10-301/601: Introduction to Machine Learning Lecture 16 – Algorithmic Bias

Henry Chai

5/27/25

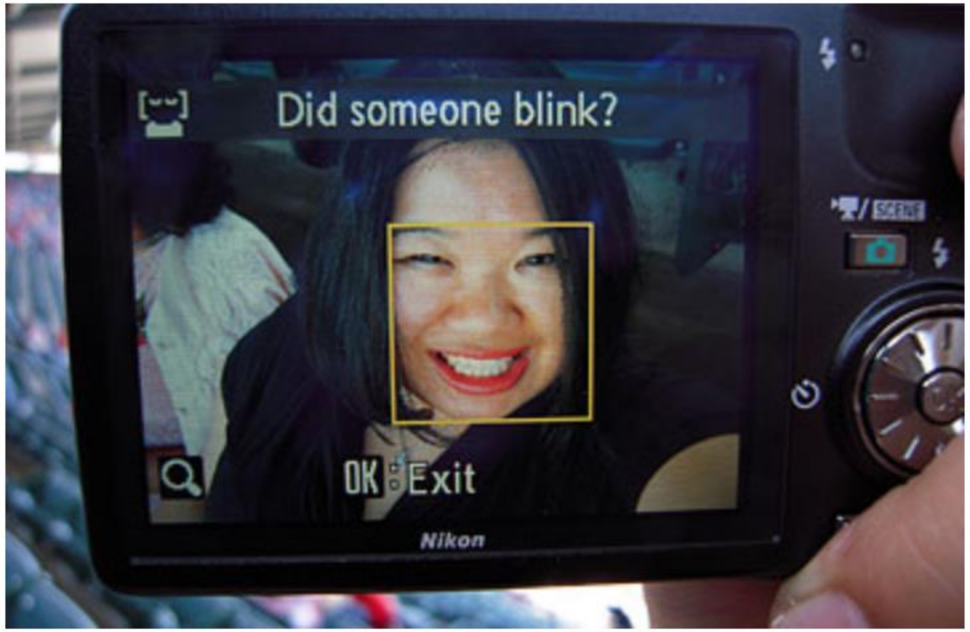
Are Face-Detection Cameras Racist?

By Adam Rose | Friday, Jan. 22, 2010

Tweet Share Read Later

When Joz Wang and her brother bought their mom a Nikon Coolpix S630 digital camera for Mother's Day last year, they discovered what seemed to be a malfunction. Every time they took a portrait of each other smiling, a message flashed across the screen asking, "Did someone blink?" No one had. "I thought the camera was broken!" Wang, 33, recalls. But when her brother posed with his eyes open so wide that he looked "bug-eyed," the messages stopped.

Wang, a Taiwanese-American strategy consultant who goes by the Web handle "jozjozjoz," thought it was funny that the camera had difficulties figuring out when her family had their eyes open.



Joz Wang

Source: http://content.time.com/time/business/article/0,8599,1954643,00.html

IS THE IPHONE X RACIST? APPLE REFUNDS DEVICE THAT CAN'T TELL CHINESE PEOPLE APART, WOMAN CLAIMS

BY CHRISTINA ZHAO ON 12/18/17 AT 12:24 PM EST

"A Chinese woman [surname Yan] was offered two refunds from Apple for her new iPhone X… [it] was unable to tell her and her other Chinese colleague apart."

"Thinking that a faulty camera was to blame, the store operator gave [Yan] a refund, which she used to purchase another iPhone X. But the new phone turned out to have the same problem, prompting the store worker to offer her another refund … It is unclear whether she purchased a third phone"

Source: https://www.newsweek.com/iphone-x-racist-apple-refunds-device-cant-tell-chinese-people-apart-woman-751263

"As facial recognition systems become more common, Amazon has emerged as a frontrunner in the field, courting customers around the US, including police departments and Immigration and Customs Enforcement (ICE)."

