New Crossover Operator for Evolutionary Rule Discovery in XCS

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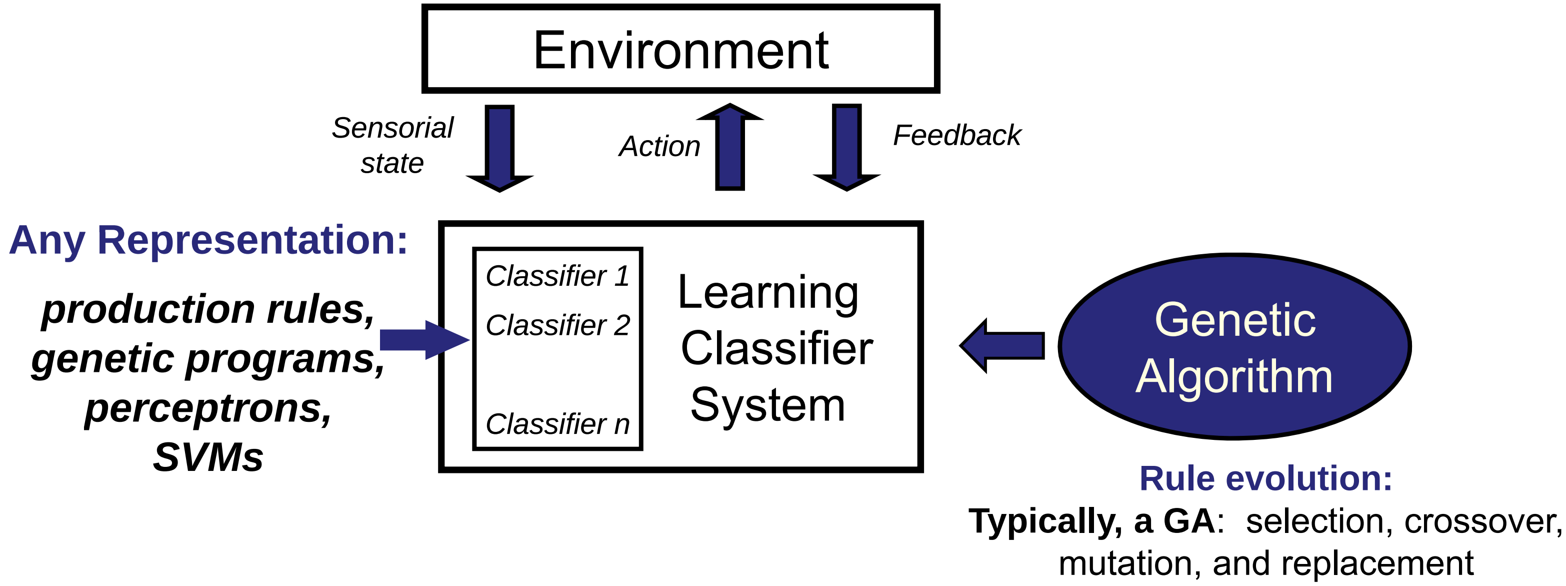
Framework

