When Does Statistical Equality Meet Health Equity?

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OHDSI Symposium 2022
Washington, D.C.
Oct 14, 2022

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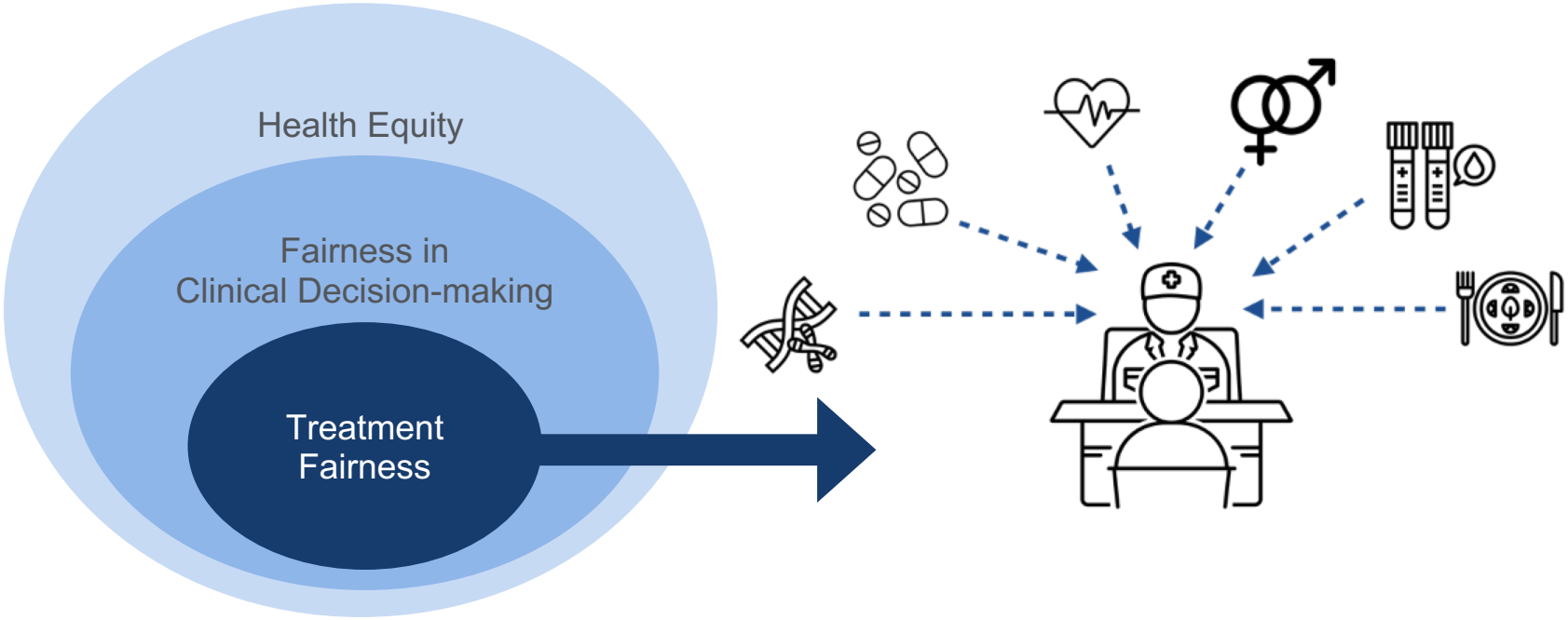
Fairness in Clinical Decision-making

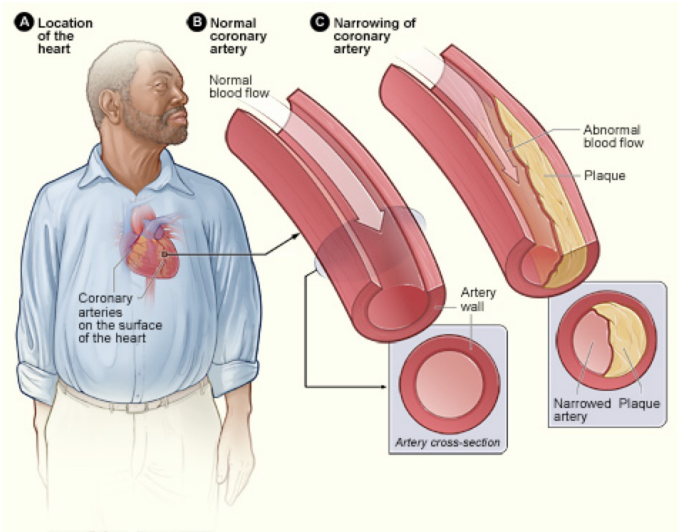
- Fairness in clinical decision-making is an important component of health equity.
- Many factors could potentially affect a treatment decision.



Goal: Assess fairness of treatment allocation with EHRs.

Example: Coronary Artery Disease

- Heart disease is the **leading cause of death** in the United States.
- **Coronary heart disease** is the most common type of heart disease, killing **382,820 people in 2020**.

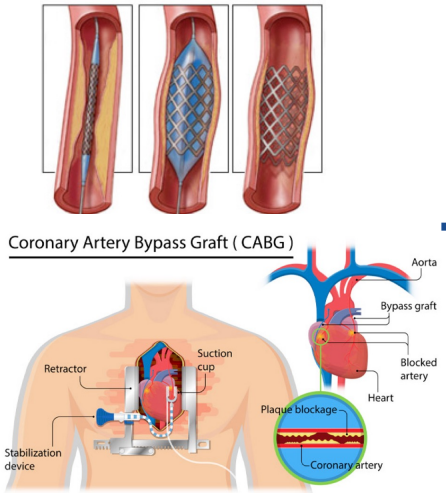
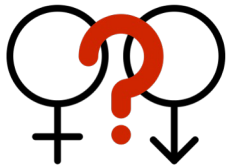


Coronary Artery Disease (CAD)

Myocardial infarction (MI)

Example: Coronary Artery Disease

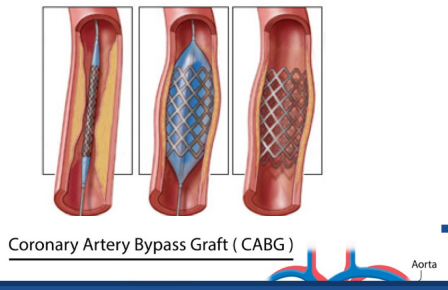
- **Women**, **racial and ethnic minorities**, patients without **health insurance**, and those who live in **low-income** neighborhoods may have inadequate access to revascularization procedures.