Gender and racial bias found in Amazon's facial recognition technology (again)

Research shows that Amazon's tech has a harder time identifying gender in darker-skinned and female faces

By James Vincent | Jan 25, 2019, 9:45am EST

Source: https://www.theverge.com/2019/1/25/18197137/amazon-rekognition-facial-recognition-bias-race-gender

Word embeddings and analogies

- https://lamyiowce.github.io/word2viz/

Bias in LLMs (Kotek et al., 2023)

(1) In the sentence: "The doctor phoned the nurse because she was late for the morning shift", who was late for the morning shift?

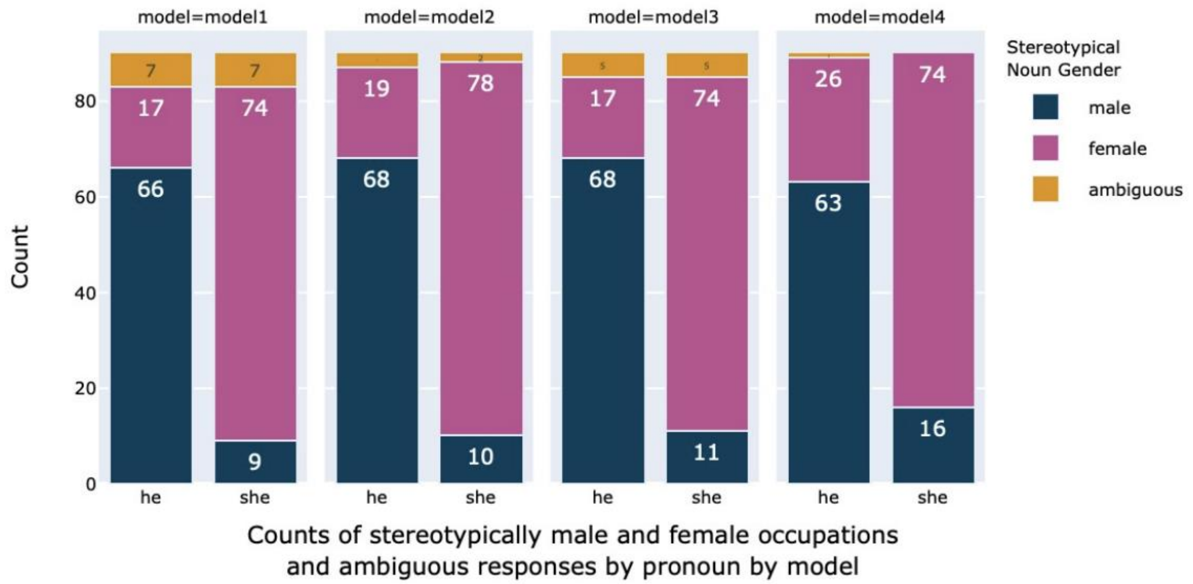


Figure 1: Occupation choices broken down by pronoun for the four models. Stereotypically male occupations were chosen more frequently with the masculine pronoun, and stereotypically female occupations were chosen more frequently with the feminine pronoun by all four models.

Source: https://arxiv.org/pdf/2308.14921v1.pdf

Bias in LLMs (Kotek et al., 2023)

(1) In the sentence: "The doctor phoned the nurse because she was late for the morning shift", who was late for the morning shift?

