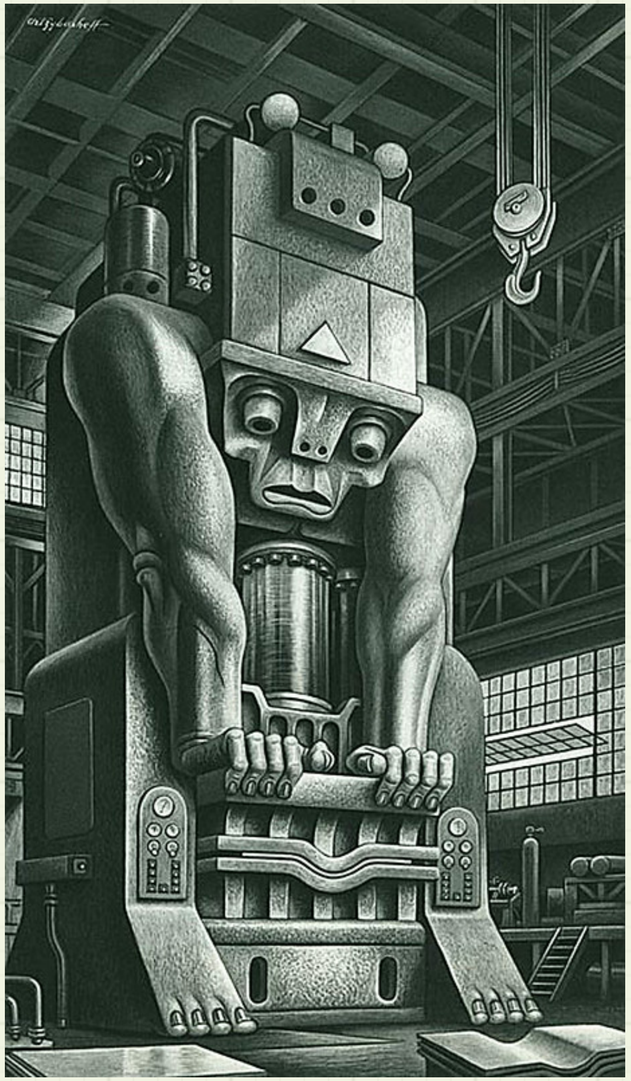


Squeezing the Most Utility from Your Models

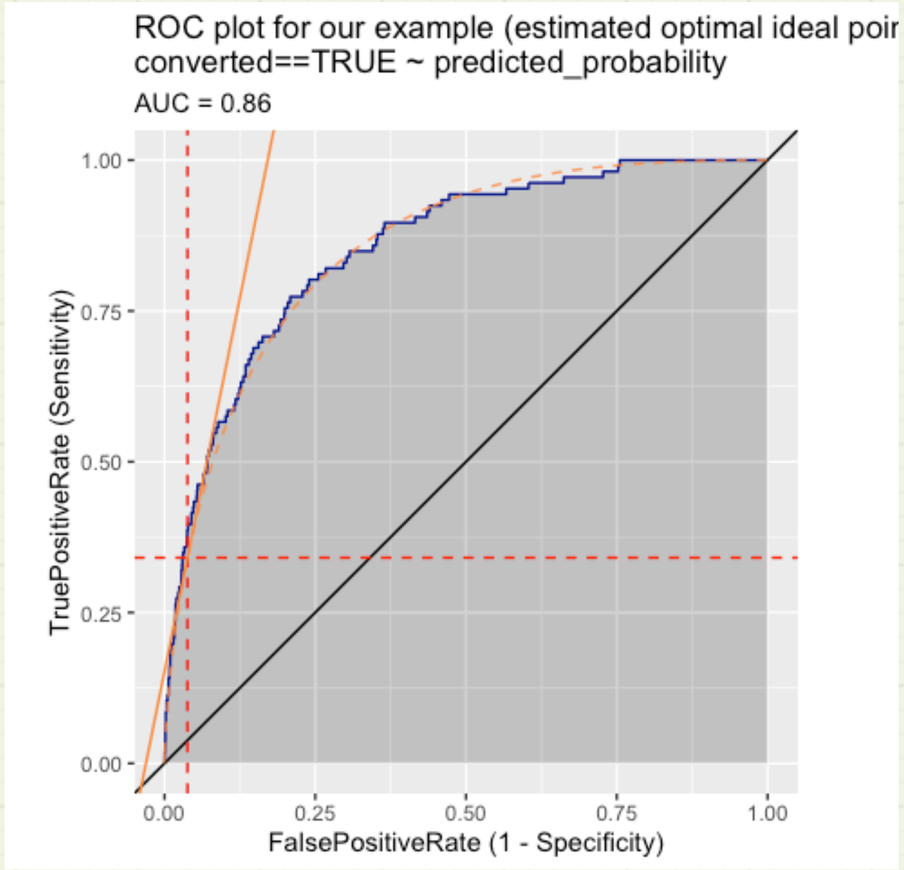
Nina Zumel
Win-Vector LLC

Illustration by Boris Artzybasheff. Source: https://www.flickr.com/photos/x-ray_delta_one/4140093007/

