

# Machine Learning in Production Measuring Fairness

# Diving into Fairness...

## Fundamentals of Engineering AI-Enabled Systems

**Holistic system view:** AI and non-AI components, pipelines, stakeholders, environment interactions, feedback loops

### Requirements:

- System and model goals
- User requirements
- Environment assumptions
- Quality beyond accuracy
- Measurement
- Risk analysis
- Planning for mistakes

### Architecture + design:

- Modeling tradeoffs
- Deployment architecture
- Data science pipelines
- Telemetry, monitoring
- Anticipating evolution
- Big data processing
- Human-AI design

### Quality assurance:

- Model testing
- Data quality
- QA automation
- Testing in production
- Infrastructure quality
- Debugging

### Operations:

- Continuous deployment
- Contin. experimentation
- Configuration mgmt.
- Monitoring
- Versioning
- Big data
- DevOps, MLOps

**Teams and process:** Data science vs software eng. workflows, interdisciplinary teams, collaboration points, technical debt

## Responsible AI Engineering

Provenance,  
versioning,  
reproducibility

Safety

Security and  
privacy

Fairness

Interpretability  
and explainability

Transparency  
and trust

Ethics, governance, regulation, compliance, organizational culture

# Reading

Required:

- Holstein, Kenneth, Jennifer Wortman Vaughan, Hal Daumé III, Miro Dudik, and Hanna Wallach. "[Improving fairness in machine learning systems: What do industry practitioners need?](#)" In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems, pp. 1-16. 2019.

Recommended:

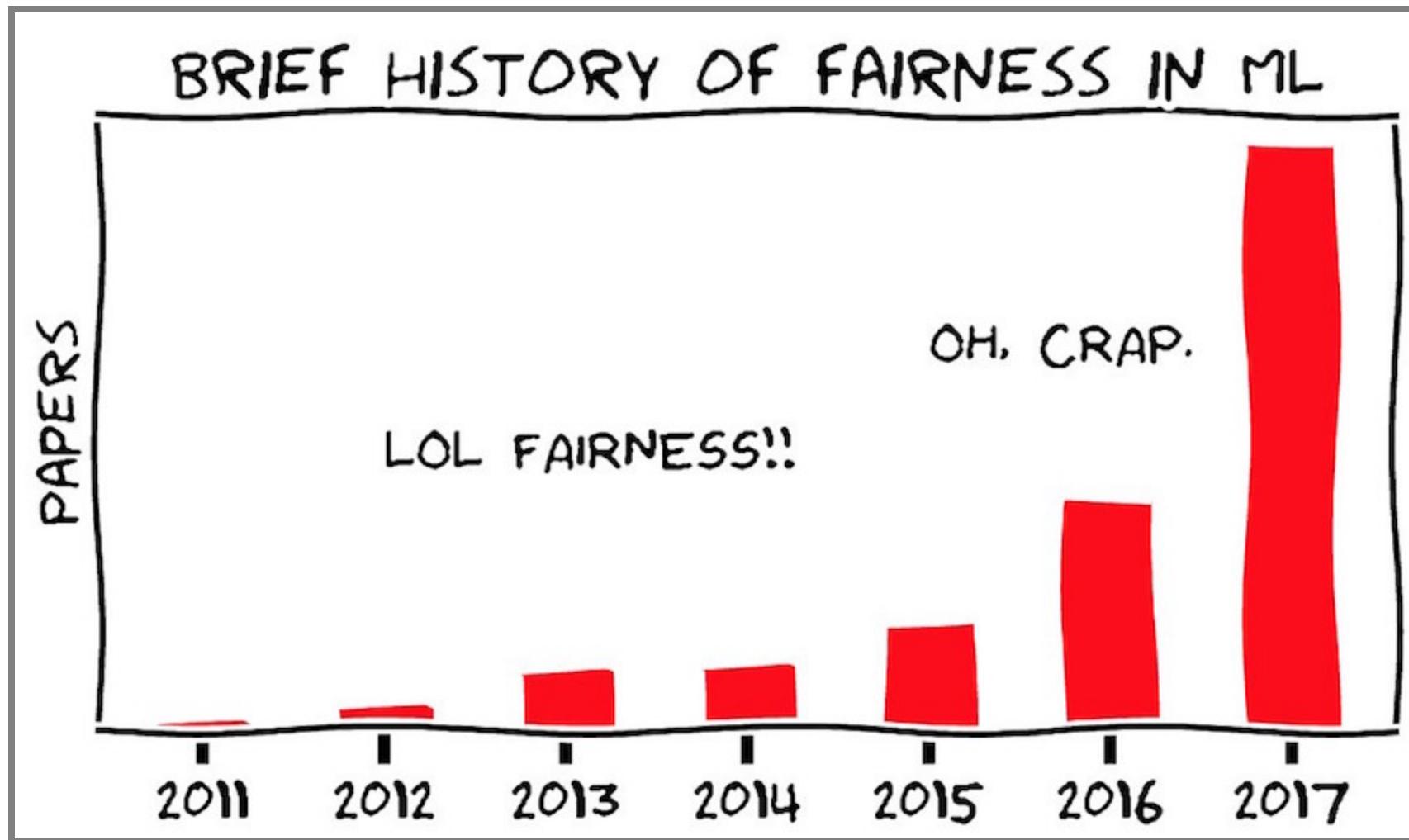
- Ian Foster, Rayid Ghani, Ron S. Jarmin, Frauke Kreuter and Julia Lane. [Big Data and Social Science: Data Science Methods and Tools for Research and Practice](#). Chapter 11, 2nd ed, 2020
- Solon Barocas and Moritz Hardt and Arvind Narayanan. [Fairness and Machine Learning](#). 2019 (incomplete book)
- Pessach, Dana, and Erez Shmueli. "[A Review on Fairness in Machine Learning](#)." ACM Computing Surveys (CSUR) 55, no. 3 (2022): 1-44.

# Learning Goals

- Understand different definitions of fairness
- Discuss methods for measuring fairness
- Outline interventions to improve fairness at the model level

# Fairness: Definitions

# Fairness is still an actively studied & disputed concept!



# Fairness: Definitions

- Anti-classification (fairness through blindness)
- Group fairness (independence)
- Equalized odds (separation)
- ...and numerous others and variations!