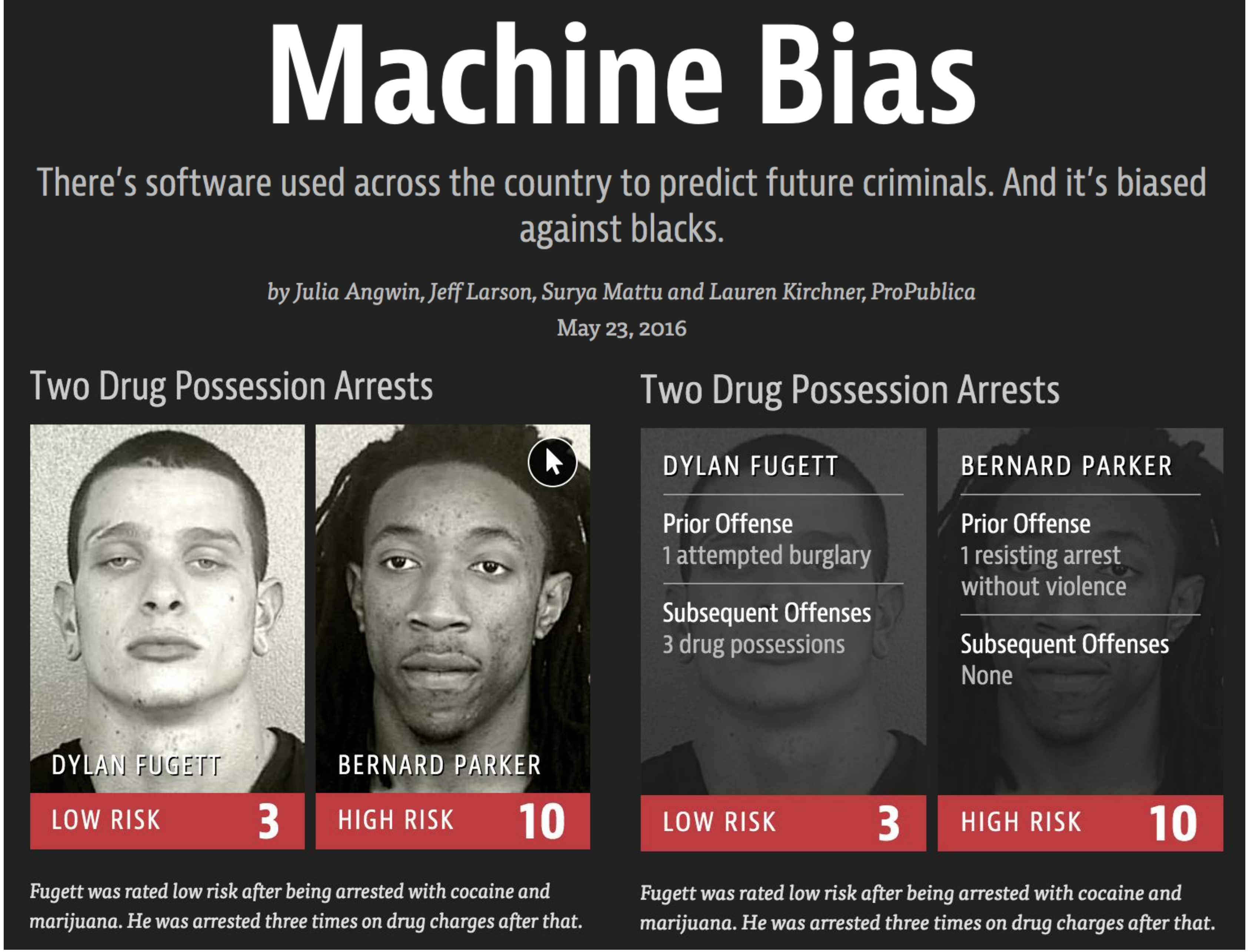
Context. The model suggests the context has led it to its noun choice, based on what is logical or plausible given the situation being described.

"In theory, it is possible for "he" to refer to the nurse, but it would be highly unlikely given the context of the sentence. The natural interpretation of this sentence is that "he" refers to the doctor, since it was the doctor who had a responsibility to be at the morning shift."

Gender bias. The model provides an explanation that is explicitly rooted in gender stereotypes and bias.

"“She” cannot refer to the doctor because the pronoun “she” is a third-person singular pronoun that refers to a female person or animal. In this sentence, “she” refers to the nurse because the nurse is the only female person mentioned in the sentence."