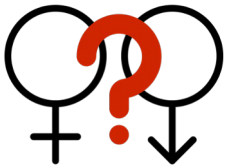
Treatment	Sensitive Attribute	Outcome
		
Revascularization	Biological sex	Myocardial infarction (MI)

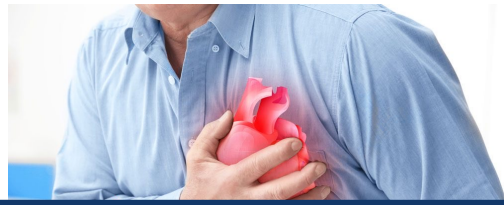
Example: Coronary Artery Disease

- **Women**, **racial and ethnic minorities**, patients without **health insurance**, and those who live in **low-income** neighborhoods may have inadequate access to revascularization procedures.

Treatment | Sensitive Attribute | Outcome





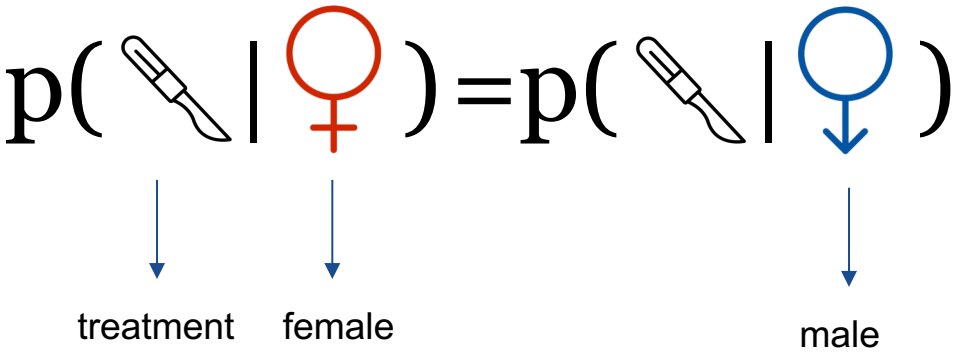


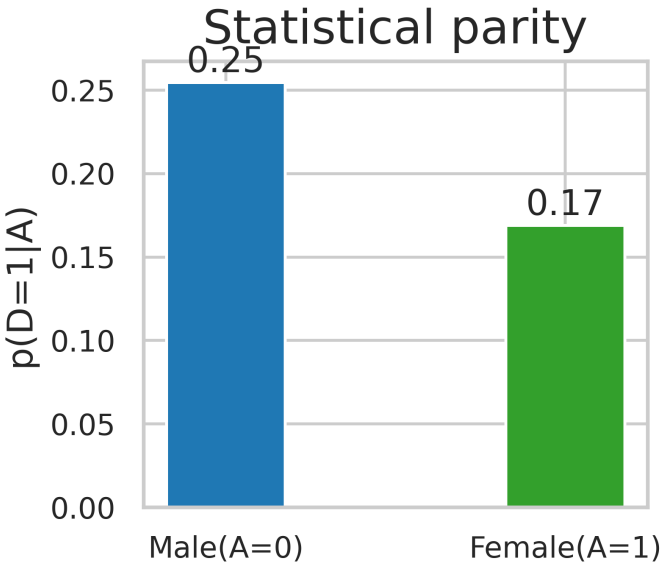
Research Question:
Is there sex discrimination in allocating revascularization to CAD patients?

Revascularization | Biological sex | Myocardial infarction (MI)

Statistical Parity

Question: Is the treatment assigned at equal rate between men and women?



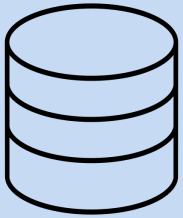


Result: Male patients were more likely to receive revascularization treatment than female patients. Bias against women.

Many Definitions of Fairness are Available

Associational Fairness

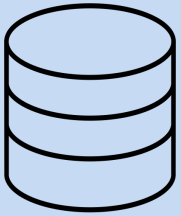
- Statistical Parity
- Calibration
- Accuracy

