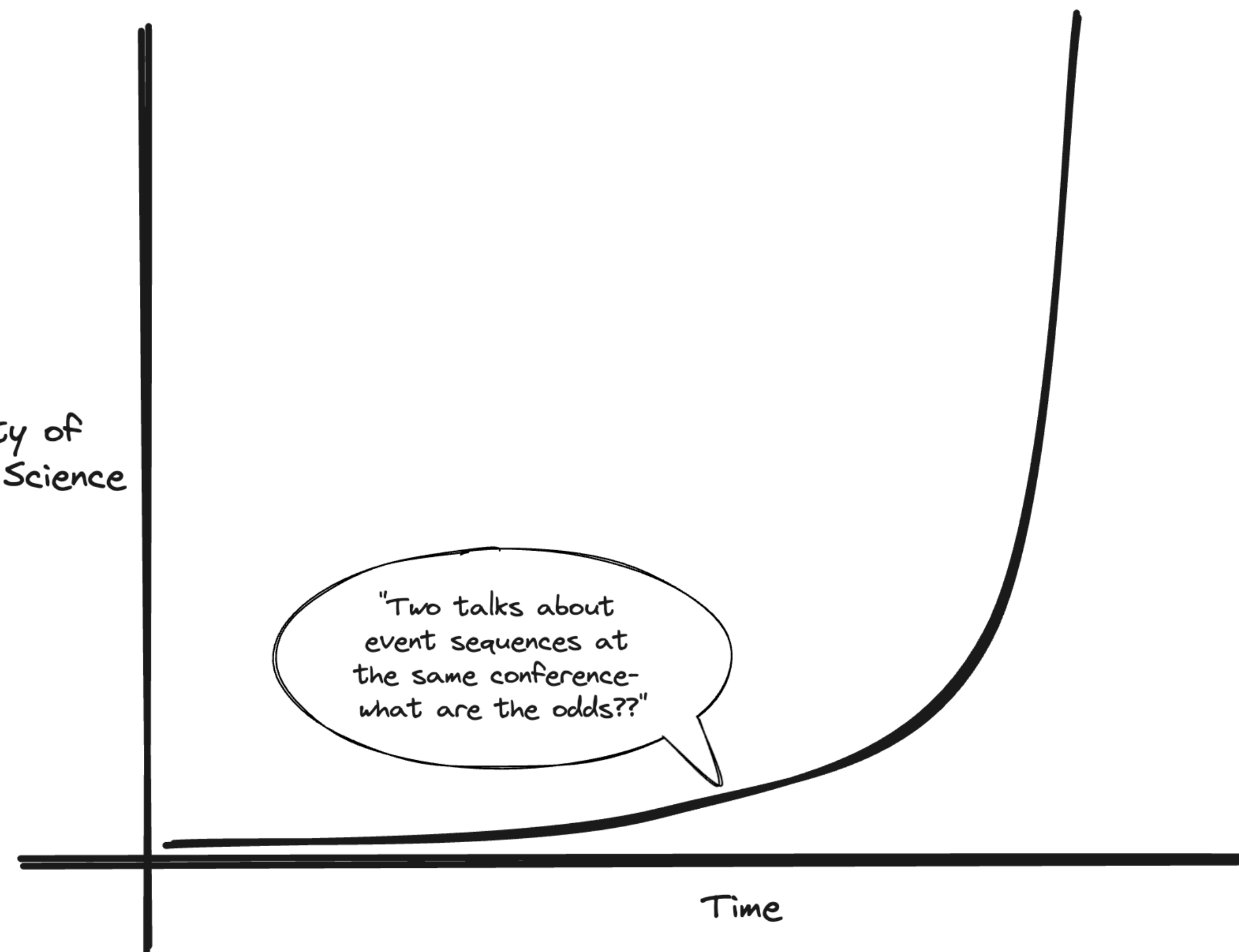


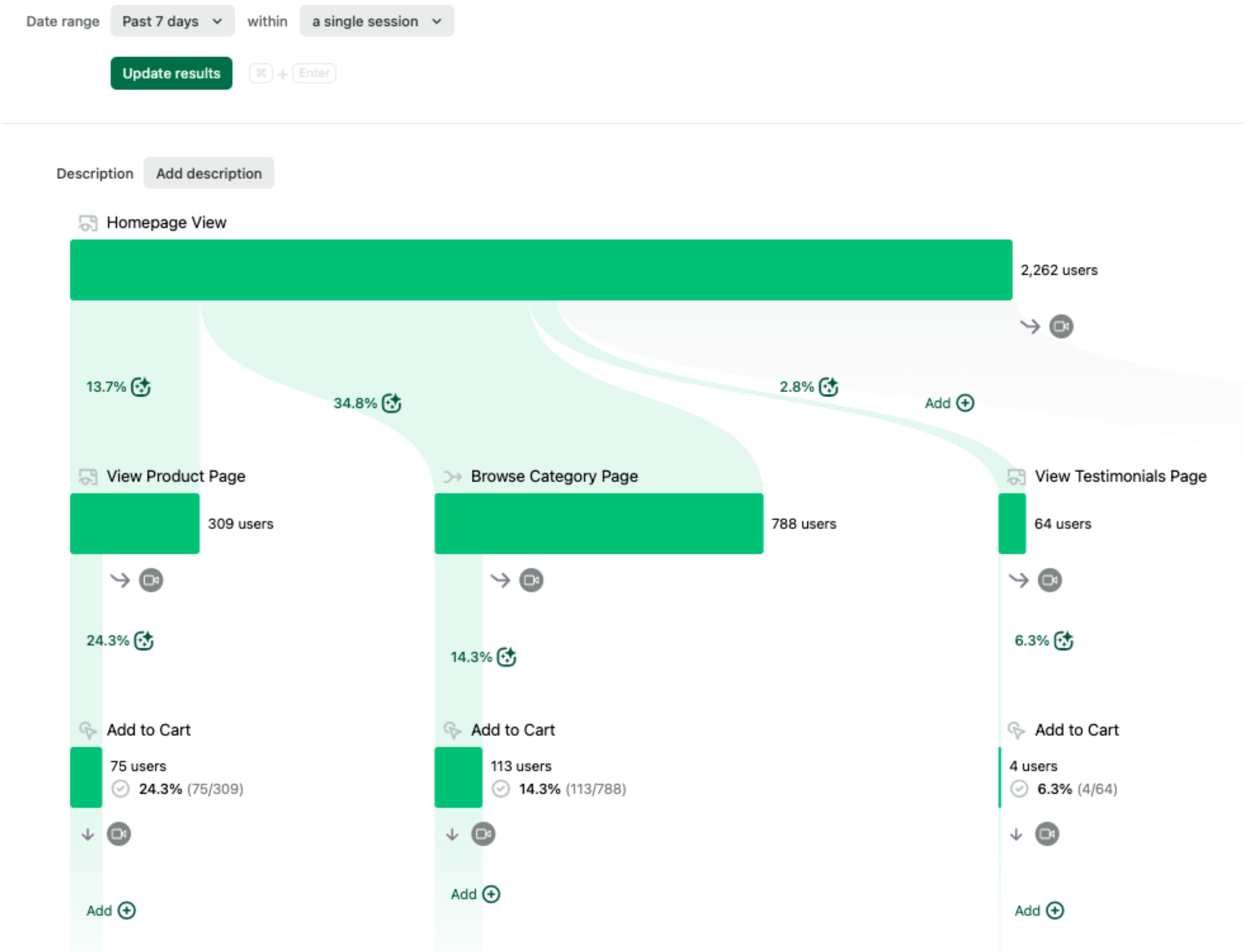


"After growing wildly for years, the field of computing appears to be reaching its infancy."

John Pierce, Bell Labs

Maturity of  
Product Science





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David Robinson

Director of Data Scientist  
at Heap, works in R.