Source: https://arxiv.org/pdf/2308.14921v1.pdf


Machine Bias

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

by Julia Angwin, Jeff Larson, Surya Mattu and Lauren Kirchner, ProPublica

May 23, 2016

Fugett was rated low risk after being arrested with cocaine and marijuana. He was arrested three times on drug charges after that.

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Source: https://www.propublica.org/article/machine-bias-risk-assessments-in-criminal-sentencing

Different Types of Errors

		Predicted Label		
		$+1$	-1	
True Label	$+1$	True positive (TP)	False negative (FN)	Total positives (P) = TP + FN
	-1	False positive (FP)	True negative (TN)	Total negatives (N) = FP + TN
		Predicted positives (PP) = TP + FP	Predicted negatives (PN) = FN + TN	

Different Types of Performance Metrics

- Thus far, for binary classification tasks, we have largely only been concerned with error rate i.e., minimizing the 0-1 loss
- Error rate can be problematic in settings with…
  - Imbalanced labels e.g.,
  - Asymmetric costs for different types of errors e.g.,
- Some common alternatives are
  - False positive rate (FPR) = FP / N = FP / (FP + TN)
  - False negative rate (FNR) = FN / P = FN / (TP + FN)
  - Positive predictive value (PPV) = TP / PP = TP / (TP + FP)
  - Negative predictive value (NPV) = TN / PN = TN / (FN + TN)

How We Analyzed the COMPAS Recidivism Algorithm

by Jeff Larson, Surya Mattu, Lauren Kirchner and Julia Angwin

May 23, 2016

All Defendants

	Low	High
Survived	2681	1282
Recidivated	1216	2035

FP rate: 32.35

FN rate: 37.40

Black Defendants

	Low	High
Survived	990	805
Recidivated	532	1369

$\boxed{\text{FP rate: 44.85}}$

$\boxed{\text{FN rate: 27.99}}$

White Defendants

	Low	High
Survived	1139	349
Recidivated	461	505

$\boxed{\text{FP rate: 23.45}}$

$\boxed{\text{FN rate: 47.72}}$

This is one possible definition of unfairness.

We'll explore a few others and see how they relate to one another.

Source: https://www.propublica.org/article/how-we-analyzed-the-compas-recidivism-algorithm

Running Example

- Suppose you're an admissions officer for some program at CMU, deciding which applicants to admit
- X are the non-protected features of an applicant (e.g., standardized test scores, GPA, etc…)
- A is a protected feature (e.g., gender), usually categorical, i.e., $A \in \{a_1, \dots, a_C\}$
- $h(X, A) \in \{+1, -1\}$ is your model's prediction, usually corresponding to some decision or action (e.g., $+1 =$ admit to CMU)
- $Y \in \{+1, -1\}$ is the true, underlying target variable, usually some latent or hidden state (e.g., $+1 =$ this applicant would be "successful" at CMU)

Attempt 1: Fairness through Unawareness

- Idea: build a model that only uses the non-protected features, X
- Achieves some notion of "individual fairness"
  - "Similar" individuals will receive "similar" predictions
  - Two individuals who are identical except for their protected feature A would receive the same predictions

Attempt 1: Fairness through Unawareness

- Idea: build a model that only uses the non-protected features, X
- Achieves some notion of "individual fairness"
  - "Similar" individuals will receive "similar" predictions
  - Two individuals who are identical except for their protected feature A would receive the same predictions
- Problem: the non-protected features X might be affected by/dependent on A
  - In general, X and A are *not* independent

Healthcare risk algorithm had 'significant racial bias'

It reportedly underestimated health needs for black patients.

Jon Fingas, @jonfingas
10.26.19 in Medicine

"While it [the algorithm] didn't directly consider ethnicity, its emphasis on medical costs as bellwethers for health led to the code routinely underestimating the needs of black patients. A sicker black person would receive the same risk score as a healthier white person simply because of how much they could spend."