Win-Vector LLC

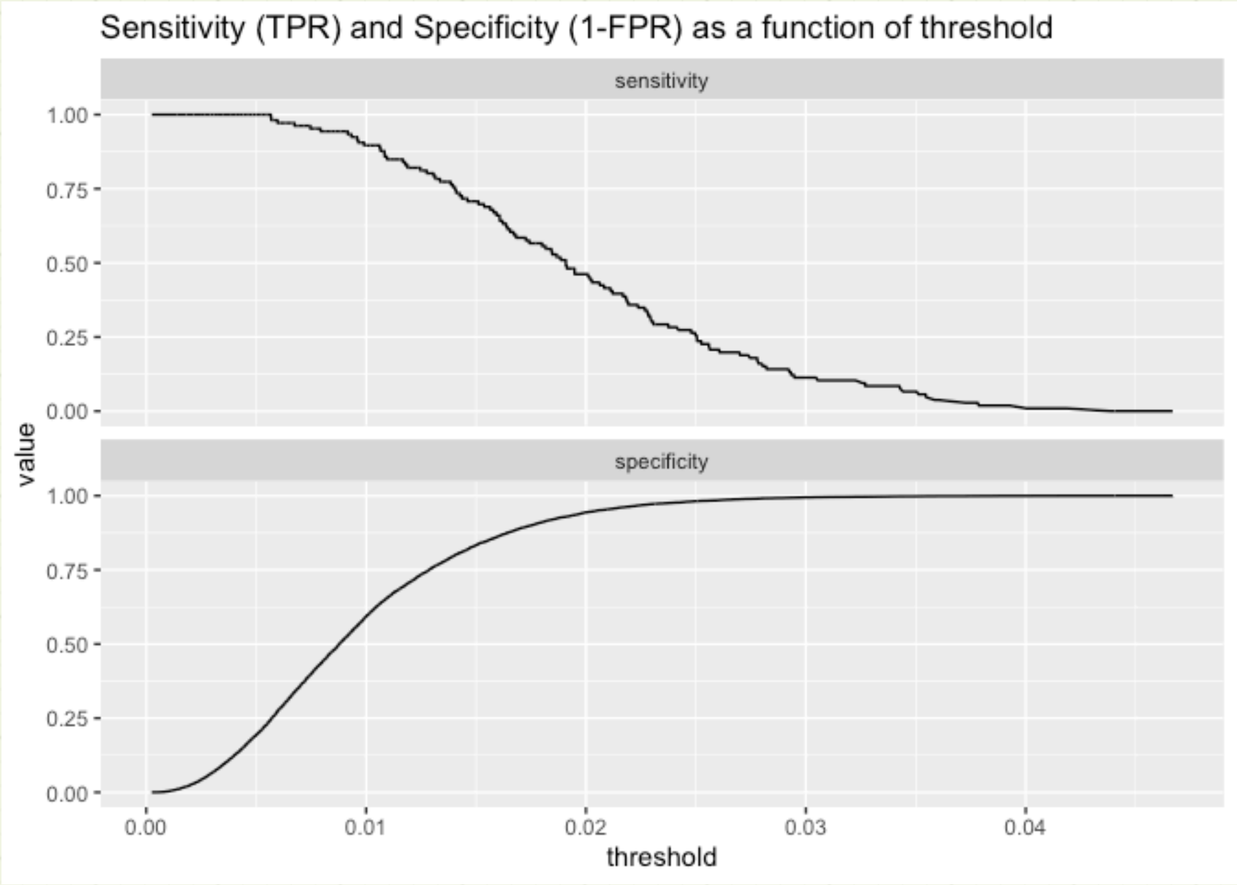
Picking Thresholds: An Alternative View

- ROCs are great for visualizing certain tradeoffs, but...
- Thresholds only implicit in the visualization
- Harder to visualize other trade-offs
  - Precision/Recall
  - Revenue vs Expenditure



