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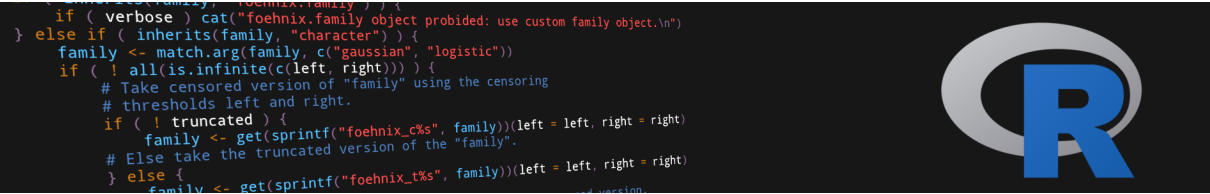

Tree Models for Assessing Covariate-Dependent Method Agreement

Siranush Karapetyan, Alexander Hapfelmeier, Achim Zeileis

https://github.com/Hapfelmeier/coat

Motivation

Goal: Assess agreement of measurements made by two (or more) methods.

Bland-Altman plot: Classic technique visualizing *limits of agreement* for differences vs. means of measurements.

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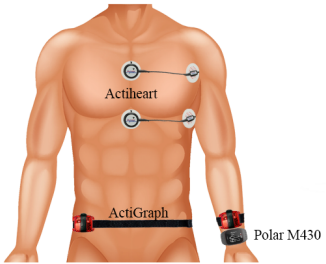
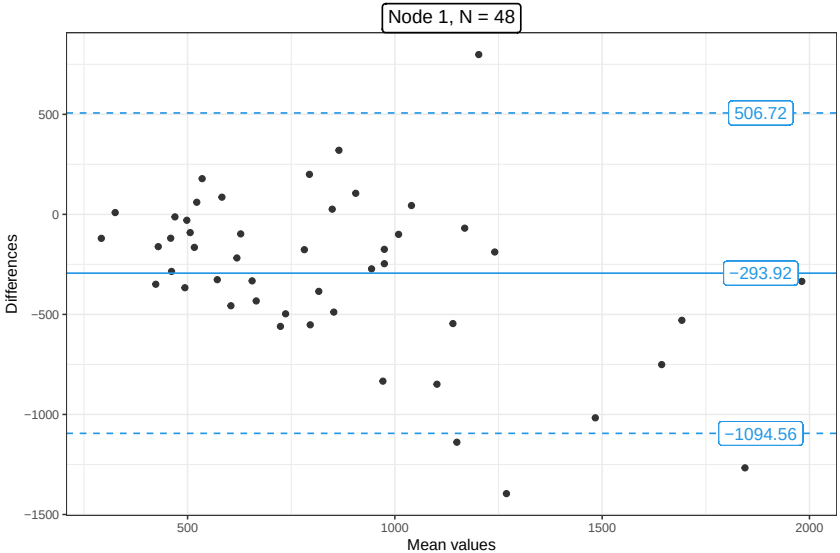
Illustration: Activity energy expenditure (AEE, in kilocalories) in 24 hours, measured by two different accelerometers (ActiGraph vs. Actiheart).

Source: Henriksen *et al.* (2019). "Validity of the Polar M430 Activity Monitor in Free-Living Conditions: Validation Study." *JMIR Formative Research*.



Motivation


Node 1, N = 48
506.72
−293.92
−1094.56
Differences
Mean values
500
0
−500
−1000
−1500
500
1000
1500
2000

Motivation

Up to now: One-fits-all paradigm in method comparison studies.

Question: Does method agreement depend on external or internal factors?

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Furthermore: Trend by mean level of agreement?

```
R> head(activity, 4)
  ActiGraph ActiheartA ActiheartB Gender Height Weight Age DominantHand Technician
1    1062.2       1086       1018 Female    166     63  39        Right      Laila
2     519.9       1182       1072 Female    166     59  57         Left      Laila
3    1268.1       2033       2019   Male    176     75  56        Right      Laila
4     571.3       1542       1967   Male    182    103  39        Right      Andre
```

Conditional method agreement

Idea: Explore covariate dependency of limits of agreement by recursive partitioning (trees).