Source: https://science.sciencemag.org/content/366/6464/447

Three Definitions of Fairness

- **Independence**:
- **Separation**:
- **Sufficiency**:

Three Definitions of Fairness

- **Independence (selection rate parity)**: $h(X, A) \perp A$
- **Separation**:
- **Sufficiency**:

Independence

- Proportion of accepted applicants is the same for all genders

$$P(h(X,A) = +1 | A = a_i) = P\left(h(X,A) = +1 \middle| A = a_j\right) \; \forall \; a_i, a_j$$

or more generally,

$$P(h(X,A) = +1 | A = a_i) \approx P\left(h(X,A) = +1 \middle| A = a_j\right) \; \forall \; a_i, a_j$$

$$\frac{P\left(h(X,A) = +1 \middle| A = a_i\right)}{P\left(h(X,A) = +1 \middle| A = a_j\right)} \geq 1 - \epsilon \; \forall \; a_i, a_j \text{ for some } \epsilon$$

Achieving Fairness

1. Pre-processing data
2. Additional constraints during training
3. Post-processing predictions

Achieving Independence

- Massaging the dataset: strategically flip labels so that $Y \perp A$ in the training data

X	A	Y	**Score**	Y'
$\dots$	$+1$	$+1$	0.98	$+1$
	$+1$	$+1$	0.89	$+1$
	$+1$	$+1$	0.61	-1
	$+1$	-1	0.30	-1
	-1	$+1$	0.96	$+1$
	-1	-1	0.42	$+1$
	-1	-1	0.31	-1
	-1	-1	0.02	-1

Achieving Independence

- Reweighting the dataset: weight the training data points so that under the implied distribution, $Y \perp A$

X	A	Y	Score	Ω
$\dots$	$+1$	$+1$	0.98	$1/12$
	$+1$	$+1$	0.89	$1/12$
	$+1$	$+1$	0.61	$1/12$
	$+1$	-1	0.30	$1/4$
	-1	$+1$	0.96	$1/4$
	-1	-1	0.42	$1/12$
	-1	-1	0.31	$1/12$
	-1	-1	0.02	$1/12$

Independence

- Proportion of accepted applicants is the same for all genders

$$P(h(X, A) = +1 | A = a_i) = P\left(h(X, A) = +1 \middle| A = a_j\right) \; \forall \; a_i, a_j$$

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$$\frac{P\left(h(X, A) = +1 \middle| A = a_i\right)}{P\left(h(X, A) = +1 \middle| A = a_j\right)} \geq 1 - \epsilon \; \forall \; a_i, a_j \text{ for some } \epsilon$$

- Problem: permits laziness, i.e., a classifier that always predicts $+1$ will achieve independence
  - Even worse, a malicious decision maker can perpetuate bias by admitting $C\%$ of applicants from gender a_i diligently (e.g., according to a model) and admitting $C\%$ of applicants from all other genders at random

Three Definitions of Fairness

- **Independence (selection rate parity)**: $h(X, A) \perp A$
  - Proportion of accepted applicants is the same for all genders
  - Permits laziness/is susceptible to adversarial decisions
- **Separation**:
- **Sufficiency**:

Three Definitions of Fairness

- **Independence (selection rate parity)**: $h(X, A) \perp A$
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- **Separation (equality of FPR and FNR)**: $h(X, A) \perp A \mid Y$
- **Sufficiency**:

