

VIII. SUPPLEMENTARY MATERIAL

A. Dataset: Adult; Algorithm: FOLD-SE

Negative Decision: $\leq 50K$

Features and Feature Values used:

- Feature: marital_status
 - 1) married_civ_spouse
 - 2) never_married
- Feature: relationship
 - 1) husband
 - 2) wife
 - 3) unmarried
- Feature: sex
 - 1) male
 - 2) female
- capital_gain: [0, 99999]
- education_num: [1, 16]
- age: [17, 90]

1) Decision Rules: We run the FOLD-SE algorithm to produce the following decision making rules:

```
label(X, '<=50K') :-  
    not marital_status(X, 'Married-civ-spouse'),  
    capital_gain(X, N1), N1=<6849.0.
```

```
label(X, '<=50K') :-  
    marital_status(X, 'Married-civ-spouse'),  
    capital_gain(X, N1), N1=<5013.0,  
    education_num(X, N2), N2=<12.0.
```

- Accuracy: 84.5%
- Precision: 86.5%
- Recall: 94.6%

2) Causal Rules: a) FOLD-SE gives Causal rules for the 'marital_status' feature having value 'never_married':

```
marital_status(X, 'Never-married') :-  
    not relationship(X, 'Husband'),  
    not relationship(X, 'Wife'),  
    age(X, N1), N1=<29.0.
```

- Accuracy: 86.4%
- Precision: 89.2%
- Recall: 76.4%

b) FOLD-SE gives Causal rules for the 'marital_status' feature having value 'Married-civ-spouse':

```
marital_status(X, 'Married-civ-spouse') :-  
    relationship(X, 'Husband').  
marital_status(X, 'Married-civ-spouse') :-  
    relationship(X, 'Wife').
```

- Accuracy: 99.1%
- Precision: 99.9%
- Recall: 98.2%

c) For values of the feature 'marital_status' that are not 'Married-civ-spouse' or 'never_married' which we shall call 'neither', a user defined rule is used

```
marital_status(X, neither) :-  
    not relationship(X, 'Husband'),  
    not relationship(X, 'Wife').
```

d) FOLD-SE gives Causal rules for the 'relationship' feature having value 'husband':

```
relationship(X, 'Husband') :-  
    not sex(X, 'Male'), age(X, N1), not (N1=<27.0).
```

- Accuracy: 82.3%
- Precision: 71.3%
- Recall: 93.2%

e) For the 'relationship' feature value of 'wife', a user defined rule is used

```
relationship(X, 'Wife') :- sex(X, 'Female').
```

B. Dataset: Adult; Algorithm: RIPPER

Negative Decision: $\leq 50K$

Features and Feature Values used:

- Feature: marital_status
 - 1) married_civ_spouse
 - 2) never_married
 - 3) divorced
- Feature: relationship
 - 1) husband
 - 2) wife
 - 3) own_child
 - 4) not_in_family
 - 5) unmarried
- Feature: education
 - 1) hs_grad
 - 2) some_college
- Feature: occupation
 - 1) farming_fishing
 - 2) adm_clerical
 - 3) machine_op_inspct
 - 4) other_service
- Feature: workclass
 - 1) never_worked
 - 2) private
- Feature: native_country
 - 1) japan
 - 2) united_States
- Feature: sex
 - 1) male
 - 2) female
- capital_gain: [0, 99999]
- education_num: [1, 16]
- age: [17, 90]
- hours_per_week: [1, 99]
- capital_loss: [0, 4356]