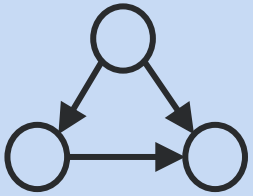


Input: Data

Causal Fairness

- Principal Fairness
- Counterfactual Fairness
- Path-Specific Fairness



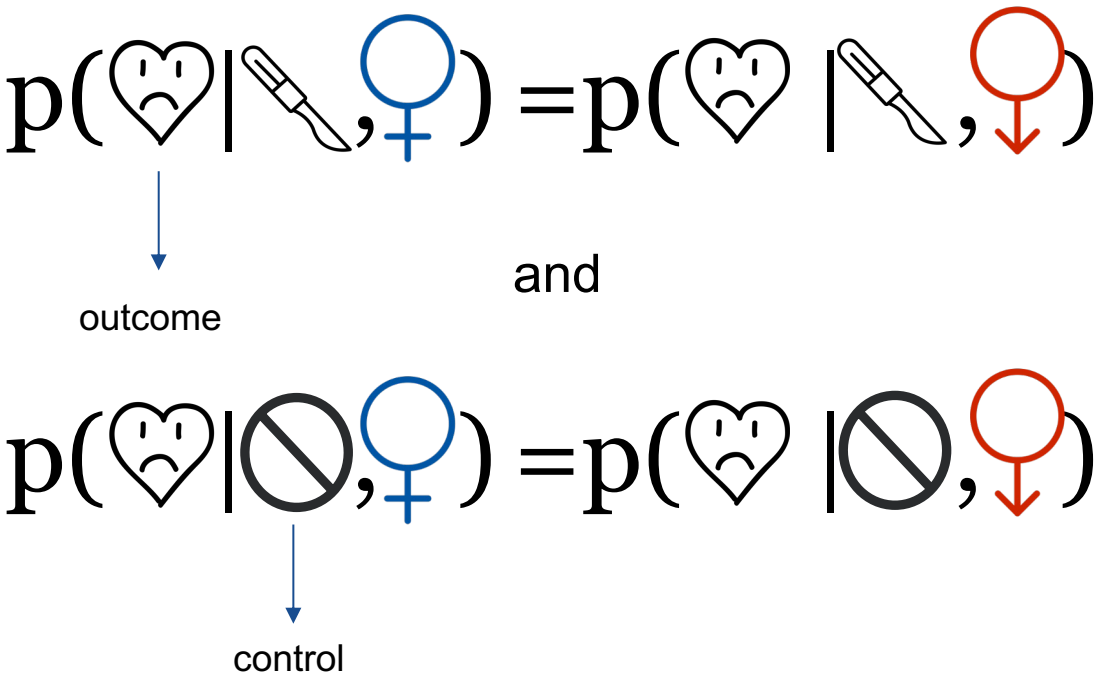


Input: Data + Causal Knowledge

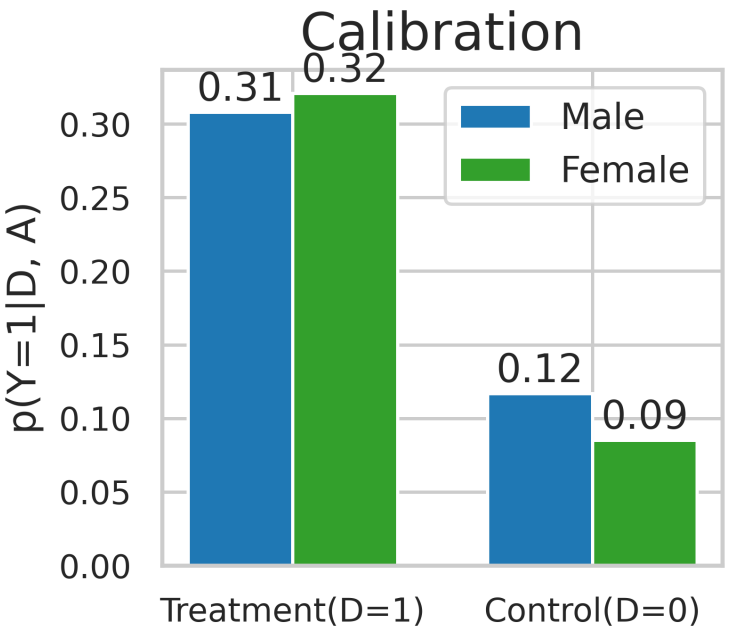
Do they lead to same conclusions? If not, which one to believe?

Calibration

Question: Does heart attack happen at equal rate between men and women, given their treatment status?



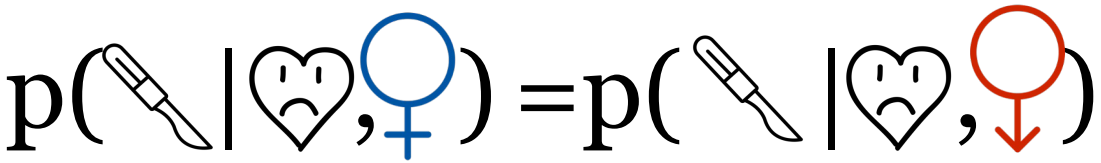
Calibration



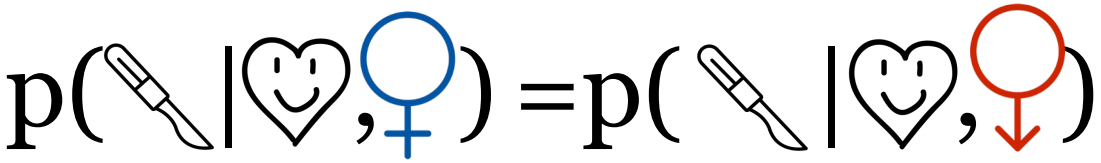
Result: Heart attack happened more frequently for male patients than for female patients in the control group. Maybe bias against men?

Accuracy

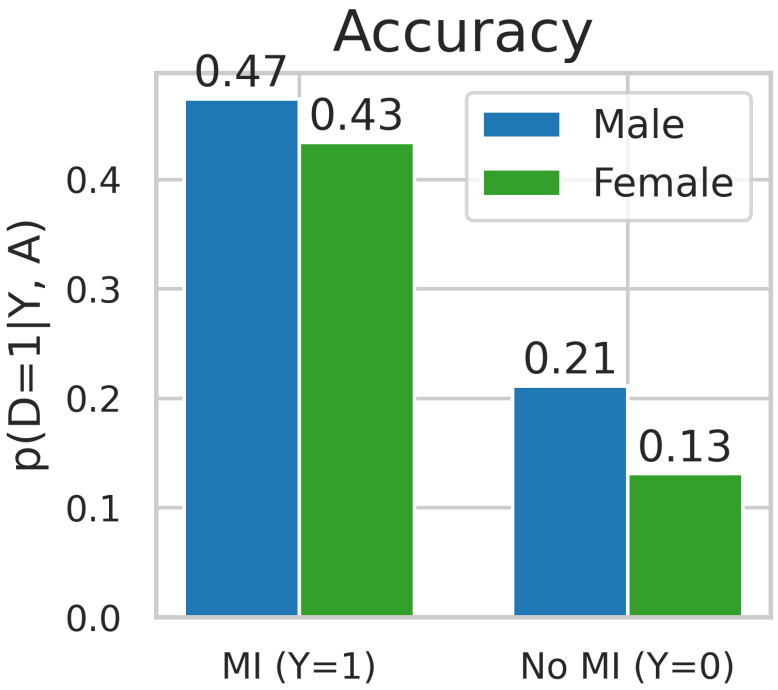
Question: Is the treatment assigned at equal rate between men and women, given their (observed) outcome?