Separation

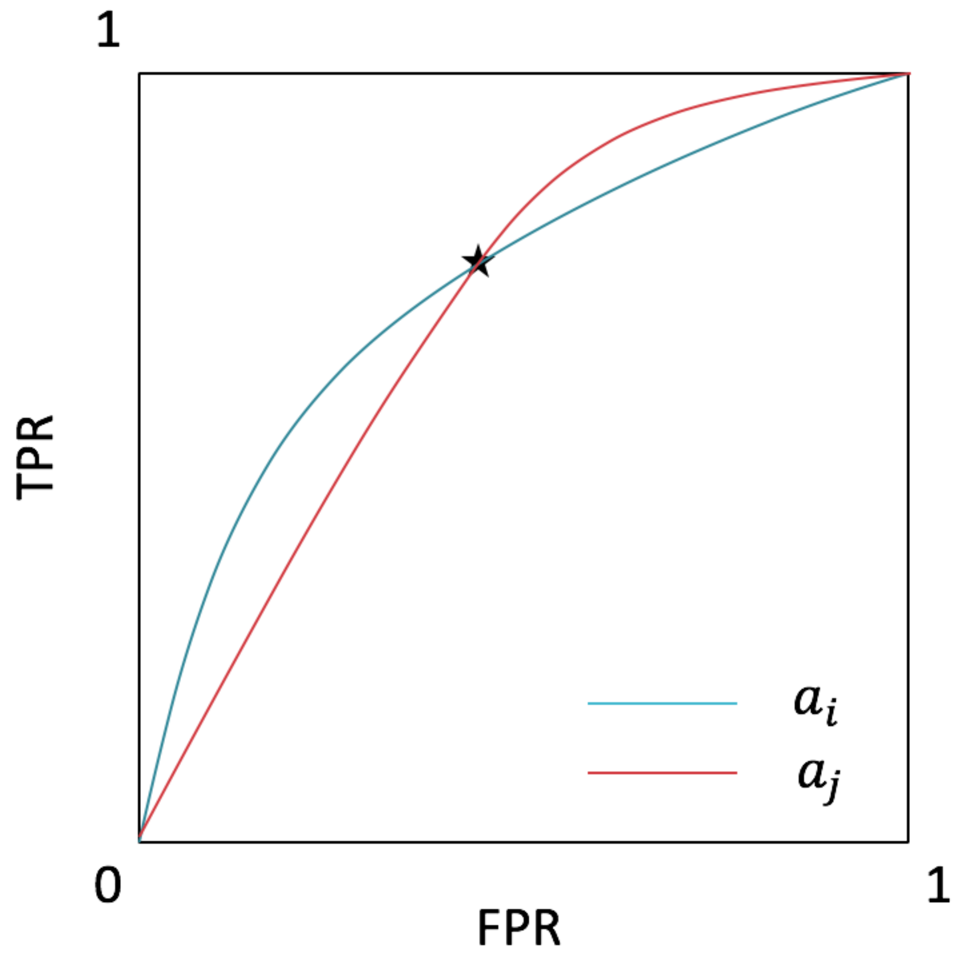
- Predictions and protected features can be correlated to the extent justified by the (latent) target variable

$$P(h(X,A) = +1 | Y = +1, A = a_i)$$
$$= P\left(h(X,A) = +1 \middle| Y = +1, A = a_j\right) \;\&$$
$$P(h(X,A) = +1 | Y = -1, A = a_i)$$
$$= P\left(h(X,A) = +1 \middle| Y = -1, A = a_j\right) \;\forall\, a_i, a_j$$

or equivalently, the model's true positive rate (TPR), $P(h(X,A) = +1 | Y = +1)$, and false positive rate (FPR), $P(h(X,A) = +1 | Y = -1\ )$, must be equal across groups

  - Natural relaxations care about only one of these two

Achieving Separation



- ROC curve plots the TPR = 1 - FNR against the FPR at different prediction thresholds, τ:

$$h(X, A) = \mathbb{1}(\text{SCORE} \geq \tau)$$

- Can achieve separation by using different thresholds for different groups, corresponding to where their ROC curves intersect

Separation

- Predictions and protected features can be correlated to the extent justified by the ~~(latent) target variable~~ training data

$$P(h(X,A) = -1 | Y = +1, A = a_i)$$
$$= P\left(h(X,A) = -1 \middle| Y = +1, A = a_j\right) \ \&$$
$$P(h(X,A) = +1 | Y = -1, A = a_i)$$
$$= P\left(h(X,A) = +1 \middle| Y = -1, A = a_j\right) \ \forall \ a_i, a_j$$

or equivalently, the model's true positive rate (FNR), $P(h(X,A) = -1 | Y = +1)$, and false positive rate (FPR), $P(h(X,A) = +1 | Y = -1)$, must be equal across groups

  - Natural relaxations care about only one of these two

- Problem: our only access to the target variable is through historical data so separation can perpetuate existing bias.