# Running Example: Mortgage Applications

- Large loans repayed over long periods, large loss on default
- Home ownership is key path to build generational wealth
- Past decisions often discriminatory (redlining)
- Replace biased human decisions by objective and more accurate ML model
  - income, other debt, home value
  - past debt and payment behavior (credit score)

# Recall: What is fair?

*Fairness discourse asks questions about how to treat people and whether treating different groups of people differently is ethical. If two groups of people are systematically treated differently, this is often considered unfair.*

# Recall: What is fair?

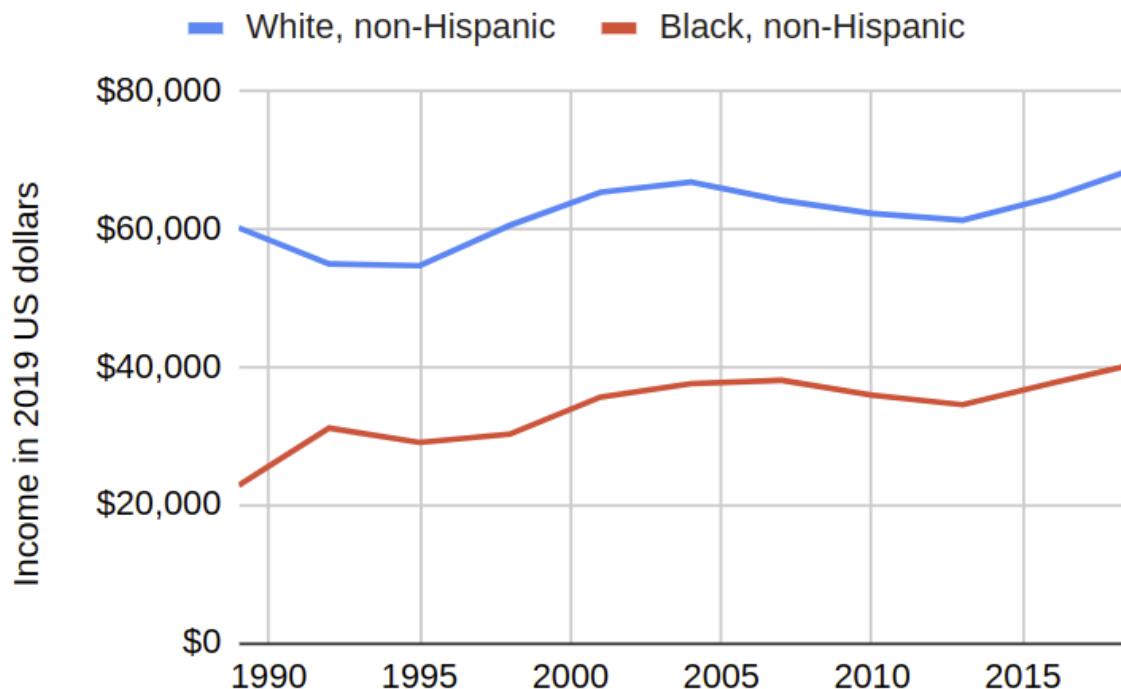
- Equal slices for everybody
- Bigger slices for active bakers
- Bigger slices for inexperienced/new members (e.g., children)
- Bigger slices for hungry people
- More pie for everybody, bake more



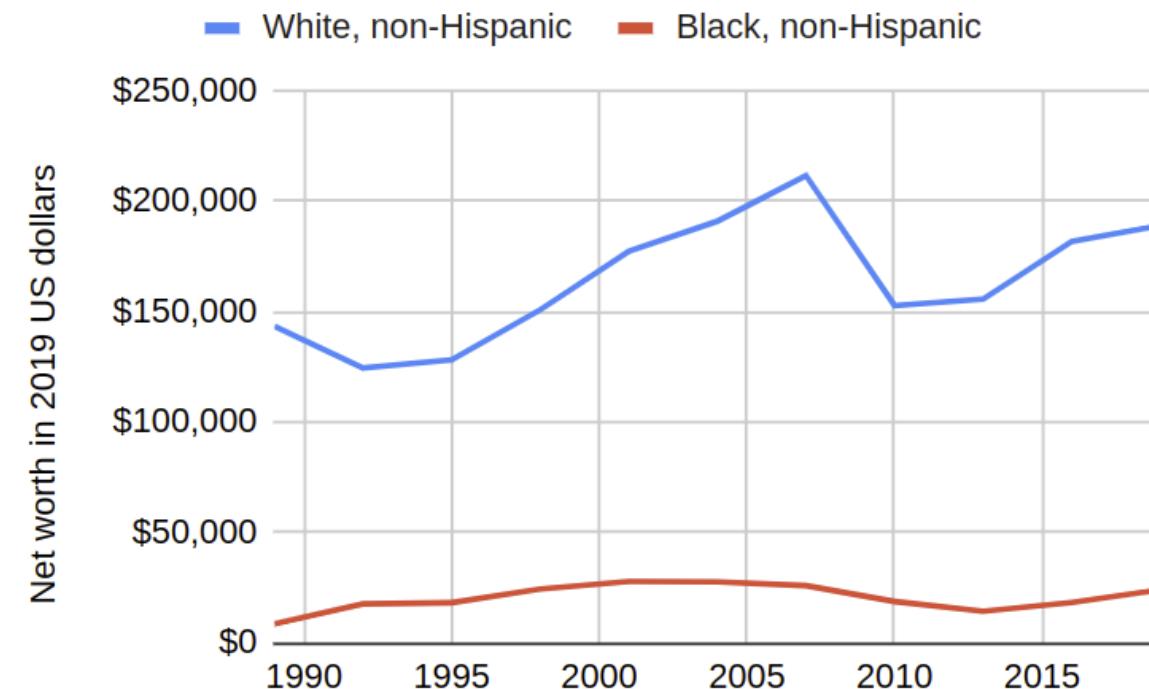
*(Not everybody contributed equally  
during baking, not everybody is  
≡ equally hungry)*

# Past bias, different starting positions

Median before-tax family income



Median family net-worth



Source: Federal Reserve's Survey of Consumer Finances

# What is fair in mortgage applications?



# Anti-classification

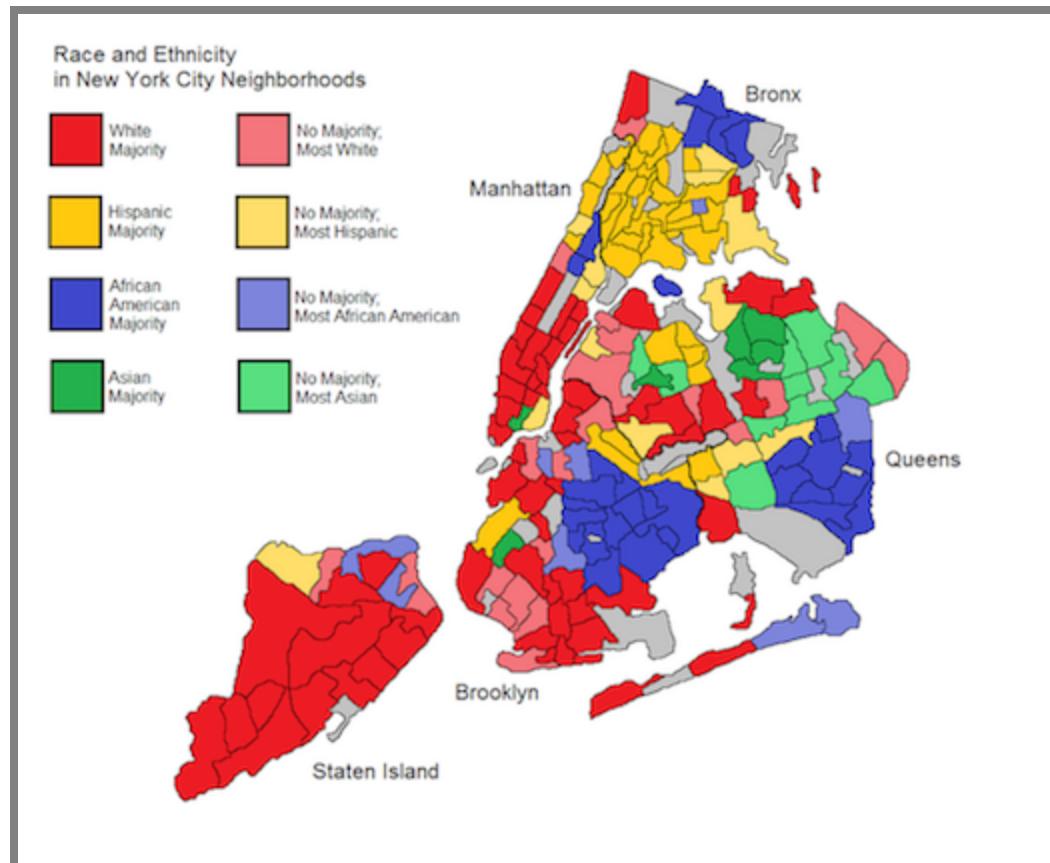
- Anti-classification (fairness through blindness)
- Group fairness (independence)
- Equalized odds (separation)
- ...and numerous others and variations!