1) Decision Rules: We run the RIPPER algorithm to produce the following decision making rules:

```
[[marital_status=never_married ^  
    relationship=own_child ^ age=<22.0.]V  
[marital_status=never_married  
^ capital_gain =< 9999.9. ]V  
[relationship=not_in_family ^
```

```

capital_gain =< 9999.9 ^ education_num
>= 7.0, education_num =< 9.0 ^
hours_per_week >= 35.0, hours_per_week
=< 40.0 ^ age >= 26.0, age =<
30.0.]V [relationship=not_in_family ^
capital_gain =< 9999.9 ^ education_num
>= 7.0, education_num =< 9.0 ^
sex=Female.]V [relationship=not_in_family
^ capital_gain =< 9999.9 ^
education=some_college ^ sex=Female
^ occupation=adm_clerical.]V
[relationship=not_in_family ^
capital_gain =< 9999.9 ^ hours_per_week
>= 35.0, hours_per_week =< 40.0
^ age >= 22.0, age =< 26.0.]V
[relationship=not_in_family
^ capital_gain =< 9999.9 ^
education_num >= 7.0, education_num
=< 9.0 ^ workclass=private ^
occupation=machine_op_inspct.]V
[relationship=not_in_family
^ capital_gain =< 9999.9 ^
education_num =< 7.0 ^ sex=Female.]V
[relationship=not_in_family
^ capital_gain =< 9999.9 ^
education=some_college ^
occupation=other_service.]V
[relationship=unmarried.]V
[relationship=not_in_family ^
capital_gain =< 9999.9 ^ hours_per_week
>= 35.0, hours_per_week =< 40.0 ^
education_num >= 7.0, education_num =<
9.0.]V [relationship=not_in_family ^
capital_gain =< 9999.9 ^ age >= 26.0,
age =< 30.0 ^ hours_per_week >= 35.0,
hours_per_week =< 40.0.]V [education_num
=< 7.0.]V [relationship=not_in_family ^
capital_gain =< 9999.9 ^ hours_per_week
>= 25.0, hours_per_week =< 35.0 ^
workclass=private ^ sex=Female.
]V [relationship=not_in_family ^
capital_gain =< 9999.9 ^ hours_per_week
=< 25.0 ^ capital_loss =< 435.6
^ native_country=united_States
^ workclass=private.]V
[marital_status=divorced ^ capital_gain
=< 9999.9 ^ hours_per_week >=
35.0, hours_per_week =< 40.0
^ education=some_college.]V
[education_num >= 7.0, education_num
=< 9.0 ^ marital_status=divorced ^
relationship=own_child.]V [education_num
>= 7.0, education_num =< 9.0 ^
occupation=other_service ^ age >= 37.0,
age =< 41.0.]V [education_num >= 7.0,
education_num =< 9.0 ^ age >= 26.0, age

```

=< 30.0.

- Accuracy: 72.42%
- Precision: 94.33%
- Recall: 67.74%

2) *Causal Rules*: Due to the low precision and recall for causal rules we obtain, we use the causal rules of FOLD-SE as described in Section VIII-A2 to denote the causal dependency while using the decision making rule of RIPPER

C. Dataset: Titanic; Algorithm: FOLD-SE

Negative Decision: 0 (perished)

Features and Feature Values used:

- Feature: gender
 - 1) male
 - 2) female
- Feature: class
 - 1) 1
 - 2) 2
 - 3) 3

1) *Decision Rules*: We run the FOLD-SE algorithm to produce the following rules:

```

survived(X, '0') :- not sex(X, 'female') .
survived(X, '0') :-
  class(X, '3'), sex(X, 'female') ,
  fare(X, N1), not (N1=<23.25) .

```

The rules described above indicate if someone perished or not.

- Accuracy: 98.6%
- Precision: 97.8%
- Recall: 100%

D. Dataset: Titanic; Algorithm: RIPPER

Negative Decision: 0 (perished)

Features and Feature Values used:

- Feature: gender
 - 1) male
 - 2) female

1) *Decision Rules*: We run the RIPPER algorithm to produce the following rules:

```

[[ sex = male ]]

```

The rules described above indicate if someone perished or not.