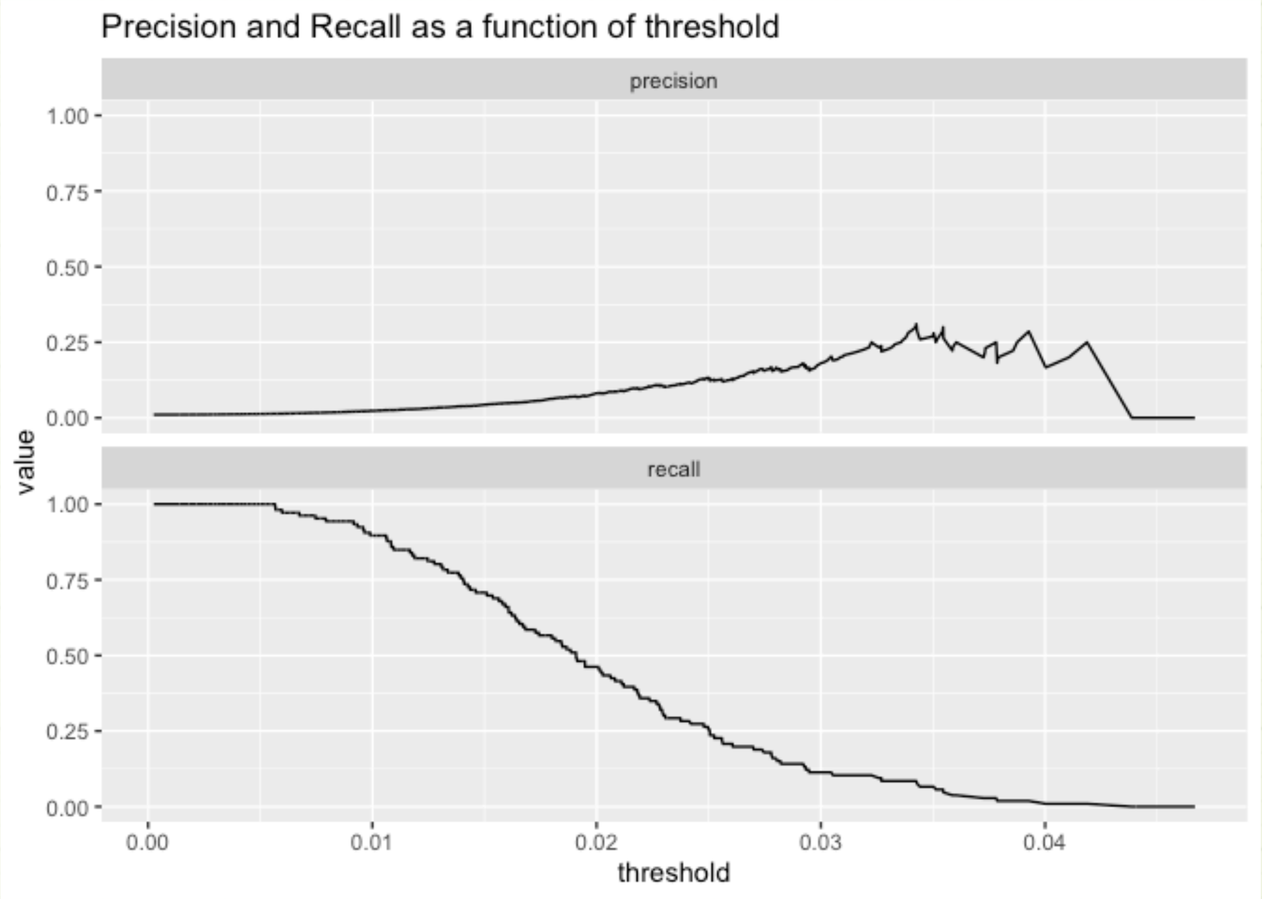
"Unroll" the ROC

```
WVPlots::ThresholdPlot(d, "predicted_probability", "converted",
                       title = "Sensitivity (TPR) and Specificity (1-FPR) as a function of threshold")
```



Tradeoffs on other Metrics

```
ThresholdPlot(d, "predicted_probability", "converted",
              metrics =c("precision", "recall"),
              title = "Precision and Recall as a function of threshold")
```



Model Performance Goals are *not* Operational Goals

- Models help make decisions that run the organization
- Accuracy metrics aren't always easy to map to operational goals

Illustration by Boris Artzybasheff, 1965. Source: https://www.flickr.com/photos/x-ray_delta_one/33275468426/

Pick Thresholds By Model
Utility

- Rewards/costs for correct/ incorrect classifications
- Assign values to TP, FP, TN, FN
  - (Generally monetary)
- (How thresholds picked via ROC)

Illustration by Boris Artzybasheff, 1949. Source: https://www.flickr.com/photos/x-ray_delta_one/33275468426/

Example 1: Sales

Identify and contact prospective customers

- Pool of 10,000 prospects
  - Conversion rate 1% (~100 customers)
- Every contact costs $$x_{contact}$$
- Every conversion is worth $$x_{sale}$$

Goal: Maximize booked net revenue

Example 1: Sales

Identify and contact prospective customers

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Goal: Maximize booked net revenue

Utilities

true positive value: $x_{sale} - x_{contact}$

(prospects contacted and converted)

Example: Sales

Identify and contact prospective customers

- Pool of 10,000 customers
  - Conversion rate 1% (~100 customers)
- Every contact costs $$x_{contact}$$
- Every conversion is worth $$x_{sale}$$

Goal: Maximize booked net revenue

Utilities

true positive value: $$x_{sale} - x_{contact}$$

false positive value: $$- x_{contact}$$

(prospects contacted who didn't convert)

Example 1: Sales

Identify and contact prospective customers

- Pool of 10,000 customers
  - Conversion rate 1% (~100 customers)
- Every contact costs $$x_{contact}$$
- Every conversion is worth $$x_{sale}$$