# Anti-Classification



# Recall: Proxies

*Features correlate with protected attributes*

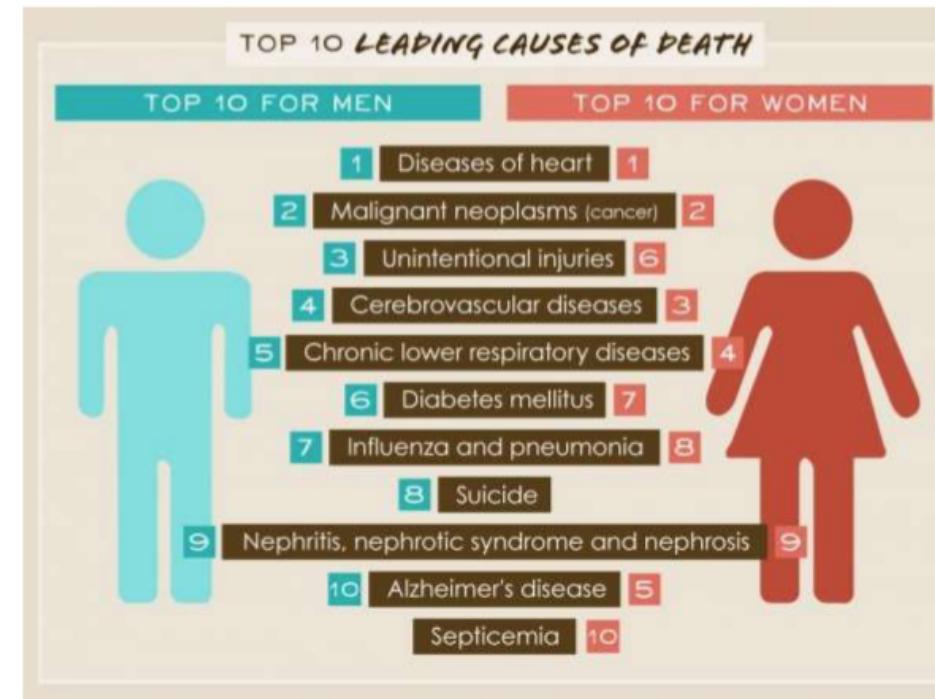


# Recall: Not all discrimination is harmful



FEDERAL TRADE COMMISSION

Mortgage discrimination is against the law.



# Anti-Classification



- Ignore certain sensitive attributes when making a decision
- Advantage: Trivial to implement and test
- Limitations
  - Sensitive attributes may be correlated with other features
  - Some ML tasks need sensitive attributes (e.g., medical diagnosis)

# Ensuring Anti-Classification

How to train models that are fair wrt. anti-classification?



# Ensuring Anti-Classification

How to train models that are fair wrt. anti-classification?

- > Simply remove features for protected attributes from training and inference data
- > Null/randomize protected attribute during inference

*(does not account for correlated attributes, is not required to)*

# Testing Anti-Classification

How do we test that a classifier achieves anti-classification?



# Testing Anti-Classification

Straightforward invariant for classifier  $f$  and protected attribute  $p$ :

$$\forall x. f(x[p \leftarrow 0]) = f(x[p \leftarrow 1])$$

*(does not account for correlated attributes, is not required to)*

Test with *any* test data, e.g., purely random data or existing test data

Any single inconsistency shows that the protected attribute was used. Can also report percentage of inconsistencies.

See for example: Galhotra, Sainyam, Yuriy Brun, and Alexandra Meliou. "[Fairness testing: testing software for discrimination](#)." In Proceedings of the 2017 11th Joint Meeting on Foundations of Software Engineering, pp. 498-510. 2017.

# Anti-Classification Discussion

*Testing of anti-classification barely needed, because easy to ensure by constructing during training or inference!*

Anti-classification is a good starting point to think about protected attributes

Useful baseline for comparison

Rarely ever used as serious fairness concept

# Group fairness

- Anti-classification (fairness through blindness)
- **Group fairness (independence)**
- Equalized odds (separation)
- ...and numerous others and variations!

# Group fairness

Key idea: Compare outcomes across two groups

- Similar rates of accepted loans across racial/gender groups?
- Similar chance of being hired/promoted between gender groups?
- Similar rates of (predicted) recidivism across racial groups?

Outcomes matter, not accuracy!

# Group fairness in discrimination law

Relates to *disparate impact* and the four-fifth rule

Can sue organizations for discrimination if they

- mostly reject job applications from one minority group (identified by protected classes) and hire mostly from another
- reject most loans from one minority group and more frequently accept applicants from another

# Notations

- $X$ : Feature set (e.g., age, race, education, region, income, etc.)
- $A \in X$ : Sensitive attribute (e.g., gender)
- $R$ : Regression score (e.g., predicted likelihood of on-time loan payment)
- $Y'$ : Classifier output
  - $Y' = 1$  if and only if  $R > T$  for some threshold  $T$
  - e.g., Grant the loan ( $Y' = 1$ ) if the likelihood of paying back > 80%
- $Y$ : Target variable being predicted ( $Y = 1$  if the person actually pays back on time)

≡ Setting classification thresholds: Loan lending example

# Group Fairness

$$P[Y' = 1 | A = a] = P[Y' = 1 | A = b]$$

- Also called *independence* or *demographic parity*
- Mathematically,  $Y' \perp A$ 
  - Prediction ( $Y'$ ) must be independent of the sensitive attribute ( $A$ )
- Examples:
  - The predicted rate of recidivism is the same across all races
  - Both women and men have the equal probability of being promoted
    - i.e.,  $P[\text{promote} = 1 | \text{gender} = M] = P[\text{promote} = 1 | \text{gender} = F]$

# Group Fairness Limitations

What are limitations of group fairness?