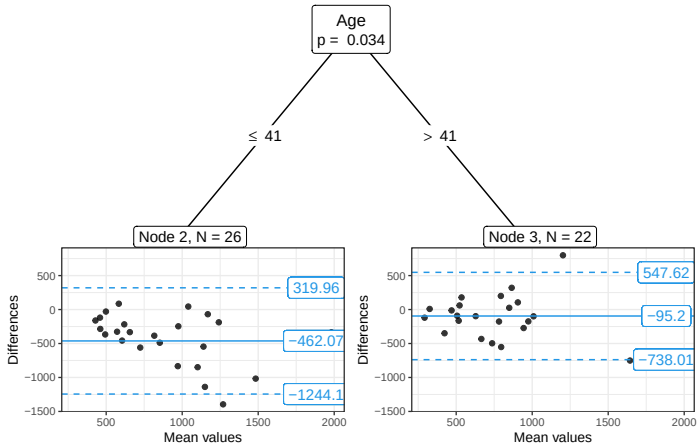
New method: Conditional method agreement trees (COAT).

Base model: Bland-Altman. Estimate mean and variance of measurement differences $Y = M_1 - M_2$.

Implementation: R package *coat*, based on *partykit*, available from GitHub and soon CRAN.

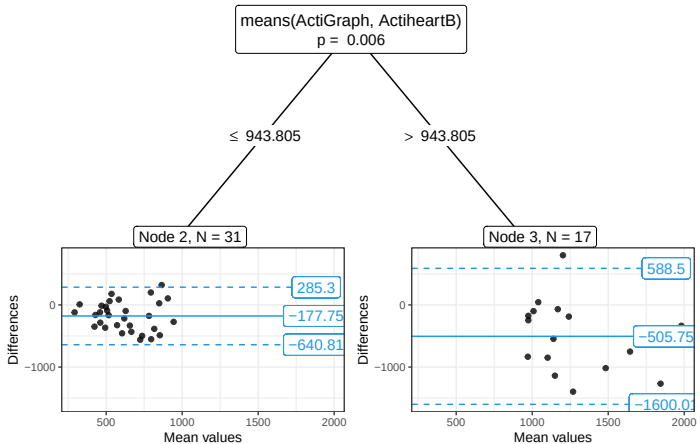
Conditional method agreement

```
R> tree1 <- coat(ActiGraph + ActiheartB ~ Gender + Height + Weight + Age +
+    DominantHand + Technician, data = activity, minbucket = 15)
R> autoplot(tree1)
```



Conditional method agreement

```
R> tree2 <- coat(ActiGraph + ActiheartB ~ Gender + Height + Weight + Age +
+    DominantHand + Technician, data = activity, minbucket = 15, means = TRUE)
R> autoplot(tree2)
```



Conditional method agreement

Algorithm:

1. A model is fit to the entire data by optimizing some objective function or a transformation function is defined.
2. A split variable is selected based on the association of some goodness-of-fit measure with each possible variable. The variable with the highest significant association is selected.
3. A split point is chosen so the goodness-of-fit is maximized in the resulting subsets.
4. Steps 1–3 are repeated until no more significant associations are found or the resulting sample is too small for further splits.

Conditional method agreement

Flavors: COAT based on conditional inference trees (CTree) vs. model-based recursive partitioning (MOB).

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CTree-based:

- *Nonparametric transformation:* Measurement differences and corresponding squared residuals.
- *Equivalent to:* Parametric maximum likelihood scores for mean and variance in normally distributed model.
- *Tests:* Asymptotic permutation tests.

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CTree-based:

- *Nonparametric transformation:* Measurement differences and corresponding squared residuals.
- *Equivalent to:* Parametric maximum likelihood scores for mean and variance in normally distributed model.
- *Tests:* Asymptotic permutation tests.

MOB-based:

- *Goodness of fit:* Maximum likelihood scores for mean and variance in normally distributed model.
- *Tests:* Asymptotic parameter instability tests (fluctuation tests).