Goal: Maximize booked net revenue

Utilities

true positive value: $$x_{sale} - x_{contact}$$

false positive value: $$- x_{contact}$$

true negative value: 0

(not contacted, wouldn't have converted)

false negative value: -0.01

(not contacted, would have converted)

Example 2: Medical Screening

Screening for a rare but serious condition

- ~1% prevalence (~100 out of 10,000 subjects)
- Test costs $T
- Follow-up costs $F
- Early treatment costs $$x_{early_treat}$
- Late treatment costs $$x_{late_treat} >> x_{early_treat}

Goal: minimize overall cost
= maximize (negative) value

Example 2: Medical Screening

Screening for a rare but serious condition

- ~1% prevalence (~100 out of 10,000 subjects)
- Test costs $T
- Follow-up costs $F
- Early treatment costs $$x_{early_treat}$
- Late treatment costs $$x_{late_treat}$ >> $$x_{early_treat}$

Goal: minimize overall cost
= maximize (negative) value

Utilities

true positive value: -(T + F + x_{early_treat})

(subject caught early)

Example 2: Medical Screening

Screening for a rare but serious condition

- ~1% prevalence (~100 out of 10,000 subjects)
- Test costs $T
- Follow-up costs $F
- Early treatment costs $$x_{early_treat}$
- Late treatment costs $$x_{late_treat}$ >> $$x_{early_treat}$

Goal: minimize overall cost
= maximize (negative) value

Utilities

true positive value: $-(T + F + x_{early\_treat})$

false positive value: -(T + F)

(subjects who mistakenly screen positive)

Example 2: Medical Screening

Screening for a rare but serious condition

- ~1% prevalence (~100 out of 10,000 subjects)
- Test costs $T
- Follow-up costs $F
- Early treatment costs $$x_{early_treat}$
- Late treatment costs $$x_{late_treat}$ >> $$x_{early_treat}$

Goal: minimize overall cost
= maximize (negative) value

Utilities

true positive value: $-(T + F + x_{early\_treat})$

false positive value: $-(T + F)$

true negative value: -T

(subjects who correctly screen negative)

Example 2: Medical Screening

Screening for a rare but serious condition

- ~1% prevalence (~100 out of 10,000 subjects)
- Test costs $T
- Follow-up costs $F
- Early treatment costs $$x_{early_treat}$
- Late treatment costs $$x_{late_treat}$ >> $$x_{early_treat}$