# Group Fairness Limitations

- Ignores possible correlation between  $Y$  and  $A$
- Rules out perfect predictor  $Y' = Y$  when  $Y$  &  $A$  are correlated
- Permits abuse and laziness: Can be satisfied by randomly assigning a positive outcome ( $Y' = 1$ ) to protected groups
  - e.g., Randomly promote people (regardless of their job performance) to match the rate across all groups

# Adjusting Thresholds for Group Fairness

Select different classification thresholds ( $t_0, t_1$ ) for different groups ( $A = 0, A = 1$ ) to achieve group fairness, such that

$$P[R > t_0 | A = 0] = P[R > t_1 | A = 1]$$

Example: Mortgage application

- R: Likelihood of paying back the loan on time
- Suppose: With a uniform threshold used (i.e.,  $R = 80\%$ ), group fairness is not achieved
  - $P[R > 0.8 | A = 0] = 0.4, P[R > 0.8 | A = 1] = 0.7$
- Adjust thresholds to achieve group fairness
  - $P[R > 0.6 | A = 0] = P[R > 0.8 | A = 1]$
- Wouldn't group  $A = 1$  argue it's unfair? When does this type of adjustment make sense?

# Testing Group Fairness

*How would you test whether a classifier achieves group fairness?*



# Testing Group Fairness

Collect realistic, representative data (not randomly generated!)

- Use existing validation/test data
- Monitor production data
- (Somehow) generate realistic test data, e.g. from probability distribution of population

Separately measure the rate of positive predictions

- e.g.,  $P[\text{promoted} = 1 \mid \text{gender} = M]$ ,  $P[\text{promoted} = 1 \mid \text{gender} = F] = ?$

Report issue if the rates differ beyond some threshold  $\epsilon$  across  
≡ groups

# Equalized odds

- Anti-classification (fairness through blindness)
- Group fairness (independence)
- **Equalized odds (separation)**
- ...and numerous others and variations!

# Equalized odds

Key idea: Focus on accuracy (not outcomes) across two groups

- Similar default rates on accepted loans across racial/gender groups?
- Similar rate of "bad hires" and "missed stars" between gender groups?
- Similar accuracy of predicted recidivism vs actual recidivism across racial groups?

Accuracy matters, not outcomes!

# Equalized odds in discrimination law

Relates to *disparate treatment*

Typically lawsuits claim that protected attributes (e.g., race, gender) were used in decisions even though they were irrelevant

- e.g., fired over complaint because of being Latino, whereas other White employees were not fired with similar complaints

Can be difficult to prove in individual cases, typically relying on shifting justifications, inconsistent application of rules, or explicit remarks overheard or documented

# Equalized odds

$$\begin{aligned} P[Y' = 1 \mid Y = 0, A = a] &= P[Y' = 1 \mid Y = 0, A = b] \\ P[Y' = 0 \mid Y = 1, A = a] &= P[Y' = 0 \mid Y = 1, A = b] \end{aligned}$$

Statistical property of *separation*:  $Y' \perp A | Y$

- Prediction must be independent of the sensitive attribute *conditional* on the target variable

# Review: Confusion Matrix

		Actual value	
		$Y = 1$	$Y = 0$
Predicted value	$Y' = 1$	True Positive Rate $P[Y' = 1   Y = 1]$	False Positive Rate $P[Y' = 1   Y = 0]$
	$Y' = 0$	False Negative Rate $P[Y' = 0   Y = 1]$	True Negative Rate $P[Y' = 0   Y = 0]$

Can we explain separation in terms of model errors?

- $P[Y' = 1 | Y = 0, A = a] = P[Y' = 1 | Y = 0, A = b]$
- $P[Y' = 0 | Y = 1, A = a] = P[Y' = 0 | Y = 1, A = b]$

# Separation

$P[Y' = 1 \mid Y = 0, A = a] = P[Y' = 1 \mid Y = 0, A = b]$  (FPR parity)

$P[Y' = 0 \mid Y = 1, A = a] = P[Y' = 0 \mid Y = 1, A = b]$  (FNR parity)

- $Y' \perp A \mid Y$ : Prediction must be independent of the sensitive attribute *conditional* on the target variable
- i.e., All groups are susceptible to the same false positive/negative rates
- Example:  $Y'$ : Promotion decision,  $A$ : Gender of applicant:  $Y$ : Actual job performance

# Testing Separation

Requires realistic representative test data (telemetry or representative test data, not random)

Separately measure false positive and false negative rates

- e.g, for FNR, compare  $P[\text{promoted} = 0 \mid \text{female, good employee}]$  vs  $P[\text{promoted} = 0 \mid \text{male, good employee}]$

*How is this different from testing group fairness?*

# Breakout: Cancer Prognosis

		Male Patient Results				Female Patient Results		
		Actual cancer	Actually no cancer			Actual cancer	Actually no cancer	
Predicted cancer	23	11	Predicted cancer	13	5	Predicted no cancer	2	480
Predicted no cancer	41	925	Predicted no cancer	2	480	Predicted cancer	13	5

In groups, post to #lecture tagging members:

- Does the model meet anti-classification fairness wrt. sex?
- Does the model meet group fairness?
- Does the model meet equalized odds?
- Is the model fair enough to use?

# Other fairness measures

- Anti-classification (fairness through blindness)
- Group fairness (independence)
- Equalized odds (separation)\*\*
- ...and numerous others and variations!

Metric #1,284.

Okay, the True Positives divided by the False Positives, multiplied by the total number of Negative Predictions, plus the temperature of the room, multiplied by the negative exponential of the number of words in this sentence, should be the same for all sensitive groups.

What are we  
measuring again?

Fairness.

Right.



# Many measures

Many measures proposed

Some specialized for tasks (e.g., ranking, NLP)

Some consider downstream utility of various outcomes

Most are similar to the three discussed

- Comparing different measures in the error matrix (e.g., false positive rate, lift)

# Comparing Fairness Criteria

# Recall: What is fair?

- Equal slices for everybody
- Bigger slices for active bakers
- Bigger slices for inexperienced/new members (e.g., children)
- Bigger slices for hungry people
- More pie for everybody, bake more



*(Not everybody contributed equally  
during baking, not everybody is  
≡ equally hungry)*

# Recall: What is fair?

*Fairness discourse asks questions about how to treat people and whether treating different groups of people differently is ethical. If two groups of people are systematically treated differently, this is often considered unfair.*

# Intuitive Justice

Research on what post people perceive as fair/just (psychology)

When rewards depend on inputs and participants can chose contributions: Most people find it fair to split rewards proportional to inputs

- *Which fairness measure does this relate to?*

Most people agree that for a decision to be fair, personal characteristics that do not influence the reward, such as sex or age, should not be considered when dividing the rewards.

- *Which fairness measure does this relate to?*

# Key issue: Unequal starting positions

Not everybody starts from an equal footing -- individual and group differences

- Some differences are inert, e.g., younger people have (on average) less experience
- Some differences come from past behavior/decisions, e.g., whether to attend college
- Some past decisions and opportunities are influenced by past injustices, e.g., redlining creating generational wealth differences

Individual and group differences not always clearly attributable, e.g., nature vs nurture discussion

# Unequal starting position

Fair or not? Should we account for unequal starting positions?

- Tom is more lazy than Bob. He should get less pie.
- People in Egypt have on average a much longer work week (53h) than people in Germany (35h). They have less time to bake and should get more pie.
- Disabled people are always exhausted quickly. They should get less pie, because they contribute less.
- Men are on average more violent than women. This should be reflected in recidivism prediction.
- Employees with a PhD should earn higher wages than those with a bachelor's degree, because they decided to invest in more schooling.
- Students from poor neighborhoods should receive extra resources at school, because they get less help at home.
- Poverty is a moral failing. Poor people are less deserving of pie.