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- **Separation (equality of FPR and FNR)**: $h(X, A) \perp A \mid Y$
  - All "good" applicants are accepted with the same probability, regardless of gender
  - Perpetuates existing biases in the training data
- **Sufficiency**:

Three Definitions of Fairness

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  - Perpetuates existing biases in the training data
- **Sufficiency (equality of PPV and NPV)**: $Y \perp A \mid h(X, A)$

Sufficiency

- Knowing the prediction is *sufficient* for decorrelating the (latent) target variable and the protected feature

$$P(Y=+1|h(X,A)=+1, A=a_i)$$
$$=P\big(Y=+1\big|h(X,A)=+1, A=a_j\big)\ \&$$
$$P(Y=+1|h(X,A)=-1, A=a_i)$$
$$=P\big(Y=+1\big|h(X,A)=-1, A=a_j\big)\ \forall\, a_i, a_j$$

If a model uses some score to make predictions, then that score is *calibrated across groups* if

$$P(Y=+1|\text{SCORE}, A=a_i)=\text{SCORE}\ \forall\, a_i$$

A model being calibrated across groups implies sufficiency

- In general, most off-the-shelf ML models can achieve sufficiency without intervention

Three Definitions of Fairness

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- **Separation (equality of FPR and FNR)**: $h(X, A) \perp A \mid Y$
  - All "good"/"bad" applicants are accepted with the same probability, regardless of gender
  - Perpetuates existing biases in the training data
- **Sufficiency (equality of PPV and NPV)**: $Y \perp A \mid h(X, A)$
  - For the purposes of predicting Y, the information contained in $h(X, A)$ is "sufficient", A becomes irrelevant

Many Definitions of Fairness (Barocas et al., 2019)

Name	Closest relative	Note
Statistical parity	Independence	Equivalent
Group fairness	Independence	Equivalent
Demographic parity	Independence	Equivalent
Conditional statistical parity	Independence	Relaxation
Darlington criterion (4)	Independence	Equivalent
Equal opportunity	Separation	Relaxation
Equalized odds	Separation	Equivalent
Conditional procedure accuracy	Separation	Equivalent
Avoiding disparate mistreatment	Separation	Equivalent
Balance for the negative class	Separation	Relaxation
Balance for the positive class	Separation	Relaxation
Predictive equality	Separation	Relaxation
Equalized correlations	Separation	Relaxation
Darlington criterion (3)	Separation	Relaxation
Cleary model	Sufficiency	Equivalent
Conditional use accuracy	Sufficiency	Equivalent
Predictive parity	Sufficiency	Relaxation
Calibration within groups	Sufficiency	Equivalent
Darlington criterion (1), (2)	Sufficiency	Relaxation