- Accuracy: 87.4%
- Precision: 89.15%
- Recall: 90.79%

E. Dataset: Cars; Algorithm: FOLD-SE

We relabel the dataset to 'positive' and 'negative' where 'negative' refers to used cars that are unacceptable for purchase.

Negative Decision: negative (reject/ used car is unacceptable for purchase)

Features and Feature Values used:

- Feature: persons
 - 1) 2

- 2) 4
- 3) more
- Feature: safety
 - 1) low
 - 2) med
 - 3) high
- Feature: buying
 - 1) low
 - 2) med
 - 3) high
 - 4) vhigh
- Feature: maint
 - 1) low
 - 2) med
 - 3) high
 - 4) vhigh

1) *Decision Rules:* We run the FOLD-SE algorithm to produce the following rules:

```
label(X, 'negative') :- persons(X, '2').
label(X, 'negative') :- safety(X, 'low').
label(X, 'negative') :- buying(X, 'vhigh'),
    maint(X, 'vhigh').
label(X, 'negative') :- not buying(X, 'low'),
    not buying(X, 'med'), maint(X, 'vhigh').
label(X, 'negative') :- buying(X, 'vhigh'),
    maint(X, 'high').
```

The rules described above indicate if the purchase of a car was rejected .

- Accuracy: 93.9%
- Precision: 100%
- Recall: 91.3%

F. Dataset: Cars; Algorithm: RIPPER

We relabel the dataset to 'positive' and 'negative' where 'negative' refers to used cars that are unacceptable for purchase.

Negative Decision: negative (reject/ used car is unacceptable for purchase)

Features and Feature Values used:

- Feature: persons
 - 1) 2
 - 2) 4
 - 3) more
- Feature: safety
 - 1) low
 - 2) med
 - 3) high
- Feature: buying
 - 1) low
 - 2) med
 - 3) high
 - 4) vhigh
- Feature: maint
 - 1) low

- 2) med
- 3) high
- 4) vhigh
- Feature: lugboot
 - 1) small
 - 2) medium
 - 3) big
- Feature: doors
 - 1) 2
 - 2) 3
 - 3) 4
 - 4) more

1) *Decision Rules:* We run the RIPPER algorithm to produce the following rules:

```
[[persons=2] V
[safety=low] V
[buying=vhigh ^ maint=vhigh] V
[lugboot=small ^ safety=med ^
    buying=high] V
[maint=vhigh ^ buying=high] V
[buying=vhigh ^ maint=high] V
[lugboot=small ^ doors=2 ^ persons=more]
    V
[safety=med ^ lugboot=small ^
    buying=vhigh] V
[safety=med ^ maint=vhigh ^
    lugboot=small] V
[safety=med ^ doors=3 ^ persons=4 ^
    lugboot=med] V
[lugboot=small ^ safety=med ^
    maint=high ^ buying=med]]
```

The rules described above indicate if the purchase of a car was rejected .

- Accuracy: 99.13%
- Precision: 99.58%
- Recall: 99.17%

G. Dataset: Voting; Algorithm: FOLD-SE

Negative Decision: 'republican'

Features and Feature Values used:

- Feature: physician_fee_freeze
 - 1) yes
 - 2) no
- Feature: budget_resolution
 - 1) yes
 - 2) no
- Feature: handicapped_infants
 - 1) yes
 - 2) no
- Feature: synfuels_corporation_cutback
 - 1) yes
 - 2) no
- Feature: mx_missile
 - 1) yes
 - 2) no

1) *Decision Rules:* We run the FOLD-SE algorithm to produce the following rules:

```
label(X, 'republican') :-
    physician_fee_freeze(X, 'y'),
    not ab2(X, 'True').
ab1(X, 'True') :- budget_resolution(X, 'y'),
    not handicapped_infants(X, 'n').
ab2(X, 'True') :-
    synfuels_corporation_cutback(X, 'y'),
    not mx_missile(X, 'n'), not ab1(X, 'True').
```

The rules described above indicate if the vote was cast for a Republican.