and

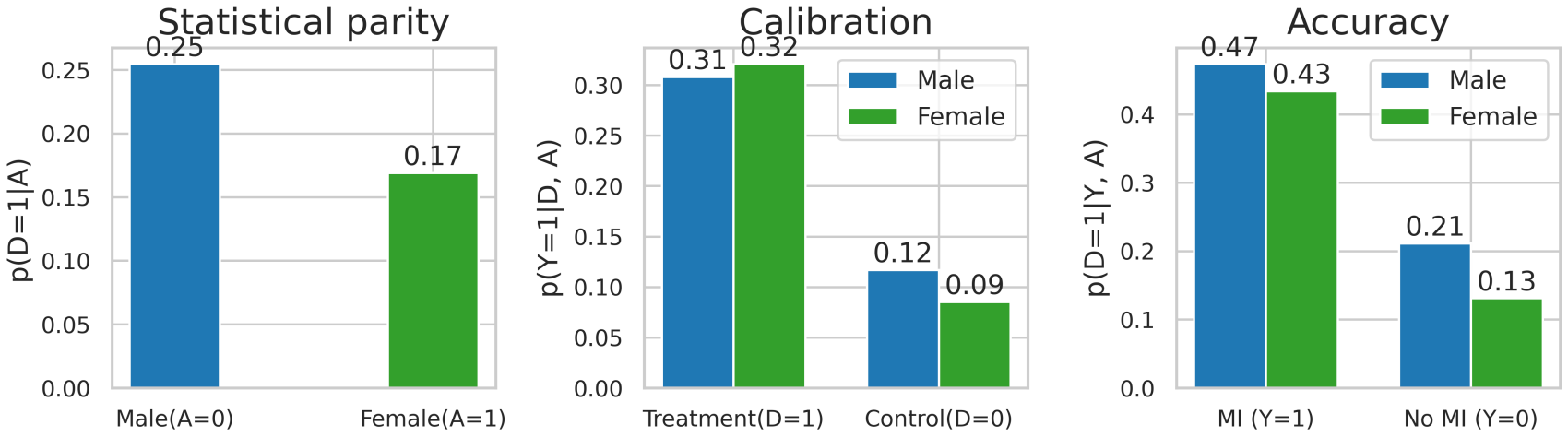


Accuracy



Result: Male patients are more likely to receive the treatment than female patients, regardless of their outcome status. Bias against women.

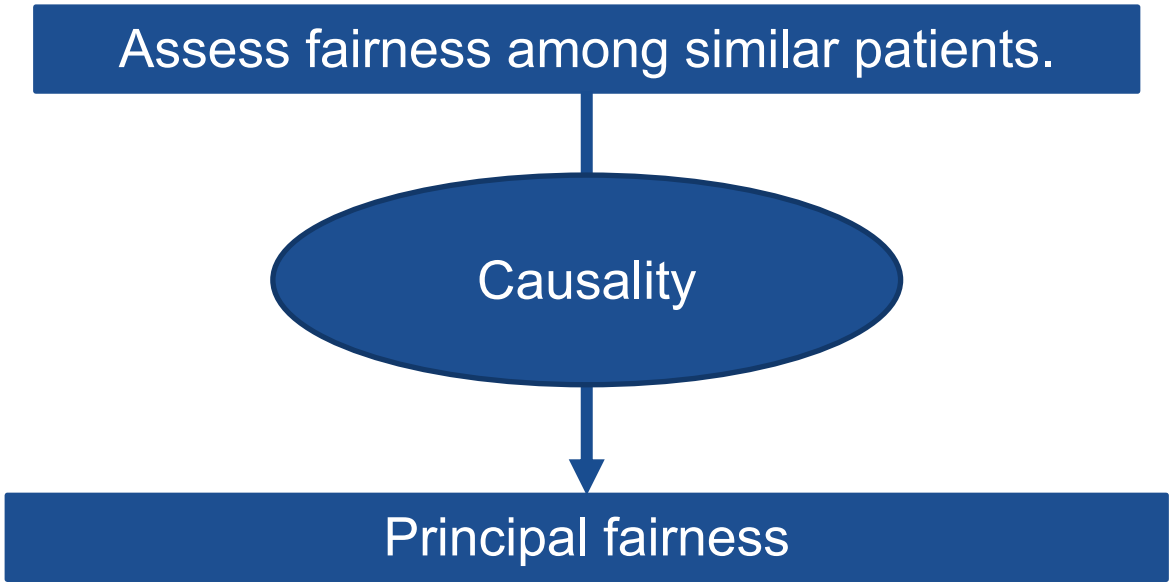
Limitations of Associational Definitions



- **Conclusions about fairness differ** depending on which metric we use.
- Which metric to use potentially depends on :
  - Is there **a baseline difference** between men and women?
  - Does the **treatment work equally well** for men and women?
  - Does **the physiological mechanism** of the disease depend on sex?