- **Michigan-style LCSs are mature learning techniques**

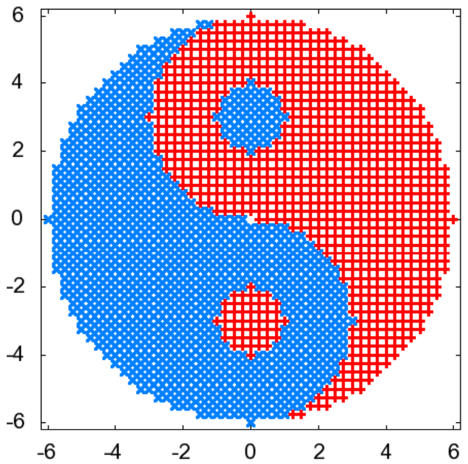


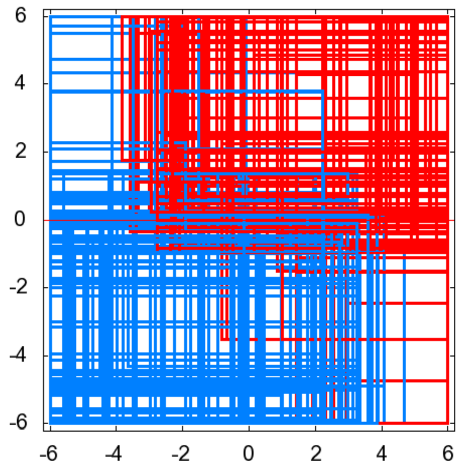
- **XCS (Wilson, 95, 98)**
  - **By far, the most influential LCS**

Motivation

Problems with continuous attributes

- Interval-based representation (Wilson, 2001)
- **IF** $v_1 \in [l_1, u_1]$ ***and*** $v_2 \in [l_2, u_2]$ ***and*** … ***and*** $v_n \in [l_n, u_n]$ **THEN** $class_i$





- **2-point crossover**
  - **Too disruptive?**
- **Mutation:** add a random uniform value
  - **Could we use more information?**

Could we design better genetic operators?

- Not exactly clear the impact of crossover and mutation
- Systematic analysis
- Creative analysis: propose new operators

Purpose of the Work

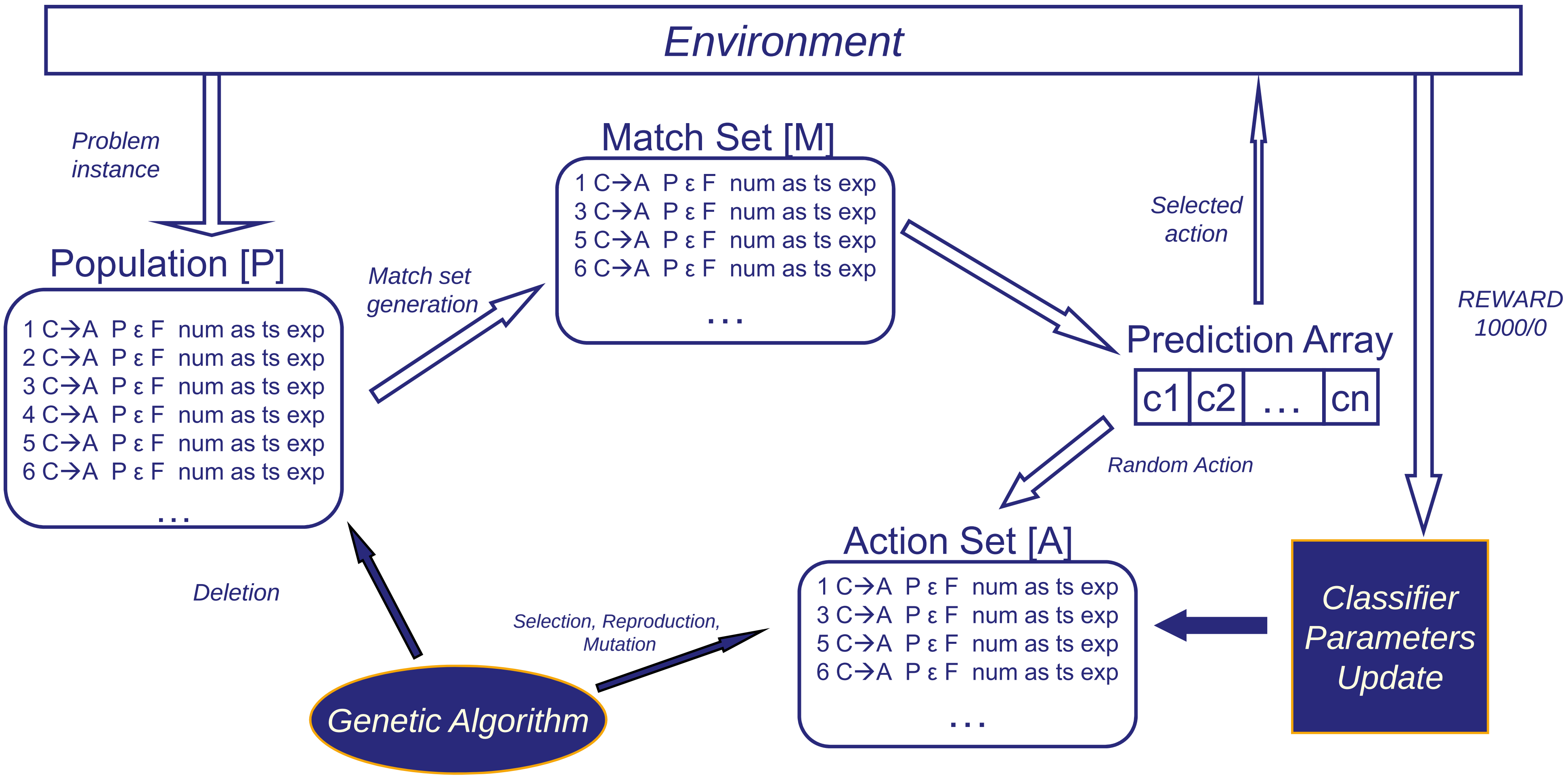
- **Previous work** **(Morales et al., 2008a)**
  - Design an XCS based on evolution strategies (ES)
  - Analyze the role of Gaussian mutation
  - **Conclusion:** **Gaussian mutation** (ES) enables XCS to approximate decision boundaries more accurately