# Dealing with unequal starting positions

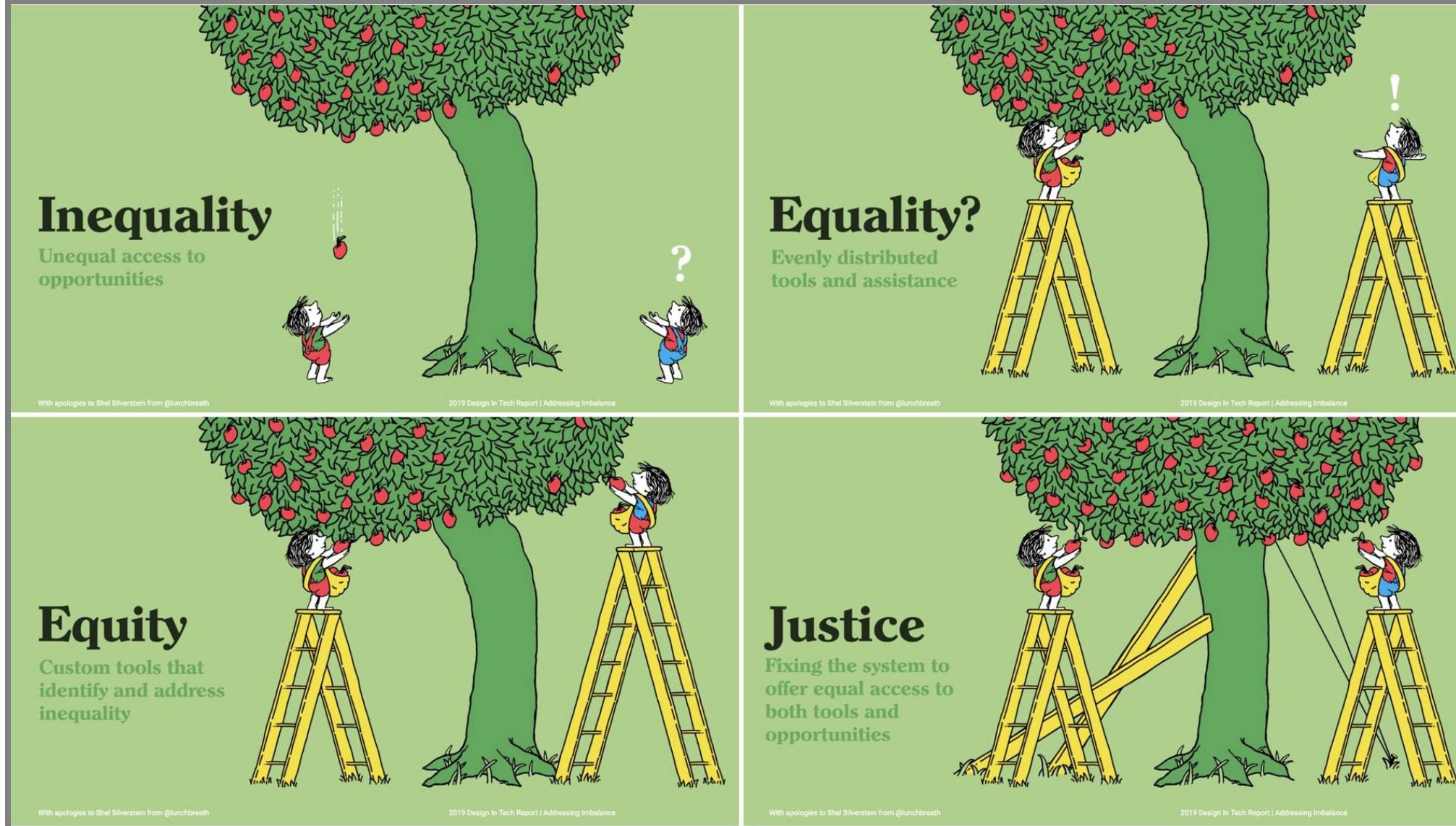
Equality (minimize disparate treatment):

- Treat everybody equally, regardless of starting position
- Focus on meritocracy, strive for fair opportunities
- Equalized-odds-style fairness; equality of opportunity

Equity (minimize disparate impact):

- Compensate for different starting positions
- Lift disadvantaged group, affirmative action
- Strive for similar outcomes (distributive justice)
- Group-fairness-style fairness; equality of outcomes

# Equality vs Equity



# Equality vs Equity

## Equality



The assumption is that **everyone benefits from the same supports**. This is equal treatment.

## Equity



**Everyone gets the supports they need** (this is the concept of "affirmative action"), thus producing equity.

## Justice



All 3 can see the game without supports or accommodations because **the cause(s) of the inequity was addressed**.  
The systemic barrier has been removed.

# Justice

Aspirational third option, that avoids a choice between equality and equity

Fundamentally removes initial imbalance or removes need for decision

Typically rethinks entire societal system in which the imbalance existed, beyond the scope of the ML product

# Choosing Equality vs Equity

Each rooted in long history in law and philosophy

Typically incompatible, cannot achieve both

Designers need to decide

Problem dependent and goal dependent

What differences are associated with merits and which with systemic disadvantages of certain groups? Can we agree on the degree a group is disadvantaged?

# Equality vs Equity and Politics

Noticeable political split

*People with right-leaning politics:* tend to prefer equality-based fairness notions of a meritocracy and decry equity-based initiatives as reverse-discrimination (discrimination against the majority group through disparate treatment)

*People with left-leaning politics:* tend to emphasize outcomes and equity-based fairness that challenge the status quo

# Trade-offs in Fairness vs Accuracy

General view: Accuracy is at odds with fairness (e.g., impossible to achieve perfect accuracy  $R = Y$  while ensuring group fairness)