Goal: minimize overall cost
= maximize (negative) value

Utilities

true positive value: $-(T + F + x_{early\_treat})$

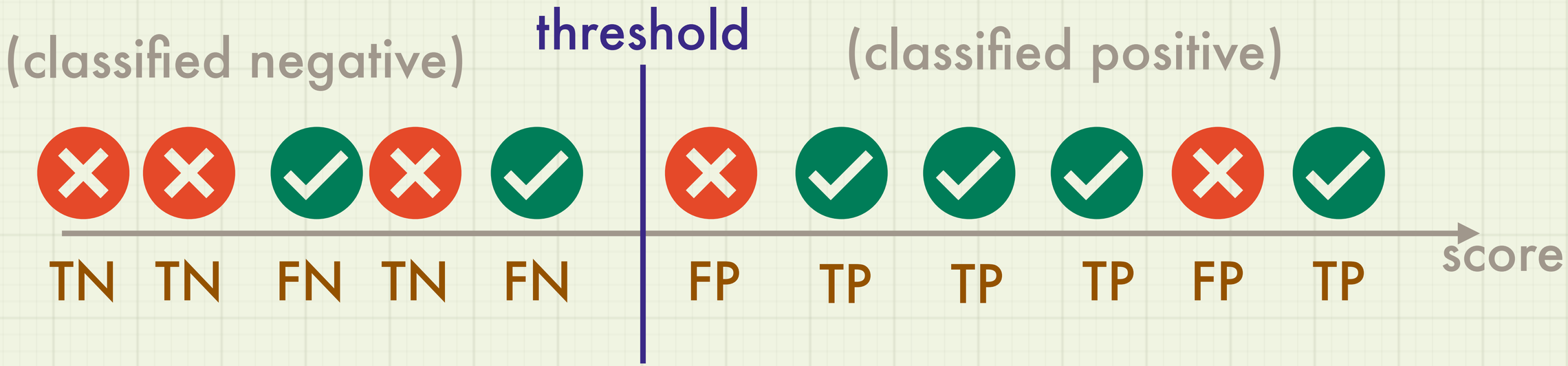
false positive value: $-(T + F)$

true negative value: $-T$

false negative value: $-(T + x_{late\_treat})$

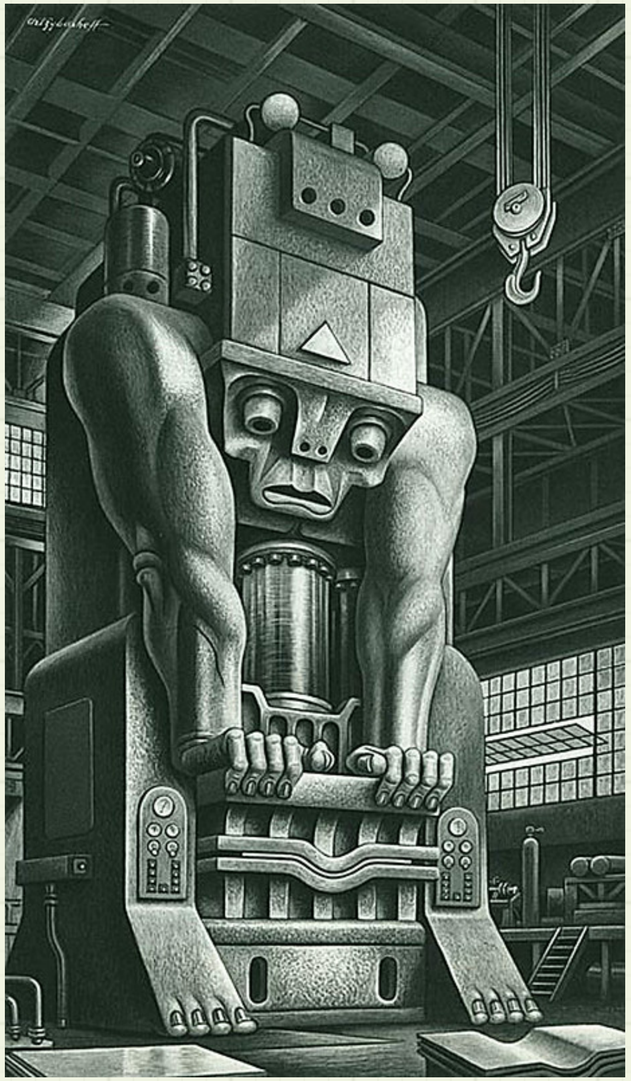
(subjects we missed in early screening)

Calculating Total Utility



utility = 3*TN_v + 2*FN_v + 2*FP_v + 4*TP_v

Optimal threshold: maximizes total utility



Let's Do It!

Illustration by Boris Artzybasheff. Source: https://www.flickr.com/photos/x-ray_delta_one/4140093007/

Back to Sales Example

`head(d)`

converted	predicted_probability
FALSE	0.0040164
FALSE	0.0199652
FALSE	0.0132867
FALSE	0.0051605
FALSE	0.0038753
FALSE	0.0057591

cost of call: $5
value of sale: $100
missed opportunity: -$0.01

```
(prevalence = mean(d$converted))
## [1] 0.0106

d$true_positive_value <- 100 - 5