- **The purpose of this work is to**
  - Design a new crossover operator, ***BLX crossover***, following the ideas observed in the ES-based XCS
  - Compare GA-based XCS and ES-based XCS with the new crossover operator.

Outline

1. Description of XCS
2. The New BLX Crossover Operator
3. Experimental Methodology
4. Results
5. Conclusions and Further Work

Description of XCS

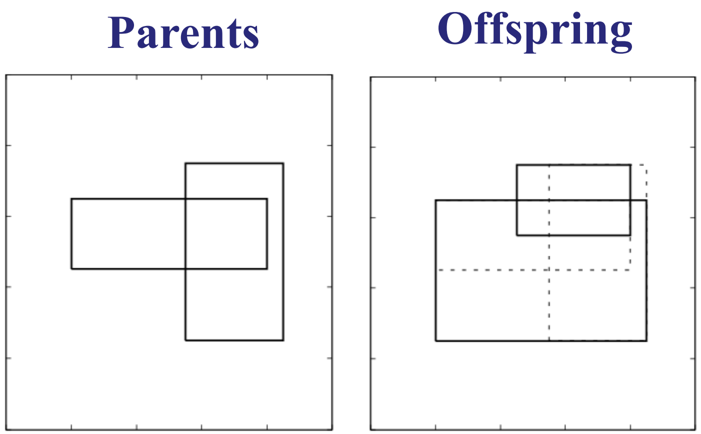


Genetic Operators

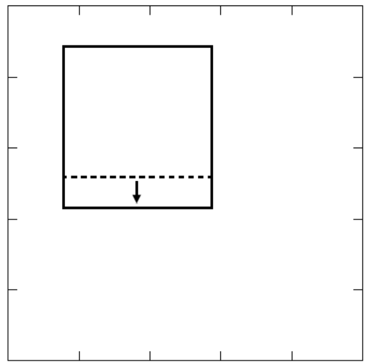
- **Selection**
  - Tournament selection
  - Proportionate selection
  - Truncation selection (ES)

- **Crossover:**
  - Two-point crossover

$$\begin{array}{l} <[0.20, 0.80], [0.45, 0.55]> \\ <[0.60, 0.85], [0.25, 0.75]> \end{array} \Longrightarrow \begin{array}{l} <[0.20, 0.85], [0.25, 0.55]> \\ <[0.60, 0.80], [0.45, 0.75]> \end{array}$$



- **Mutation:**
  - **GA-based XCS:** Add a uniform random value
  - **ES-based XCS:** Add a Gaussian random value