Fairness imposes constraints, limits what models can be learned

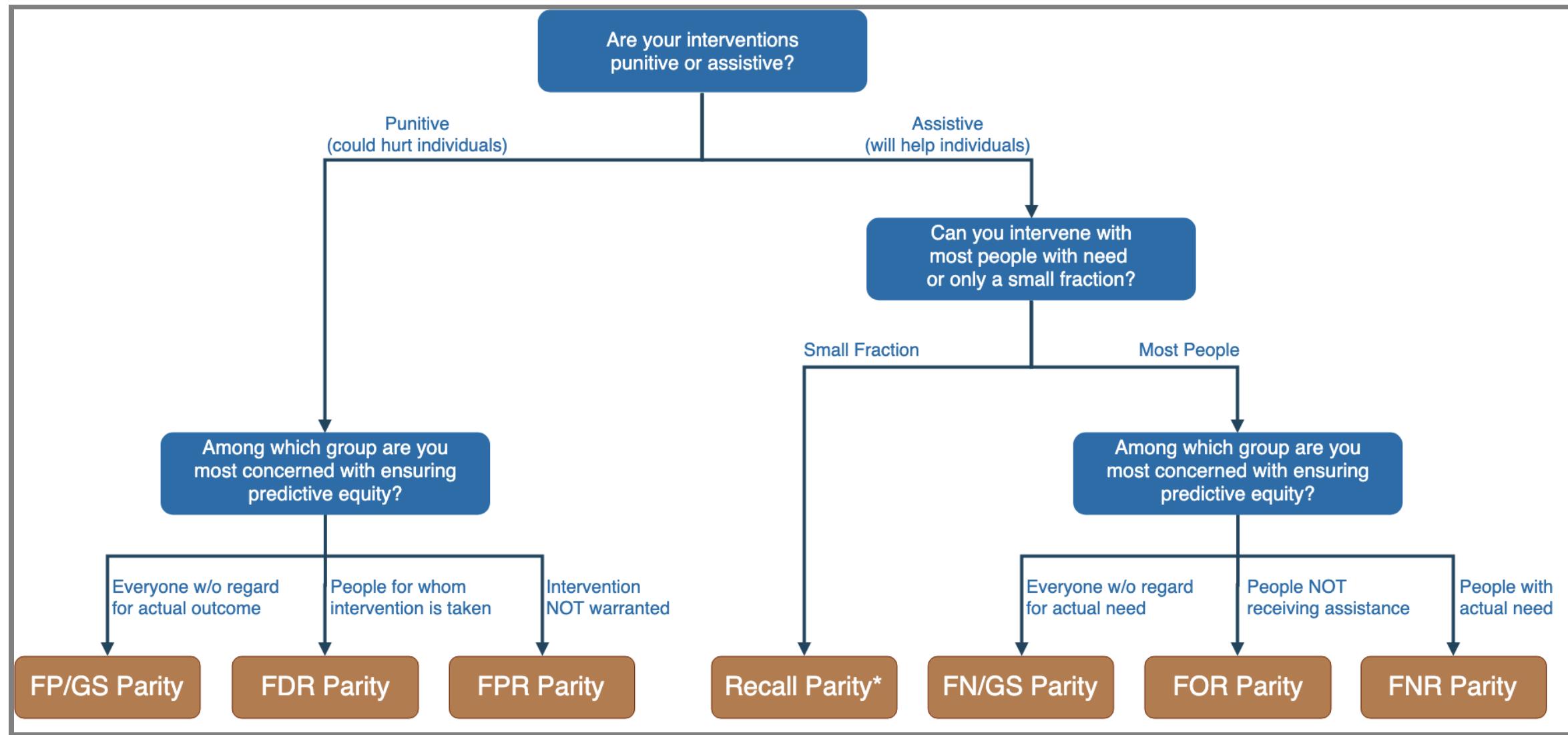
But: Arguably unfair predictions not desirable, accuracy based on misleading ground truth

Determine how much compromise in accuracy or fairness is acceptable to your stakeholders; is accuracy the right measure or based on the right data?

# Some Guidance on Equality Metric:

Are the interventions punitive or assistive

- Punitive (could hurt individuals): Focus on similar false positive rates
- Assistive (will help individuals): Focus on similar recall, false negative rates



Ian Foster, Rayid Ghani, Ron S. Jarmin, Frauke Kreuter and Julia Lane. [Big Data and Social Science: Data Science Methods and Tools for Research and Practice](#). Chapter 11, 2nd ed, 2020

# Identifying Fairness Goals is a Requirements Engineering Problem

- What is the goal of the system? What benefits does it provide and to whom?
  - What subpopulations (including minority groups) may be using or be affected by the system? What types of harms can the system cause with discrimination?
  - Who are the stakeholders of the system? What are the stakeholders' views or expectations on fairness and where do they conflict? Are we trying to achieve fairness based on equality or equity?
  - Does fairness undermine any other goals of the system (e.g., accuracy, profits, time to release)?
  - Are there legal anti-discrimination requirements to consider? Are there societal expectations about ethics that relate to this product? What is the activist position?
- ≡ • ...

# Discussion: Fairness Goal for Mortgage Applications?



# Discussion: Fairness Goal for Mortgage Applications?

Disparate impact considerations seem to prevail -- group fairness

Need to justify strong differences in outcomes

Can also sue over disparate treatment if bank indicates that protected attribute was reason for decision

# Discussion: Fairness Goal for College Admission?



# Discussion: Fairness Goal for College Admission?

Strong legal precedents

Very limited scope of *affirmative action*

Most forms of group fairness likely illegal

In practice: Anti-classification

# Discussion: Fairness Goal for Hiring Decisions?



# Law: "Four-fifth rule" (or "80% rule")

- Group fairness with a threshold:  $\frac{P[R=1|A=a]}{P[R=1|A=b]} \geq 0.8$
- Selection rate for a protected group (e.g.,  $A = a$ ) < 80% of highest rate => selection procedure considered as having "adverse impact"
- Guideline adopted by Federal agencies (Department of Justice, Equal Employment Opportunity Commission, etc.,) in 1978
- If violated, must justify business necessity (i.e., the selection procedure is essential to the safe & efficient operation)
- Example: Hiring 50% of male applicants vs 20% female applicants hired ( $0.2/0.5 = 0.4$ ) -- Is there a business justification for hiring men at a higher rate?

# Discussion: Fairness Goal for Cancer Prognosis?



# Discussion: Fairness Goal for Recidivism Prediction?



Bernard Parker, left, was rated high risk; Dylan Fugett was rated low risk. (Josh Ritchie for ProPublica)

## Machine Bias

There's software used across the country to predict future criminals. And it's biased against blacks.

# Discussion: Recidivism Prediction?

- ProPublica investigation:  
COMPAS violates separation  
w/ FPR & FNR
- Northpointe response:  
COMPAS is fair because it has  
similar FDRs across both races
- *Is COMPAS both fair & unfair at  
the same time? Which definition  
is the "right" one?*

Metric	Caucasian	African American
False Positive Rate ( <i>FPR</i> )	23%	45%
False Negative Rate ( <i>FNR</i> )	48%	28%
False Discovery Rate ( <i>FDR</i> )	41%	37%

[Figure from Big Data and Social Science, Ch. 11](#)