                        # conversion - cost
d$false_positive_value <- -5
                        # the cost of a call
d$true_negative_value <-  0
d$false_negative_value <- -0.01
                      # a small penalty
```

Calculate model utility

```
library(sigr)
values <- model_utility(
              d,
              model_name = 'predicted_probability',
                  # column of scores
              outcome_name = 'converted')
                  # actual outcomes
```

`sigr::model_utility()` returns
a data frame of utility calculations
as a function of threshold

Calculate model utility

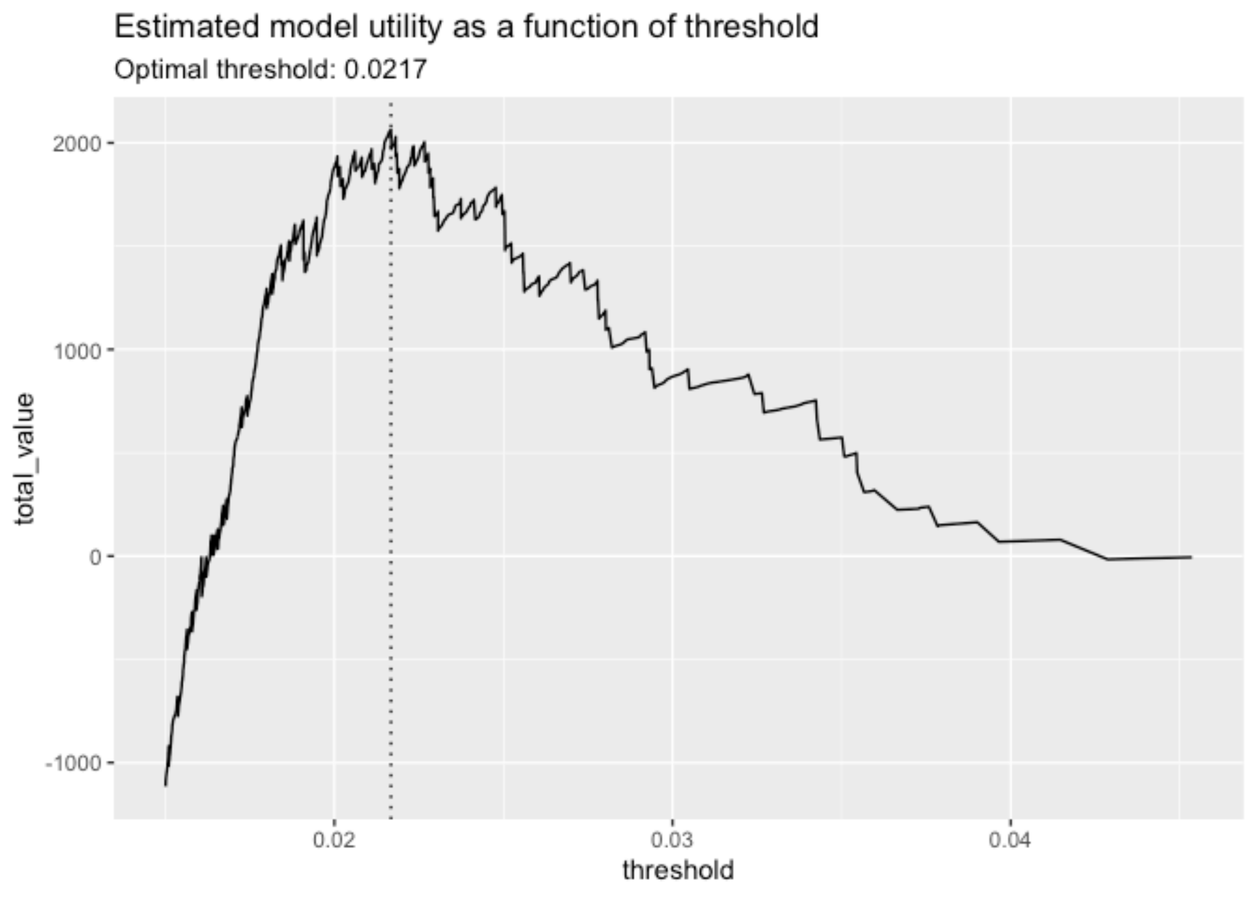
```
library(sigr)
values <- model_utility(
              d,
              model_name = 'predicted_probability',
                  # column of scores
              outcome_name = 'converted')
                  # actual outcomes
```