Conditional method agreement

Details: Tests in COAT (CTree).

```
R> sctest(tree2, node = 1)
          Gender Height Weight      Age DominantHand Technician
statistic 0.8363 0.5861 2.7550 10.33618       1.1945     1.6932
p.value   0.9995 0.9999 0.8692  0.03919       0.9963     0.9802
          means(ActiGraph, ActiheartB)
statistic                    14.105662
p.value                       0.006039
```

Conditional method agreement

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          means(ActiGraph, ActiheartB)
statistic                    14.105662
p.value                       0.006039

R> sctest(tree2, node = 2)
          Gender Height Weight    Age DominantHand Technician
statistic 1.3391 4.2119 0.2114 3.2824       0.3686     3.3210
p.value   0.9934 0.5969 1.0000 0.7785       1.0000     0.7713
          means(ActiGraph, ActiheartB)
statistic                       7.7676
p.value                         0.1354
```

Simulation study

Comparison: Performance of three tree models.

- CTree for measurement differences only ($Y = M_1 - M_2$).
- COAT based on CTree.
- COAT based on MOB.

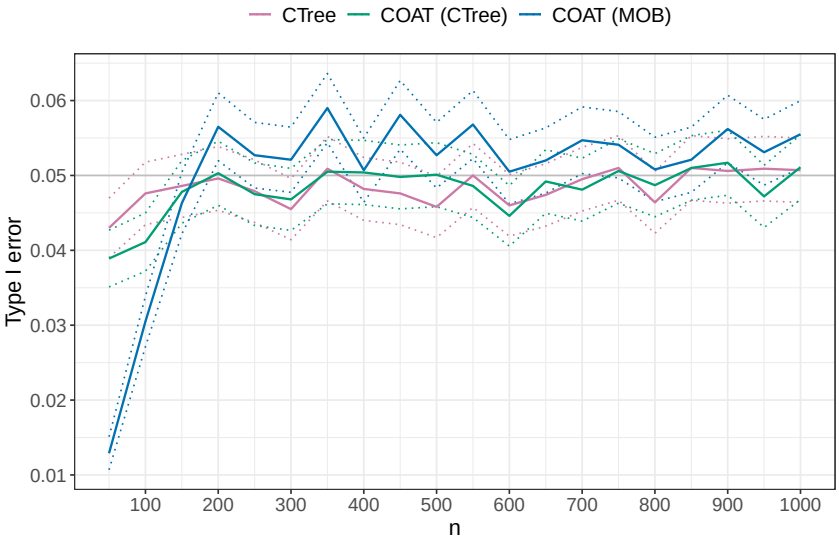
Measurements: $M_j \sim \mathcal{N}(\mu_j, \sigma_j^2)$ for $j = 1, 2$.

Split variables: $X_1, \ldots, X_5 \sim \mathcal{N}(0, 1)$ independently.

Sample sizes: $n = 50, 100, \ldots, 1\,000$.

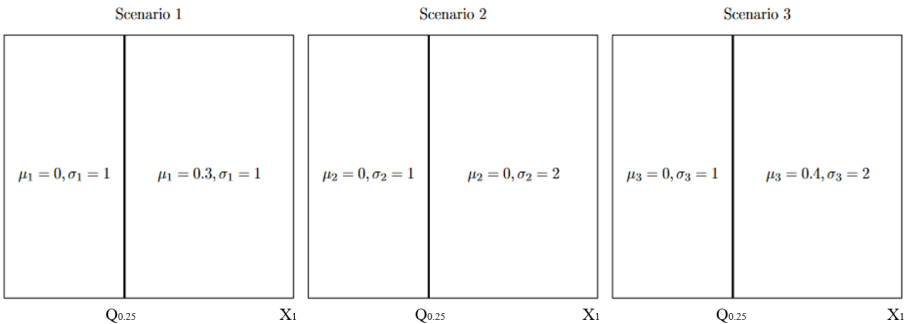
Replications: $10\,000$.

Simulation study: Null

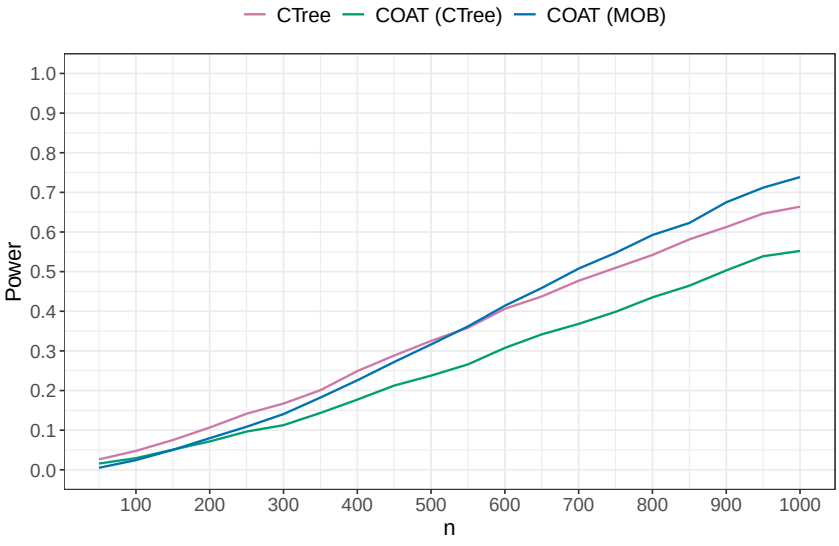


Simulation study: Stump

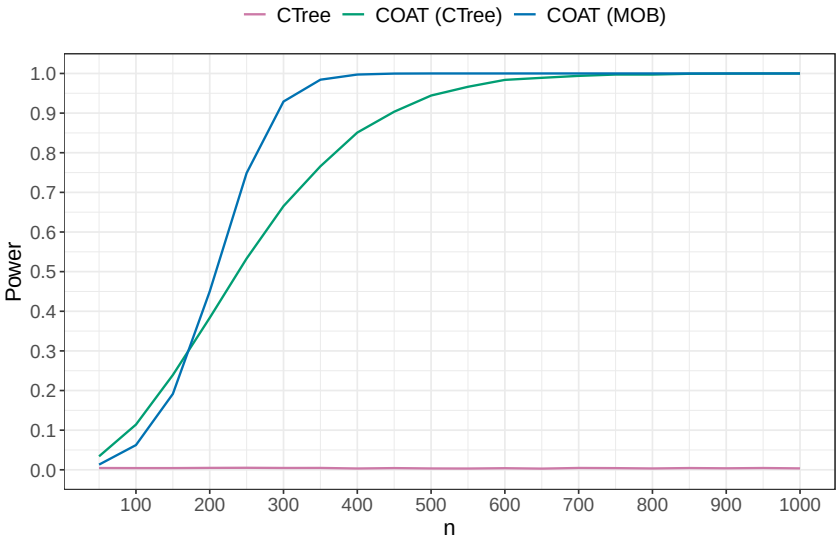
Stump scenarios: Power to detect split in one variable.



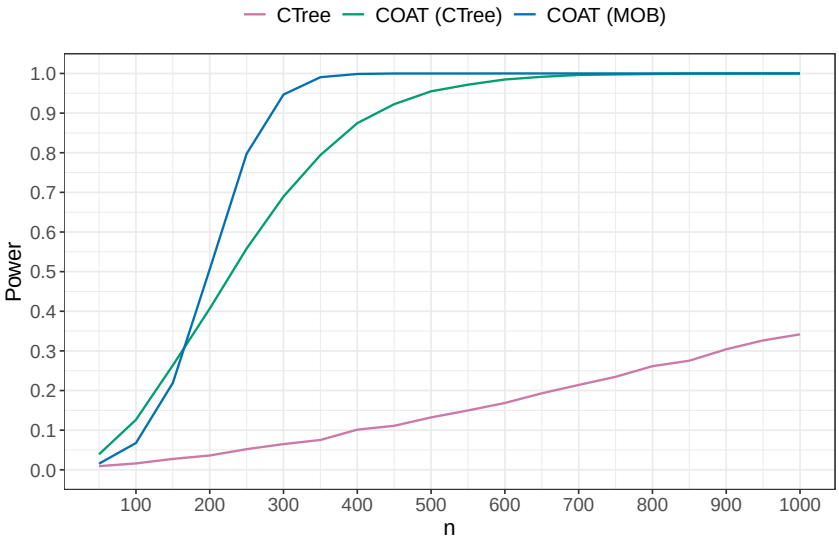
Simulation study: Stump 1