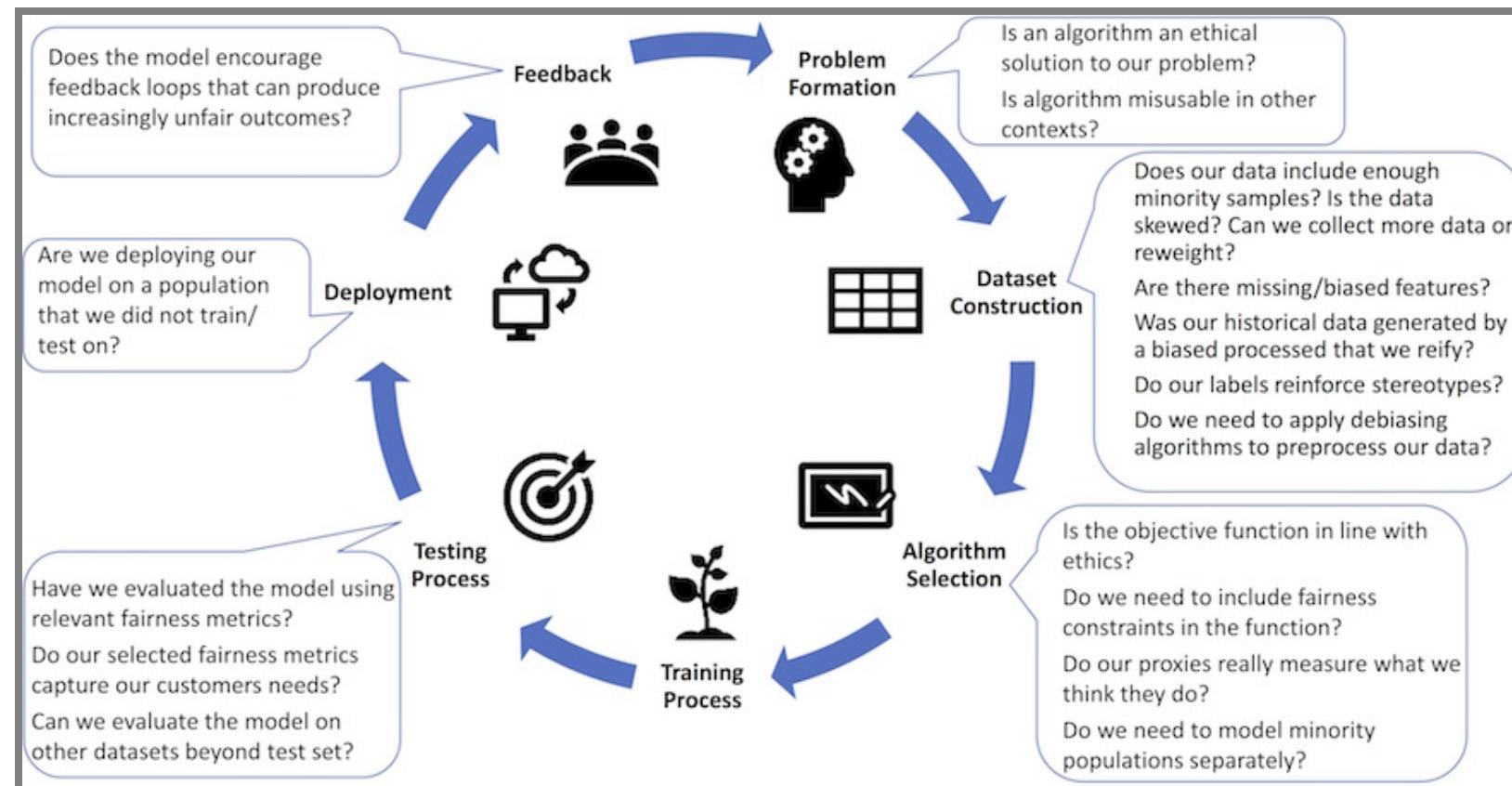
# Improving Fairness of a Model

In all pipeline stages:

- Data collection
- Data cleaning, processing
- Training
- Inference
- Evaluation and auditing

# Today: Model-centric view

Consider fairness throughout the ML lifecycle!



From *Fairness-aware Machine Learning*, Bennett et al., WSDM Tutorial (2019).

# 1. Improve with Model Evaluation and Auditing

Lots of tools to measure and visualize fairness with many metrics

Can be integrated in notebooks and production (telemetry, monitoring)

Audit: In-depth evaluation of a model snapshot

Efforts to crowdsource feedback and audits

Debugging tools to investigate potential fairness issues

# Example audit tool: Aequitas

**Aequitas**  
Bias & Fairness Audit

[Home](#) [Code](#) [About](#)

## Bias and Fairness Audit Toolkit

The Bias Report is powered by [Aequitas](#), an open-source bias audit toolkit for machine learning developers, analysts, and policymakers to audit machine learning models for discrimination and bias, and make informed and equitable decisions around developing and deploying predictive risk-assessment tools.

```
graph LR; A[Upload Data] --> B[Select Protected Groups]; B --> C[Select Fairness Metrics]; C --> D[The Bias Report]
```

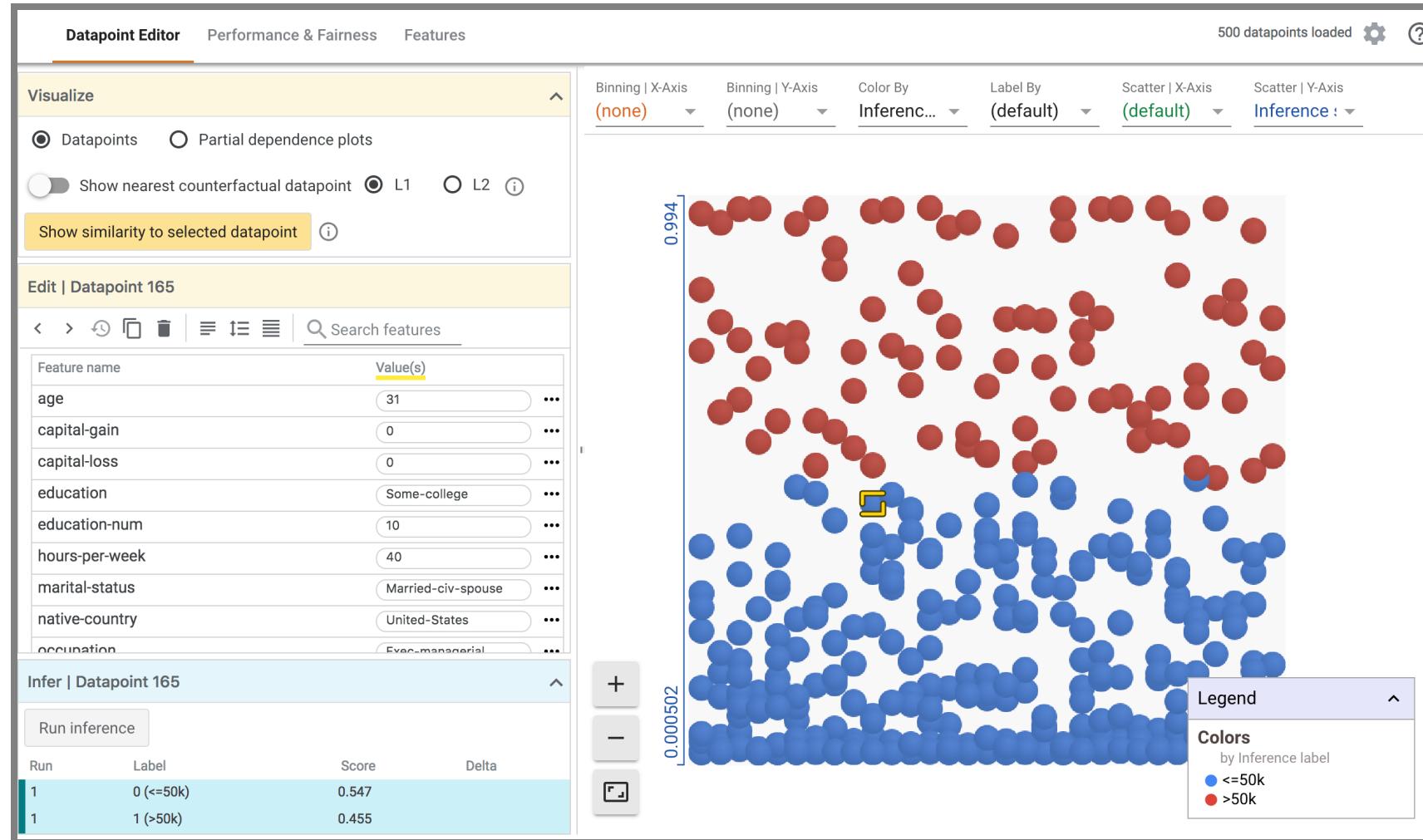
# Example audit tool: Aequitas

## Audit Results: Bias Metrics Values

race

Attribute Value	False Discovery Rate Disparity	False Positive Rate Disparity
African-American	0.91	1.91
Asian	0.61	0.37
Caucasian	1.0	1.0
Hispanic	1.12	0.92
Native American	0.61	1.6
Other	1.12	0.63