model	predicted_probability
threshold	**0.01493523**
count_taken	**1751**
fraction_taken	0.1751
true_positive_value	7125
false_positive_value	-8380
true_negative_value	0
false_negative_value	-0.31
total_value	**-1255.31**
true_negative_count	8218
false_negative_count	31
true_positive_count	75
false_positive_count	1676

threshold: 0.015

- contact 1751 prospects (of 10,000)
- 75 conversions (of 106 possible)
- earned $7125, spent $8380
- **total utility -$1255.31**

Utility as a function of threshold



threshold	0.021672
count_taken	**427.000000**
true_positive_count	42.000000
false_positive_count	385.000000
true_negative_count	9509.000000
false_negative_count	64.000000
fraction_taken	0.042700
total_value	**2064.360000**

Comparing to Best Possible Performance

Our model realized 2064/10070 = 20.1% of best possible

```
# add a column for the wizard model
d$wizard <- with(d, ifelse(converted, 1.0, 0.0))

# calculate the wizard's model utilities
wizard_values <- model_utility(d,
                               model_name = 'wizard',
                               outcome_name = 'converted')
```

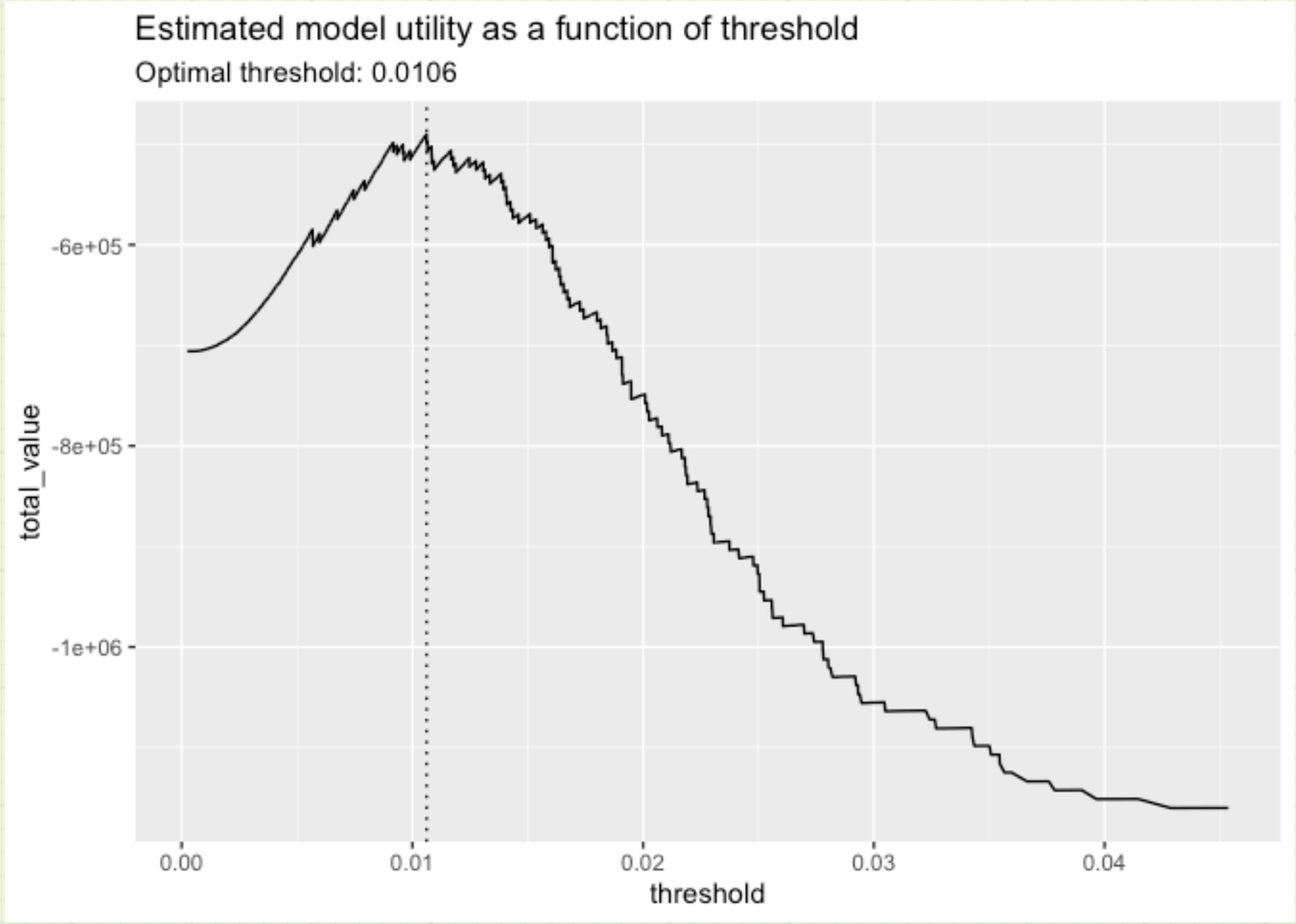
threshold	count_taken	fraction_taken	total_value	
0.0	10000	1.0000	-39400.00	(contact everyone)
0.5	**106**	**0.0106**	**10070.00**	**(contact exactly the right prospects)**
NA	0	0.0000	-1.06	(contact no one)

Medical Screening Example

```
x_test = 10
x_follow_up = 50
x_early_treatment = 1000
x_late_treatment = 10000

d$true_positive_value <- -(x_test + x_follow_up + x_early_treatment)
d$false_positive_value <- -(x_test + x_follow_up)
d$true_negative_value <-  -x_test
d$false_negative_value <-  -(x_test + x_late_treatment)
```