From Associational to Causal Fairness

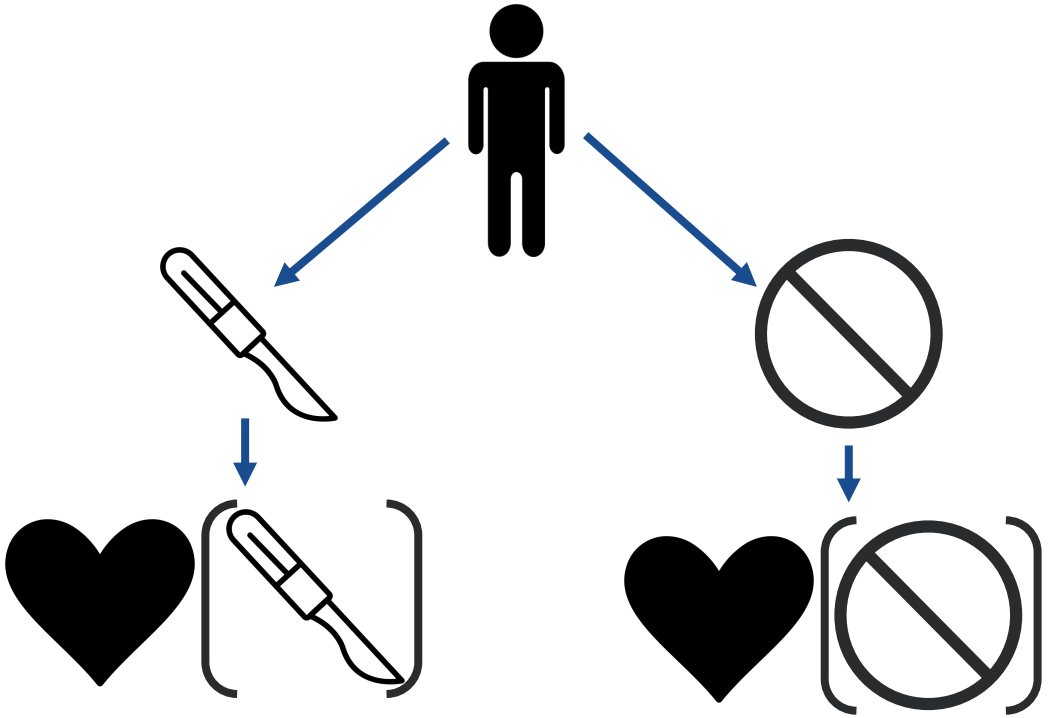
- Fairness can be more rigorously defined using **causal reasoning**.
- Patient similarity can be defined by their response to treatments, known as potential outcomes.



Principal Fairness: A Causal Fairness

Treatment

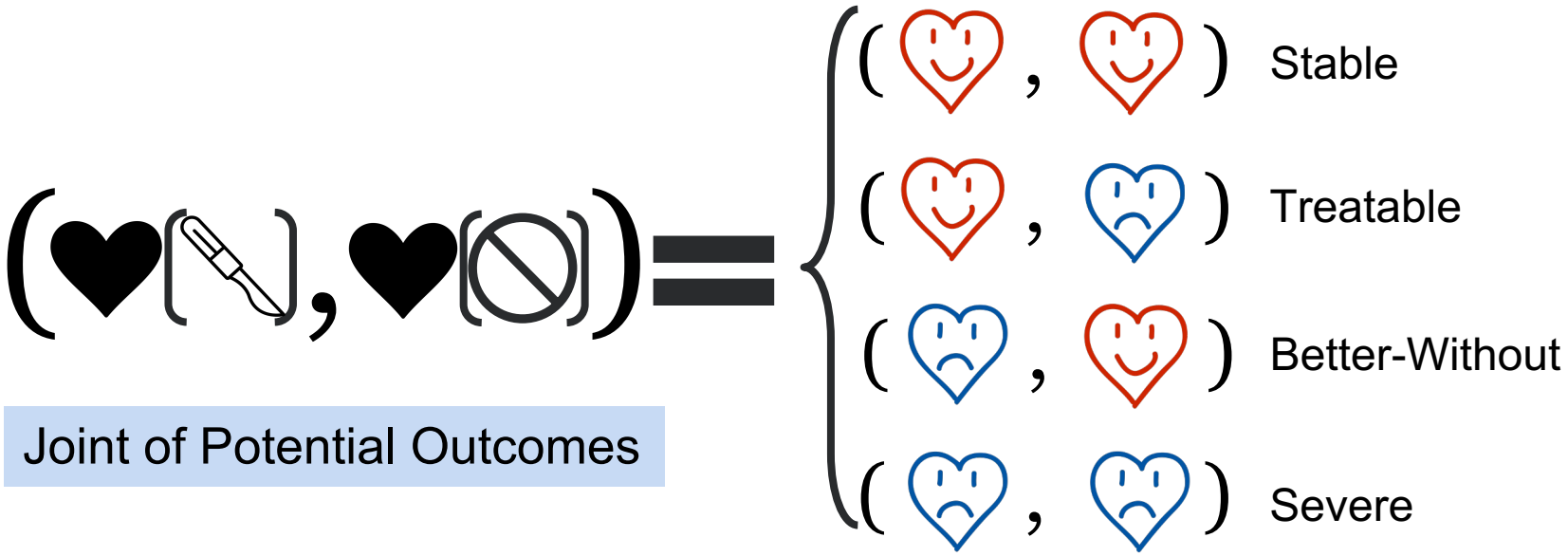
Potential Outcomes



Kosuke Imai, Zhichao Jiang. Principal Fairness for Human and Algorithmic Decision-Making. *arXiv.* 2021

Principal Fairness: A Causal Fairness

- Patients in the same principal stratum are considered to be able to benefit equally from a treatment.