- 1) Accuracy: 97.7%
- 2) Precision: 97%
- 3) Recall: 97%

H. Dataset: Voting; Algorithm: RIPPER

Negative Decision: 'republican'

Features and Feature Values used:

- Feature: physician_fee_freeze
 - 1) yes
 - 2) no
- Feature: synfuels_corporation_cutback
 - 1) yes
 - 2) no

1) *Decision Rules:* We run the RIPPER algorithm to produce the following rules:

```
[physician_fee_freeze=y ^
    synfuels_corporation_cutback=n] v
[physician_fee_freeze=y]
```

The rules described above indicate if the vote was cast for a Republican.

- Accuracy: 96.5%
- Precision: 94.2%
- Recall: 97.05%

I. Dataset: Mushroom; Algorithm: FOLD-SE

Negative Decision: 'p' (poisonous)

Features and Feature Values used:

- Feature: odor
 - 1) n
 - 2) f
- Feature: spore_print_color
 - 1) r
 - 2) b
- Feature: bruises
 - 1) f
 - 2) t
- Feature: stalk_root
 - 1) c
 - 2) r
 - 3) b
- Feature: gill_spacing
 - 1) c
 - 2) w

1) *Decision Rules:* We run the FOLD-SE algorithm to produce the following rules:

```
label(X, 'p') :- not odor(X, 'n'),
    not ab1(X, 'True'), not ab2(X, 'True'),
    not ab3(X, 'True').
label(X, 'p') :- spore_print_color(X, 'r').
ab1(X, 'True') :- not bruises(X, 'f'),
    stalk_root(X, 'c').
ab2(X, 'True') :- not bruises(X, 'f'),
    stalk_root(X, 'r').
ab3(X, 'True') :- not gill_spacing(X, 'c'),
    not bruises(X, 'f').
```

The rules described above indicate if a mushroom is poisonous.

- Accuracy: 99.8%
- Precision: 100%
- Recall: 99.6%

J. Dataset: Mushroom; Algorithm: RIPPER

Negative Decision: 'p' (poisonous)

Features and Feature Values used:

- Feature: odor
 - 1) f
 - 2) p
 - 3) c
- Feature: gill_size
 - 1) n
 - 2) b
- Feature: gill_color
 - 1) n
 - 2) b
- Feature: spore_print_color
 - 1) r
 - 2) b
- Feature: stalk_surface_below_ring
 - 1) y
 - 2) k
- Feature: stalk_surface_above_ring
 - 1) y
 - 2) k
- Feature: stalk_color_above_ring
 - 1) y
 - 2) c
- Feature: habitat
 - 1) l
 - 2) g
- Feature: cap_color
 - 1) e
 - 2) w

1) *Decision Rules:* We run the RIPPER algorithm to produce the following rules:

```
[odor=f] V
[gill-size=n ∧ gill-color=b] V
[gill-size=n ∧ odor=p] V
[odor=c] V
[spore-print-color=r] V
[stalk-surface-below-ring=y ∧
 stalk-surface-above-ring=k] V
[stalk-color-above-ring=y] V
[habitat=l ∧ cap-color=w]
```

The rules described above indicate if a mushroom is poisonous.

- Accuracy: 100%
- Precision: 100%
- Recall: 100%

K. Dataset: Dropout; Algorithm: FOLD-SE

Negative Decision: 'Dropout'

Features and Feature Values used:

- Feature: debtor
 - 1) 0
 - 2) 1
- Feature: course
 - 1) 171
 - 2) 33
- Feature: curricular_units_2nd_sem_grade - [0, 18.57]
- Feature: admission_grade - [95, 190]

1) *Decision Rules:* We run the FOLD-SE algorithm to produce the following rules:

```
label(X, 'Dropout') :-
  curricular_units_2nd_sem_grade(X, N1),
  N1 <= 10.667.
```

```
label(X, 'Dropout') :- not debtor(X, '1').
```

The rules described above indicate if someone is a dropout in college.