# Example debugging tool: What-If



## 2. Improve during Model Inference

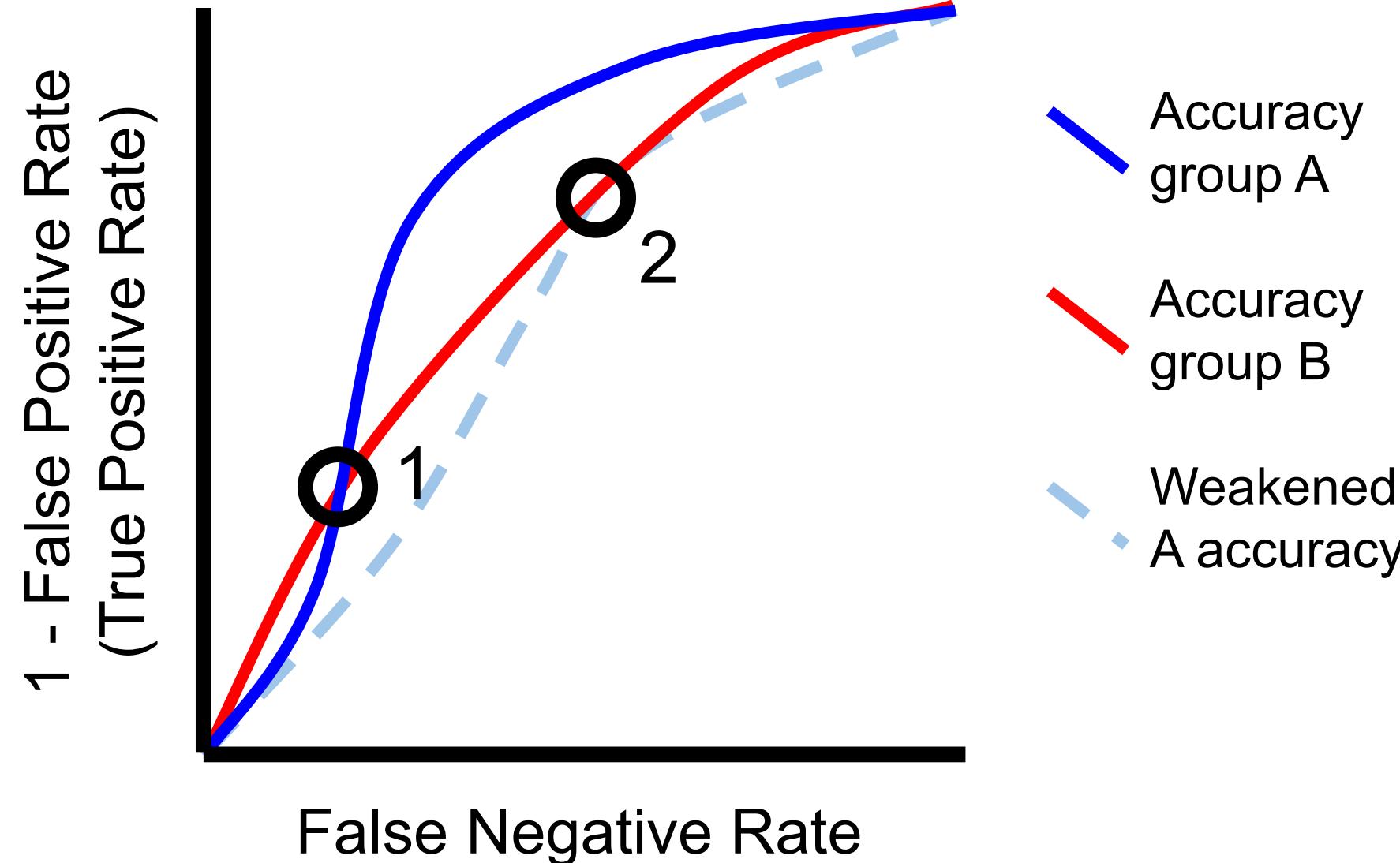
Remove/scramble protected attributes and correlated attributes?  
(anti-classification)

Calibrate by adjusting thresholds (group fairness, equalized odds)

- $P[R > t_0 | A = 0] = P[R > t_1 | A = 1]$

Weaken predictor for one group?

# Example: Tweaking Thresholds



# 3. Improve during Model Training

Incorporate fairness metric during training, e.g., in loss function

Use fairness for model selection/hyperparameter tuning

Weigh training data differently based on (expected) bias or trust

Much research, many approaches...

Further reading: Pessach, Dana, and Erez Shmueli. "[A Review on Fairness in Machine Learning](#)."  
ACM Computing Surveys (CSUR) 55, no. 3 (2022): 1-44.

# 4. Improve during Data Cleaning, Feature Engineering

Remove features for protected attributes; measure correlations to identify proxies  
<- anti-classification

Correct for known biases, e.g.,

- Discard known biased training data, fix *tainted labels*
- Remove training data influenced by *feedback loop*
- Analyze data for *limited features*, remove or enhance
- Augment data for *sample size disparity*
- Normalize data across subpopulations

Active research field of data debugging to find influential outliers and potential  
≡ bias (more later in Explainability lecture)

# 5. Improvement during Data Collection

Carefully review data collection procedures, sampling biases, what data is collected, how trustworthy labels are, etc.

Can address most sources of bias: tainted labels, skewed samples, limited features, sample size disparity, proxies:

- deliberate what data to collect
- collect more data, oversample where needed
- extra effort in unbiased labels

Potentially expensive, but typically **highest leverage point**

# Outlook: Building Fair ML-Based Products

**Next lecture:** Fairness is a *system-wide* concern

- Identifying and negotiating fairness requirements
- Fairness beyond model predictions (product design, mitigations, data collection)
- Fairness in process and teamwork, barriers and responsibilities
- Documenting fairness at the interface
- Monitoring
- Promoting best practices

# Summary

- Three definitions of fairness: Anti-classification, group fairness, equalized odds
- Tradeoffs between fairness criteria
  - What is the goal?
  - Key: how to deal with unequal starting positions
- Improving fairness of a model
  - In all *pipeline stages*: data collection, data cleaning, training, inference, evaluation

# Further Readings

- Ian Foster, Rayid Ghani, Ron S. Jarmin, Frauke Kreuter and Julia Lane. [Big Data and Social Science: Data Science Methods and Tools for Research and Practice](#). Chapter 11, 2nd ed, 2020
- Solon Barocas and Moritz Hardt and Arvind Narayanan. [Fairness and Machine Learning](#). 2019 (incomplete book)
- Pessach, Dana, and Erez Shmueli. "[A Review on Fairness in Machine Learning](#)." ACM Computing Surveys (CSUR) 55, no. 3 (2022): 1-44.

# Practitioner Challenges