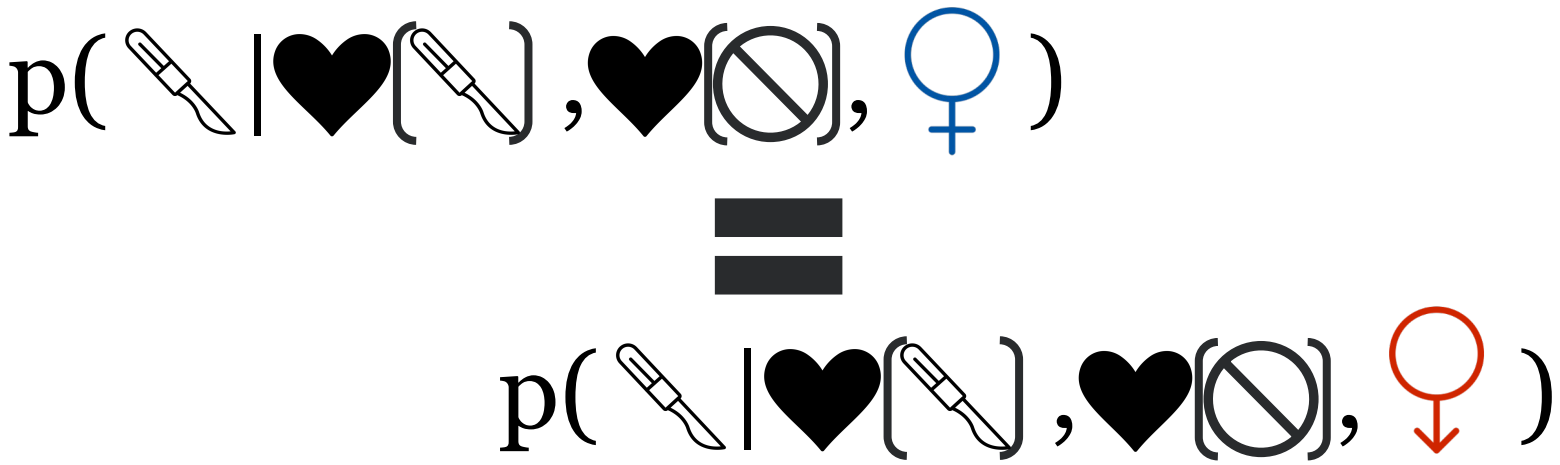


Joint of Potential Outcomes

Principal Strata

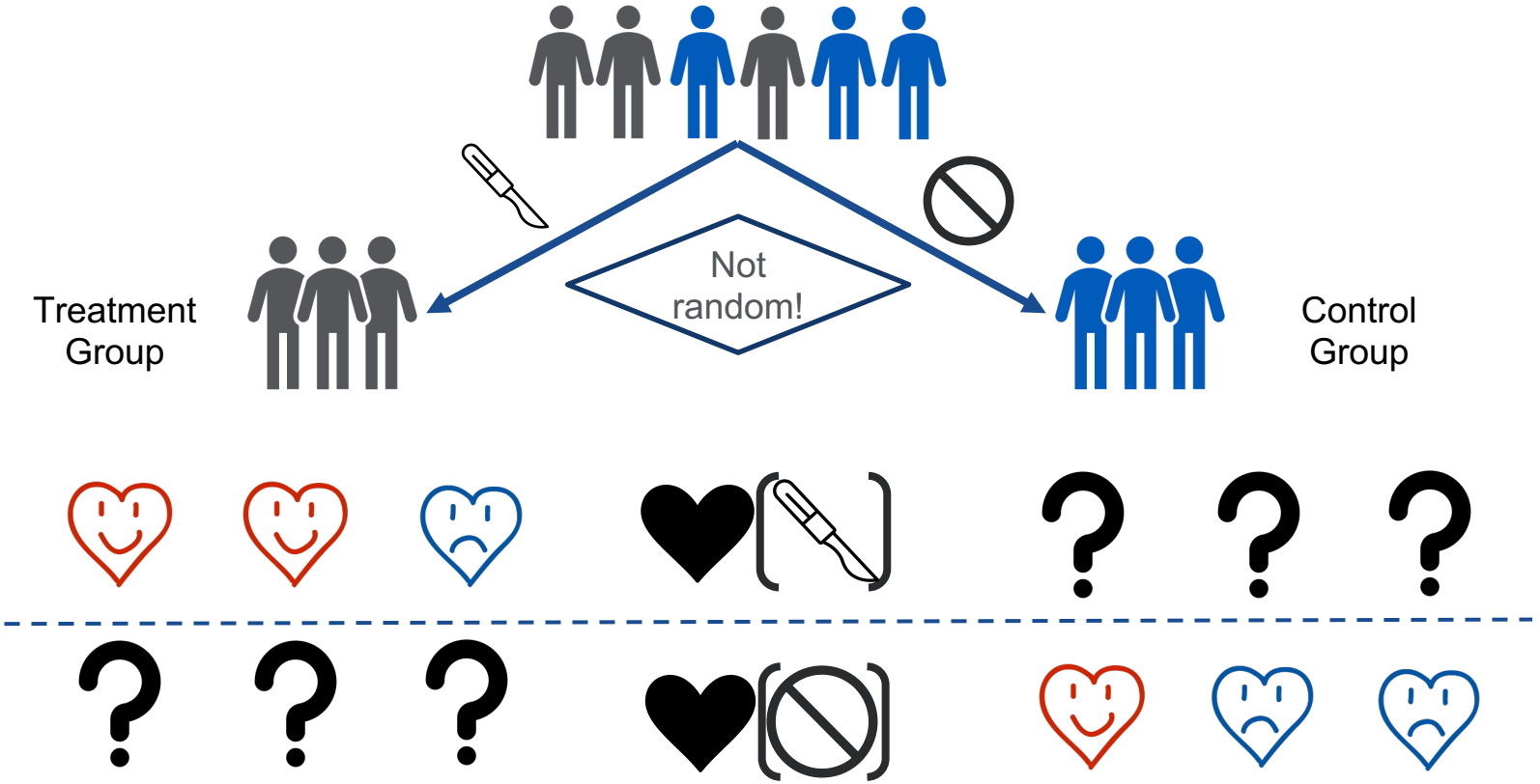
Principal Fairness: A Causal Fairness

- A treatment satisfies principal fairness if the treatment is assigned at **equal rates** between men and women who would **benefit equally from the treatment** (i.e., patients in the same principal stratum).



A Fundamental Problem in Causal Inference

- Only half of the potential outcomes are observed.