- Accuracy: 84%
- Precision: 74.9%
- Recall: 73.8%

L. Dataset: Dropout; Algorithm: RIPPER

Negative Decision: 'Dropout'

Features and Feature Values used:

- Feature: tuitionfeesuptodate
 - 1) 0
 - 2) 1
- Feature: debtor
 - 1) 0
 - 2) 1
- Feature: displaced
 - 1) 0
 - 2) 1
- Feature: scholarshipholder
 - 1) 0

2) 1

- Feature: curricularunits2ndsem_approved - [0, 20]
- Feature: applicationmode - [1, 57]
- Feature: curricularunits2ndsem_enrolled - [0, 23]
- Feature: curricularunits2ndsem_evaluations - [0, 33]
- Feature: course - [3, 9991]
- Feature: mothersqualification - [1, 44]
- Feature: fathersqualification - [1, 44]
- Feature: curricularunits2ndsem_approved - [0, 20]
- Feature: age_at_enrollment - [17, 70]
- Feature: admissiongrade - [95, 190]
- Feature: mothersoccupation - [0, 194]
- Feature: previousqualification - [95, 190]

M. Decision Rules

We run the RIPPER algorithm to produce the following rules:

```
[Curricularunits2ndsem-approved=<1.0 ∧
 Tuitionfeesuptodate=0 ∧ Debtor=0] V
[Curricularunits2ndsem-approved=<1.0 ∧
 Applicationmode=17.0-39.0] V
[Curricularunits2ndsem-approved=<1.0 ∧
 Curricularunits2ndsem-enrolled=5.0-6.0 ∧
 Curricularunits2ndsem-evaluations=<5.0]
V
[Curricularunits2ndsem-approved=<1.0 ∧
 Course=9238.0-9500.0] V
[Curricularunits2ndsem-approved=<1.0 ∧
 Displaced=0 ∧
 Curricularunits2ndsem-enrolled=5.0-6.0 ∧
 Mothersqualification=<3.0] V
[Curricularunits2ndsem-approved=<1.0 ∧
 Displaced=0 ∧
 Fathersqualification=19.0-37.0 ∧
 Mothersqualification=19.0-37.0] V
[Tuitionfeesuptodate=0 ∧
 Curricularunits2ndsem-approved=1.0-3.0]
V
[Curricularunits2ndsem-approved=<1.0 ∧
 Debtor=1 ∧
 Curricularunits2ndsem-evaluations=<5.0]
V
[Curricularunits2ndsem-approved=<1.0 ∧
 Displaced=0] V
[Curricularunits2ndsem-approved=1.0-3.0 ∧
 Curricularunits1stsem-approved=2.0-4.0 ∧
 Mothersqualification=19.0-37.0 ∧
 Ageatenrollment=>34.2] V
[Tuitionfeesuptodate=0 ∧
 Curricularunits1stsem-approved=2.0-4.0 ∧
 Mothersqualification=<3.0] V
[Tuitionfeesuptodate=0] V
[Curricularunits2ndsem-approved=1.0-3.0
∧
 Fathersqualification=19.0-37.0 ∧
 Admissiongrade=138.3-146.22] V
```

```
[Curricularunits2ndsem-approved=1.0-3.0 ^  
  Ageatenrollment=27.0-34.2] V  
[Curricularunits2ndsem-approved=1.0-3.0 ^  
  Applicationmode=17.0-39.0 ^  
  Mothersoccupation=3.0-4.0] V  
[Scholarshipholder=0 ^  
  Curricularunits1stsem-approved=2.0-4.0 ^  
  Curricularunits2ndsem-enrolled=5.0-6.0 ^  
  Previousqualification-grade=130.0-133.1]
```

The rules described above indicate if someone is a dropout in college.

- Accuracy: 84%
- Precision: 74.9%
- Recall: 73.8%