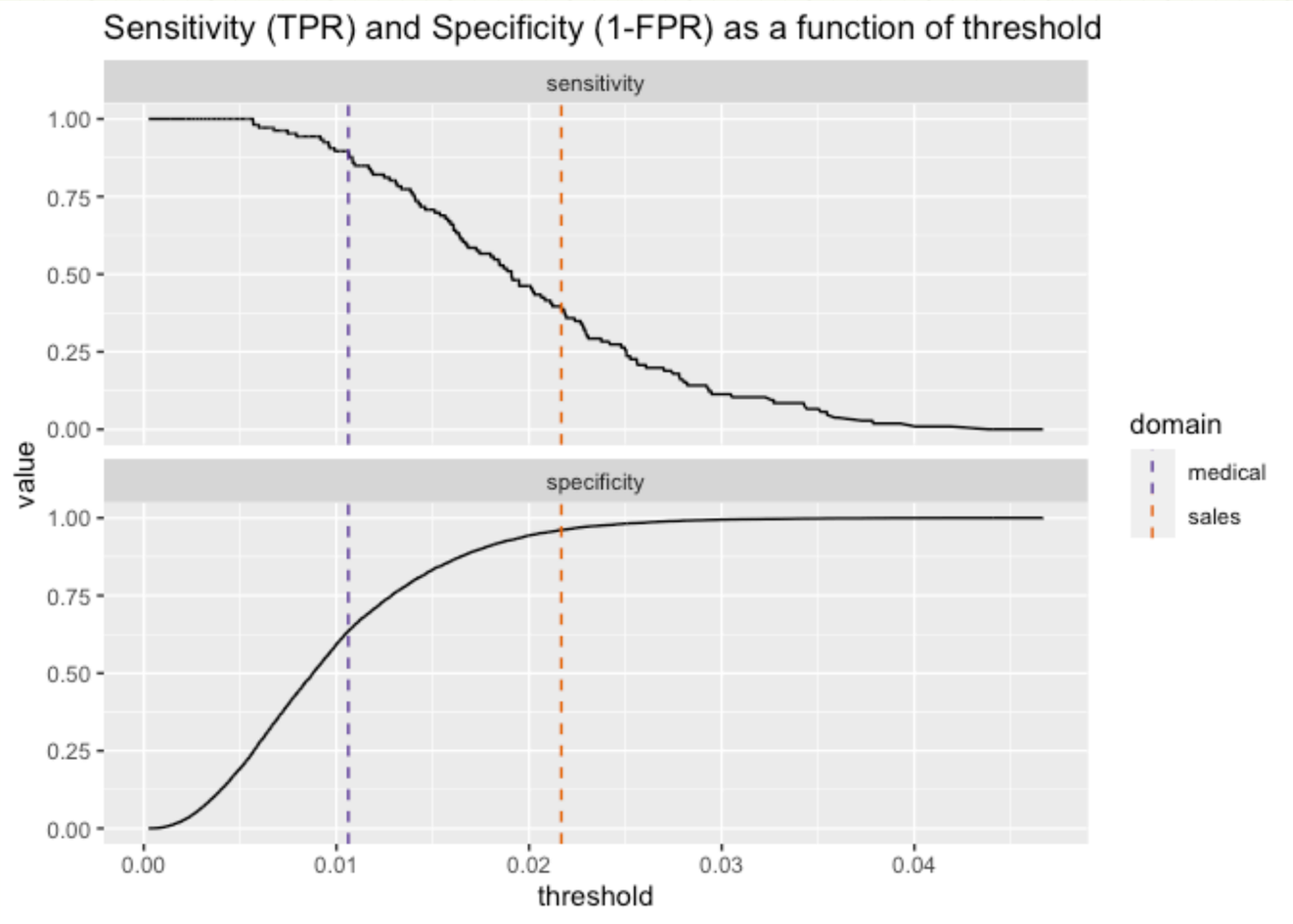
Find the Best Threshold



threshold	1.06178E-02
count_taken	3704
true_positive_count	95
false_positive_count	3609
true_negative_count	6285
false_negative_count	11
fraction_taken	0.03704
total_value	-490200

Lowest possible cost: $211,300

Same Model Performance, Different Operational Goals



Medical:

High sensitivity important

False Negatives expensive

Sales:

Higher specificity preferred

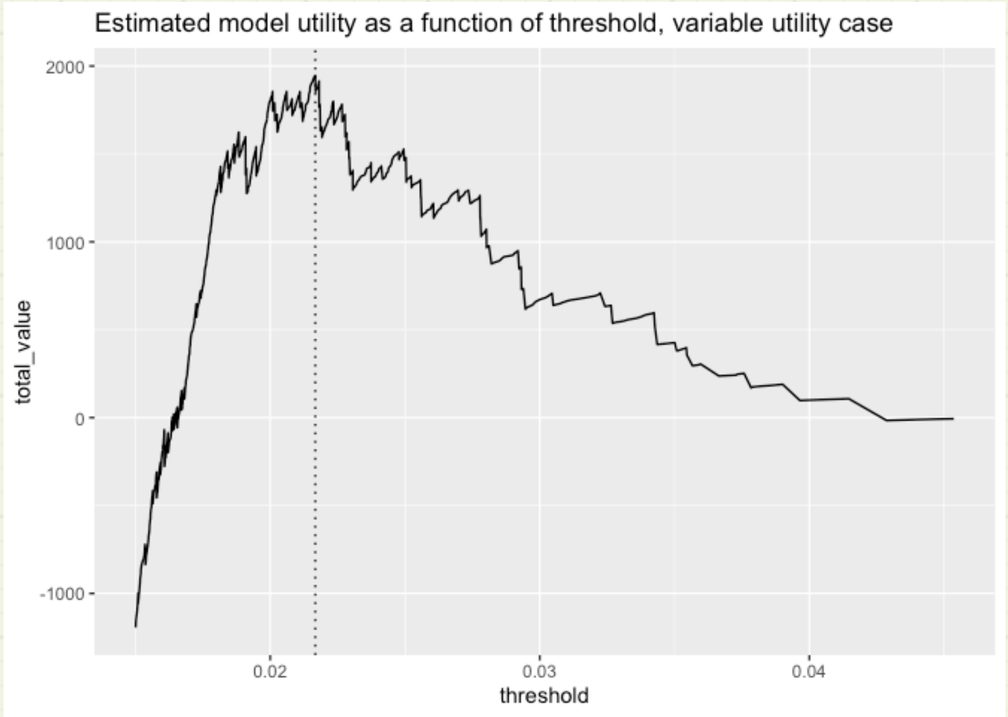
False Positives add up

Advanced: Variable Utilities

```
d$false_positive_value <- -5        # the cost of a call
d$true_negative_value <-  0
d$false_negative_value <- -0.01     # a small penalty

# replace the true positive value with a varying value
d$true_positive_value <- rnorm(nrow(d), mean = 100, sd = 25) - 5    # revenue - cost

values <- model_utility(d,
                        model_name = 'predicted_probability',
                        outcome_name = 'converted')
```



Takeaways

- Accuracy metrics don't always express how (or whether) a model meets operational goals
- Utilities express model performance in "operational units" (e.g. $)
  - Quantify tradeoffs between false positives and missed opportunities
- Somewhat more intuitive way to elicit performance goals from stakeholders and business partners

Illustration from https://www.slideshare.net/pattygutierrez927980/microeconomics-13841011

Thank You