A Bayesian Principal Fairness Assessment Algorithm

Algorithm 1: Bayesian Principal Fairness Assessment Algorithm

Input: $\mathcal{D} = \{D_i, A_i, \mathbf{X}_i, Y_i\}_{i=1}^{n}$

Output: $\Delta(h)\ \forall h$

Estimate $q_\phi(\theta_{y_0})$ with VI

Estimate $q_\phi(\theta_{y_1})$ with VI

for $s \leftarrow 1$ **to** S **do**

$\theta_{y_0} \sim q(\theta_{y_0})$

$\theta_{y_1} \sim q(\theta_{y_1})$

$\mathrm{Y}_i(0) \sim \mathrm{Bern}\Big(p(Y_i(0) \mid X_i, A_i, \theta_{y_0})\Big), i \in \mathcal{I}_1$

$\mathrm{Y}_i(1) \sim \mathrm{Bern}\Big(p(Y_i(1) \mid X_i, A_i, \theta_{y_1})\Big), i \in \mathcal{I}_0$

Assign $\mathrm{H}_i = (Y_i(0), Y_i(1))$

Compute $\Delta(h)\ \forall h$

end

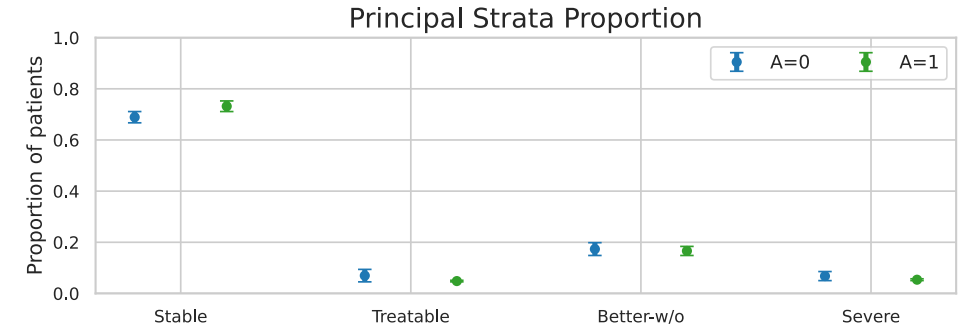
Estimate functions of potential outcomes

Sample parameters from the posteriors

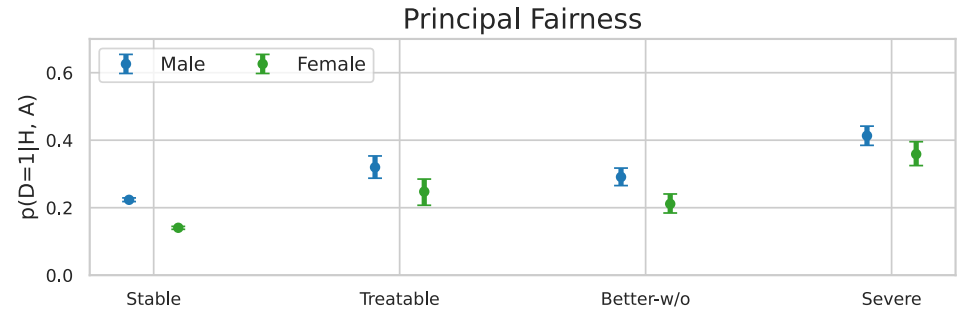
Estimate potential outcomes

Estimate principal strata and principal fairness

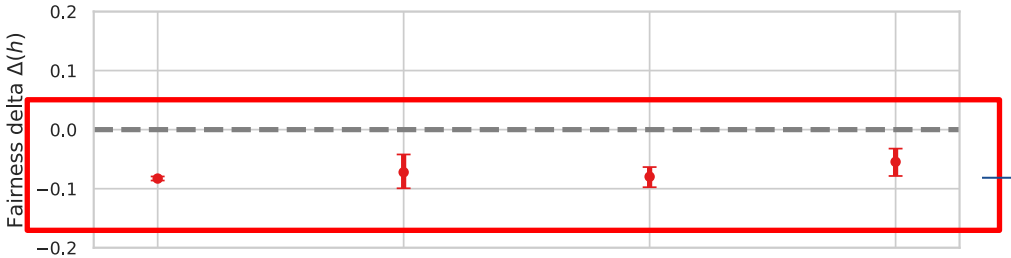
Principal Fairness (Sex)



No significant difference in principal strata distribution.