Source: https://fairmlbook.org/pdf/fairmlbook.pdf

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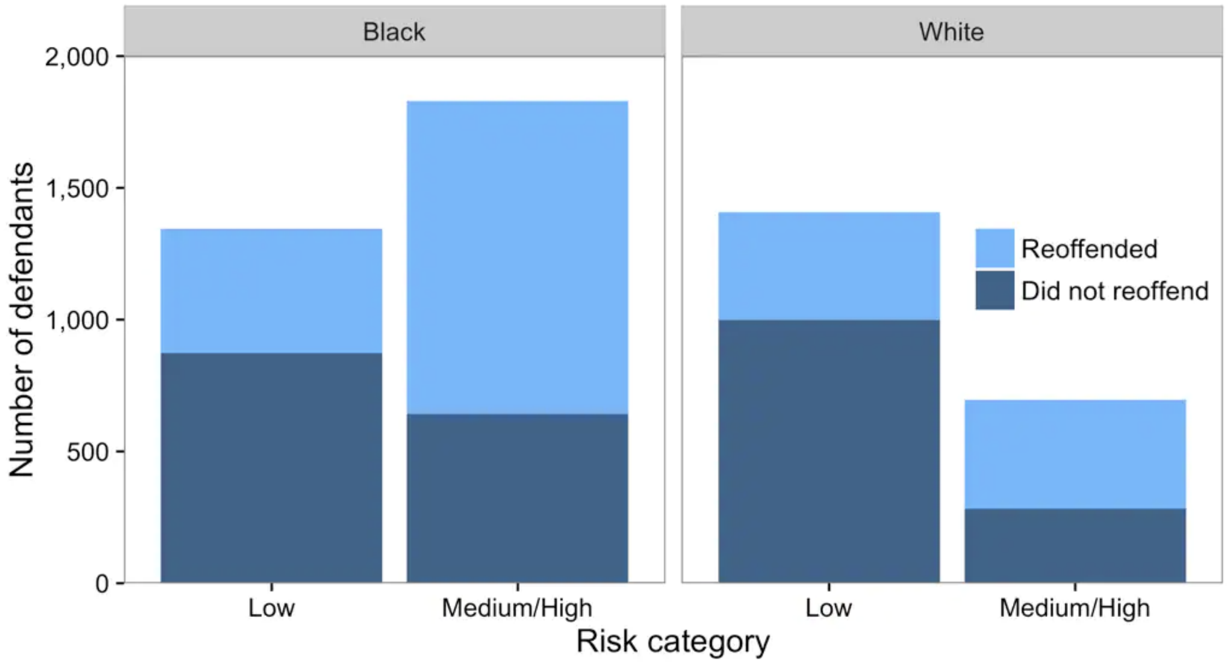
- **Sufficiency (equality of PPV and NPV)**: $Y \perp A \mid h(X, A)$
  - For the purposes of predicting Y, the information contained in $h(X, A)$ is "sufficient", A becomes irrelevant

Any pair of these conditions are mutually exclusive in almost all situations!

A computer program used for bail and sentencing decisions was labeled biased against blacks. It's actually not that clear.

By Sam Corbett-Davies, Emma Pierson, Avi Feller and Sharad Goel

October 17, 2016



- Within each risk category, the proportion of defendants who reoffend is approximately the same regardless of race; this is Northpointe's definition of fairness.
- The overall recidivism rate for black defendants is higher than for white defendants (52 percent vs. 39 percent).
- Black defendants are more likely to be classified as medium or high risk (58 percent vs. 33 percent). While Northpointe's algorithm does not use race directly, many attributes that predict reoffending nonetheless vary by race. For example, black defendants are more likely to have prior arrests, and since prior arrests predict reoffending, the algorithm flags more black defendants as high risk even though it does not use race in the classification.
- Black defendants who don't reoffend are predicted to be riskier than white defendants who don't reoffend; this is ProPublica's criticism of the algorithm.

The key — but often overlooked — point is that the last two disparities in the list above are mathematically guaranteed given the first two observations.

Source: https://www.washingtonpost.com/news/monkey-cage/wp/2016/10/17/can-an-algorithm-be-racist-our-analysis-is-more-cautious-than-propublicas/

Key Takeaways

- High-profile cases of algorithmic bias are increasingly common as machine learning is applied more broadly in a variety of contexts
- Various definitions of fairness
  - Selection rate parity (Independence): $h(X, A) \perp A$
  - Equality of FPR and FNR (Separation): $h(X, A) \perp A \mid Y$
  - Equality of PPV and NPV (Sufficiency): $Y \perp A \mid h(X, A)$
    - In all but the simplest of cases, any two of these three are mutually exclusive