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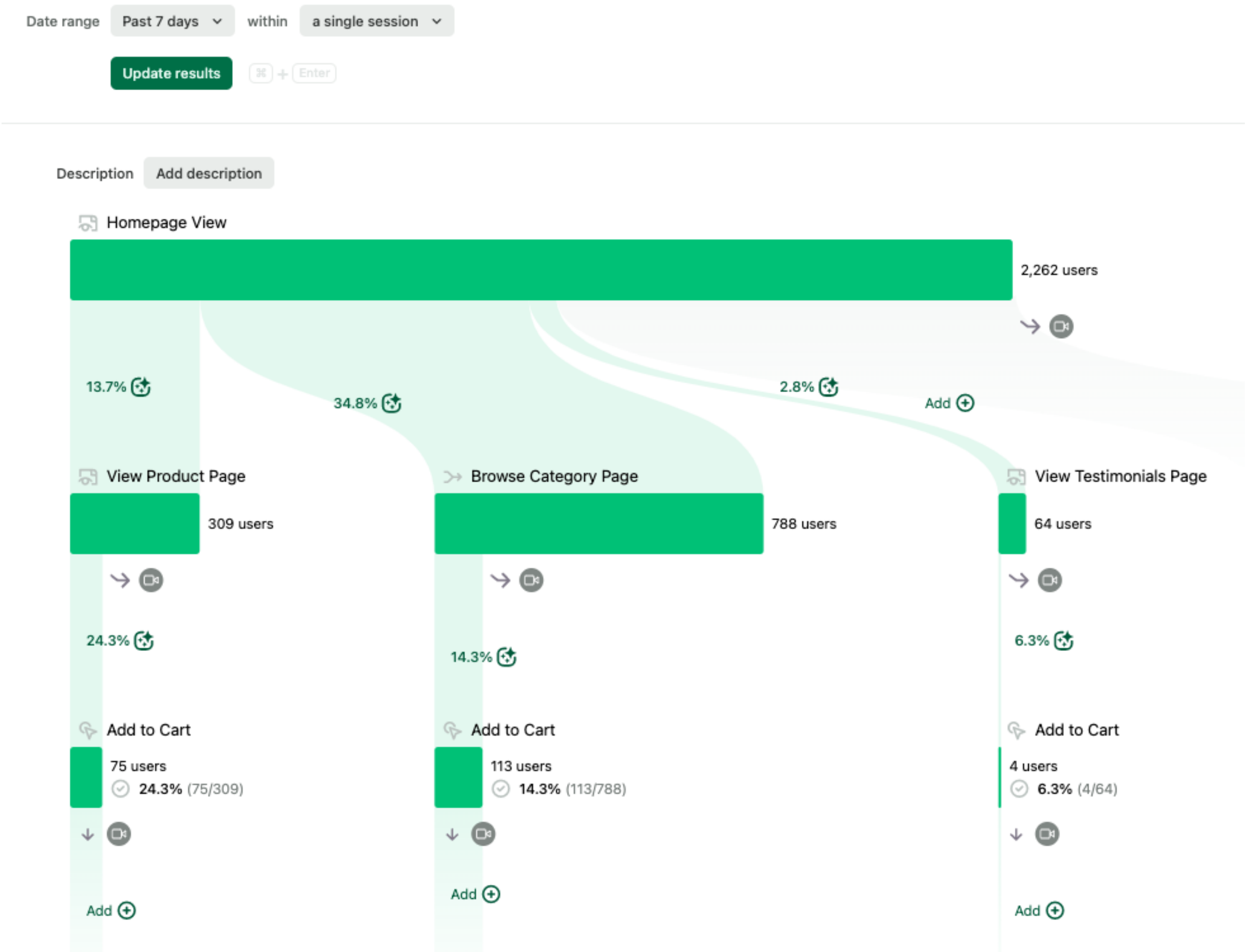
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# Thank you!

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