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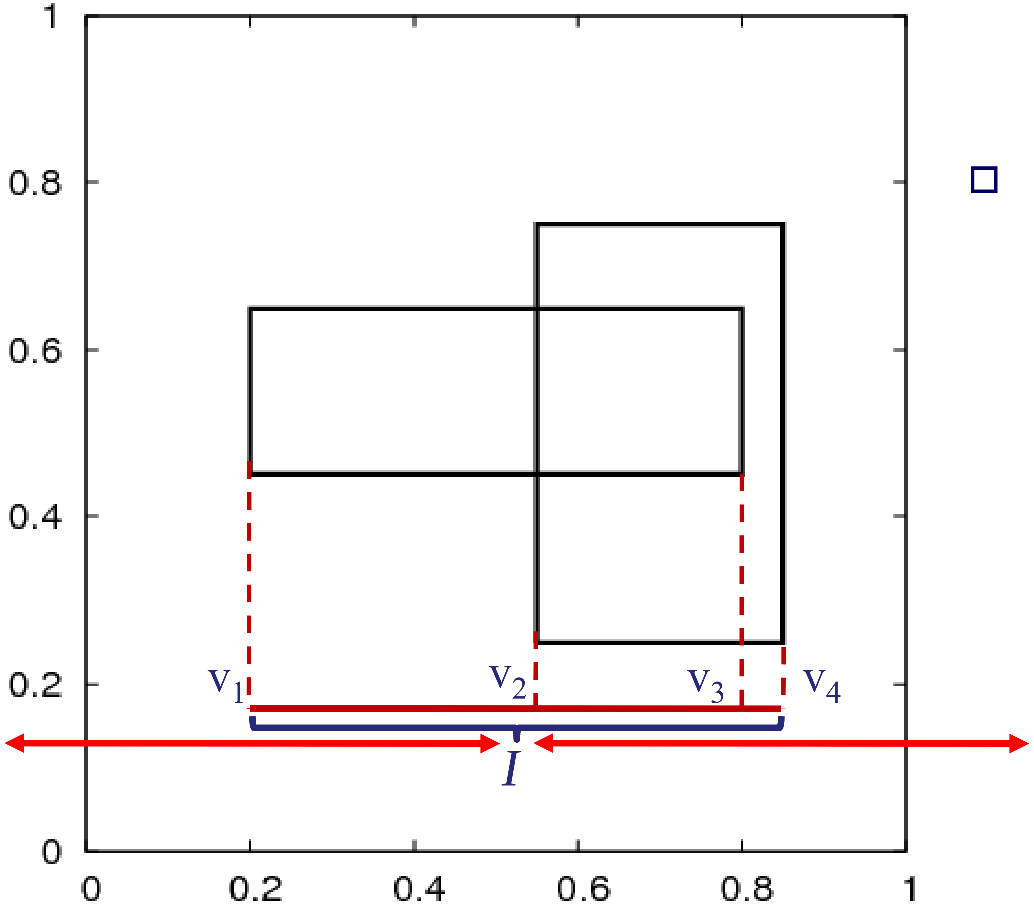
BLX-Crossover Operator

- **Problem with two-point crossover:**
  - Offspring maintain parent's boundaries
  - Mutation is responsible for modifying these boundaries

- **Advantage of evolution strategies:**
  - Mutation is more focused
  - Mutation is applied more often

- **Aim of BLX-Crossover**
  - Combine the ***innovation*** power of 2-point crossover with also ***local search*** by permitting moving the boundaries

BLX-Crossover Operator



- For each offspring o1 and o2, the intervals of each attribute [ℓi, ui] are generated as:
  - α = rand(0,0.5)
  - $\ell_{o1} = v_1 + \alpha I$ rand {-1, 1}
  - $\ell_{o2} = v_1 + (1-\alpha) I$ rand {-1, 1}
  - $u_{o1} = v_4 + \alpha I$ rand {-1, 1}
  - $u_{o2} = v_4 + (1-\alpha) I$ rand {-1, 1}

- Key aspects:
  - Boundaries *move according to I*, the distance between parents bounds
  - When one offspring is practically equal to the parents ($\alpha \approx 0$), the other is very different from them ($\alpha \approx 0.5$)