Simulation study: Stump 2

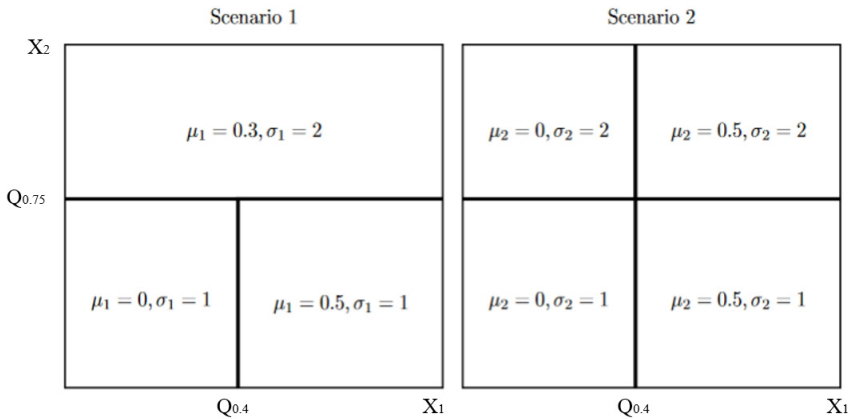


Simulation study: Stump 3

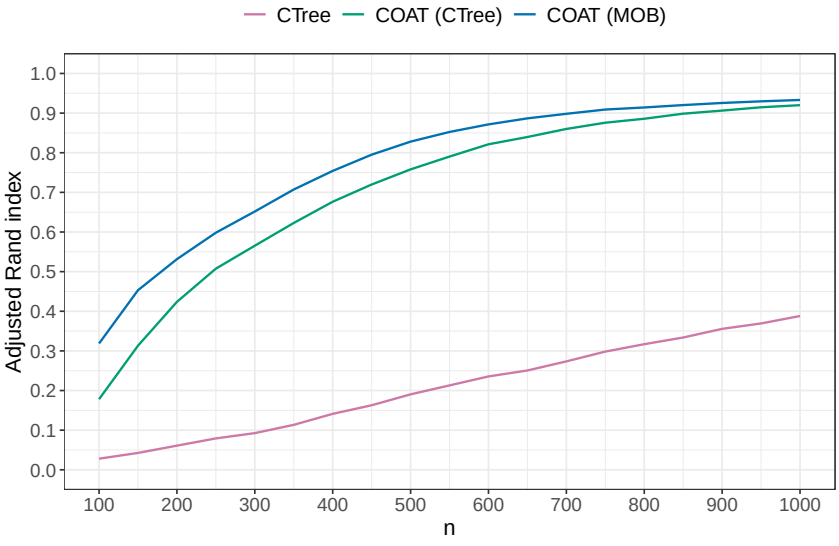


Simulation study: Tree

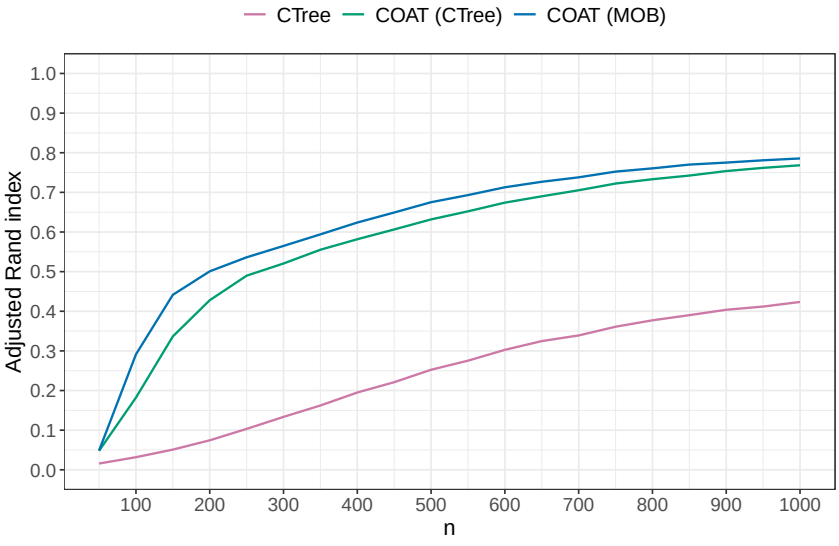
Tree scenarios: Adjusted Rand index to recover partition in two variables.



Simulation study: Tree 1



Simulation study: Tree 2



References

Karapetyan S, Zeileis A, Henriksen A, Hapfelmeier A (2023). “Tree Models for Assessing Covariate-Dependent Method Agreement.” *arXiv.org E-Print Archive*, arXiv:2306.04456. doi:10.48550/arXiv.2306.04456

Henriksen A, Grimsgaard S, Horsch A, Hartvigsen G, Hopstock L (2019). “Validity of the Polar M430 Activity Monitor in Free-Living Conditions: Validation Study.” *JMIR Formative Research*, **3**(3):e14438. doi:10.2196/14438

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