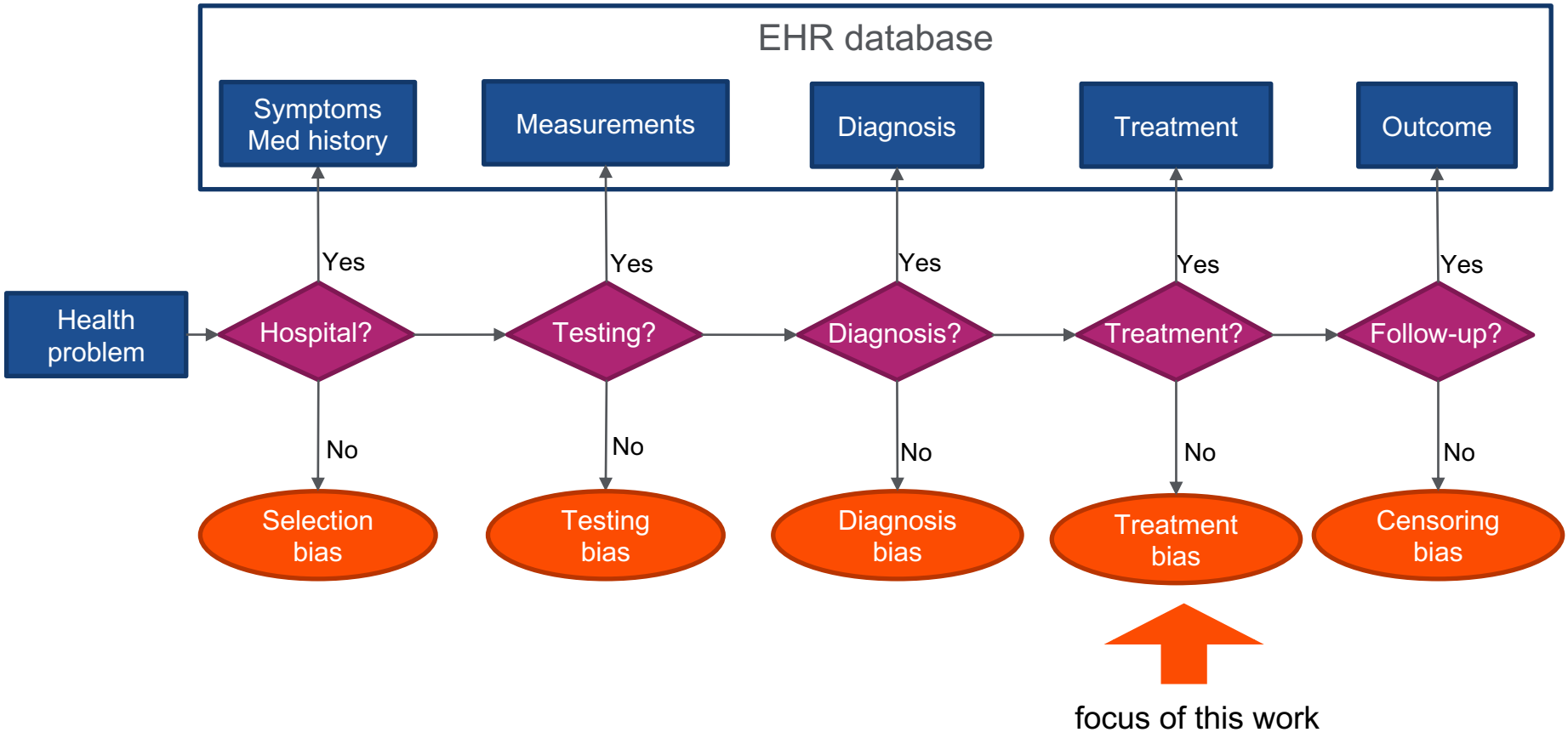


Treatment probability is highest in the severe group.



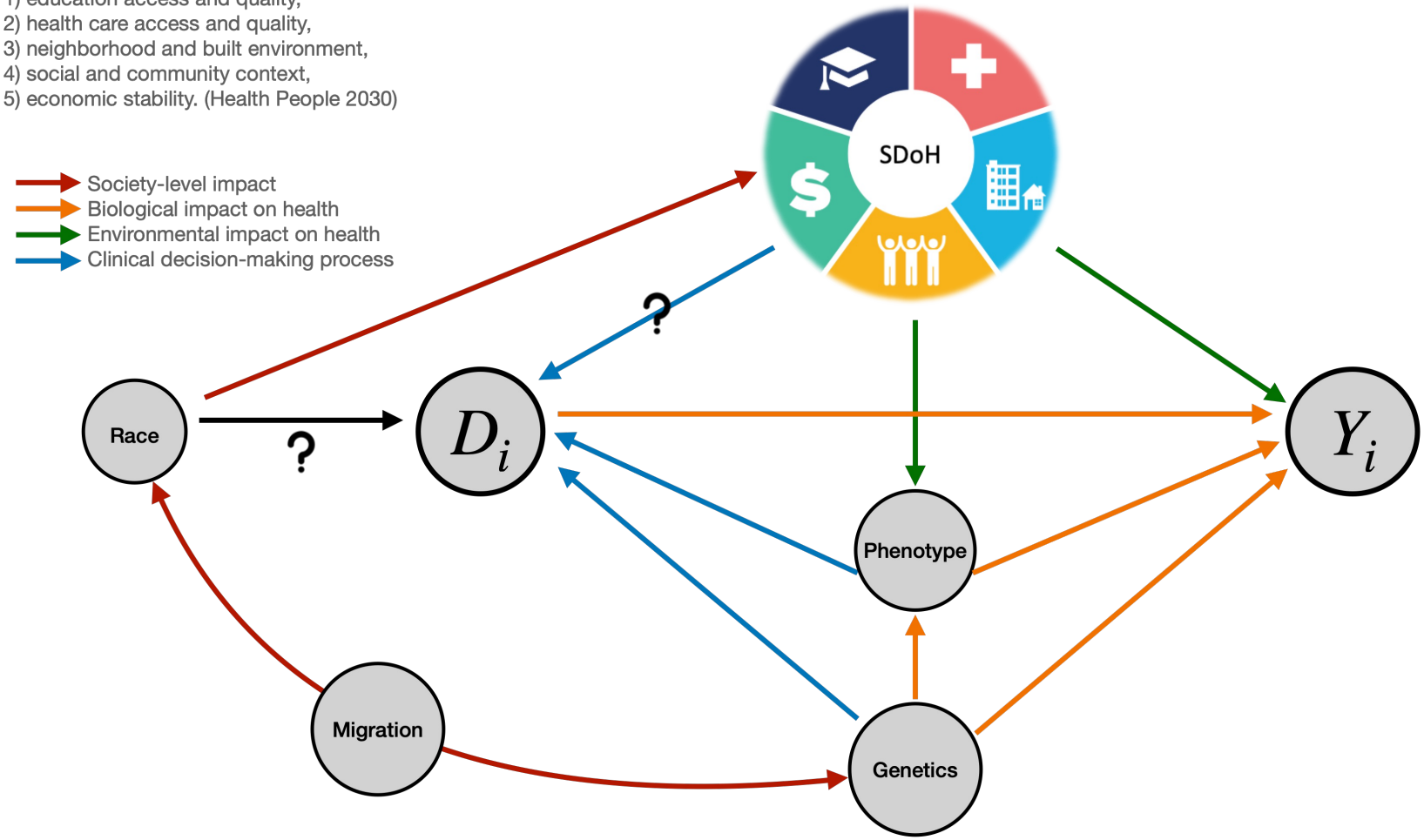
Bias against women.

Bias in the health care process



Causal Reasoning and Causal Inference for Fairness Evaluation

Social determinants of health (SDoH) include
1) education access and quality,
2) health care access and quality,
3) neighborhood and built environment,
4) social and community context,
5) economic stability. (Health People 2030)



Conclusions and Future Directions

Statistical Equality ≠ Health Equity

Causality is important in fairness assessment.

Accounting for bias from multiple stages and multiple sources is important in health care.

Acknowledgments


George Hripcsak


David Blei


Noemie Elhadad


Anna Ostropolets


Lauren Richter


Yixin Wang

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