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Experimental Methodology

- **Experiments on 12 real-world data sets from the UCI repository**
  - 10-fold cross validation

Id.	dataset	#Inst	#Fea	#Re	#In	#No	#Cl	%MisInst
bal	Balance	625	4	4	0	0	3	0
bpa	Bupa	345	6	6	0	0	2	0
gls	Glass	214	9	9	0	0	6	0
h-s	Heart-s	270	13	13	0	0	2	0
irs	Iris	150	4	4	0	0	3	0
pim	Pima	768	8	8	0	0	2	0
tao	Tao	1888	2	2	0	0	2	0
thy	Thyroid	215	5	5	0	0	3	0
veh	Vehicle	846	18	18	0	0	4	0
wbcd	Wisc. breast-cancer	699	9	0	9	0	2	2.3
wdbc	Wisc. diagnose breast-cancer	569	30	30	0	0	2	0
wne	Wine	178	13	13	0	0	3	0

Experimental Methodology

- **XCS configured as:**
  - Iter=100000, N = 6400, $\theta_{GA} = 50$, $P_{cross} = 0.8$, $P_{mut} = 0.04$, r_0 = 0.6, m_0 = 0.1
- **Comparison of:**
  - XCS-GA with proportionate and tournament selection
  - XCS-ES with proportionate, tournament and truncation selection
  - XCS-GA with two point-crossover
- **Why this comparison?**
  - Does BLX approach XCS-GA to XCS-ES?
  - Is BLX better than 2-point crossover in XCS?

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Results

- Test Accuracy

XCS-GA with proportionate

XCS-ES with proportionate

XCS-GA with tournament

XCS-ES with tournament

XCS-ES with truncation

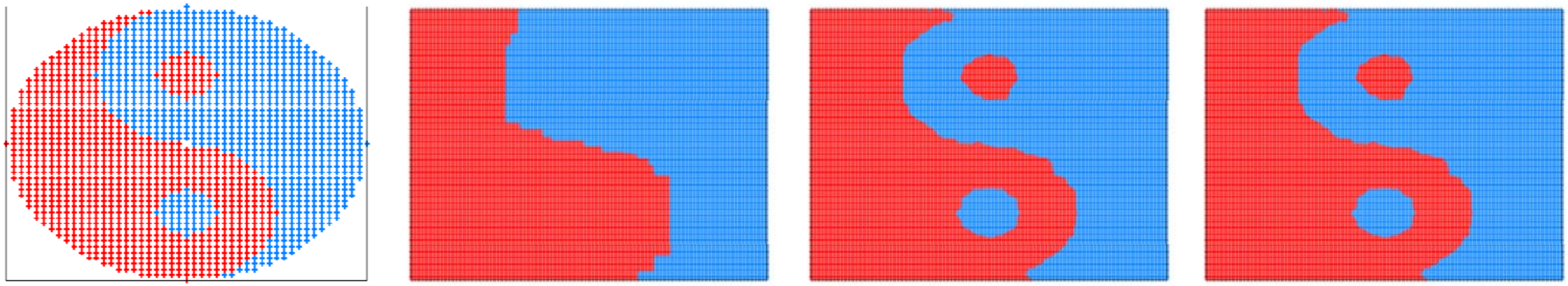
Original XCS

Data set	XCS-GA ps	XCS-ES ps	XCS-GA ts	XCS-ES ts	XCS-ES tr	XCS-GA tp
bal	86.29 (1)	85.39 (5)	85.44 (4)	85.55 (2.5)	85.55 (2.5)	83.20 (6)
bpa	69.18 (1)	65.89 (6)	68.11 (3.5)	68.11 (3.5)	66.76 (5)	68.21 (2)
gls	69.94 (5)	70.25 (4)	71.65 (2)	71.49 (3)	69.16 (6)	72.12 (1)
h-s	39.51 (4)	38.64 (6)	38.76 (5)	39.88 (3)	43.21 (2)	46.91 (1)
irs	95.11 (4)	95.11 (4)	95.33 (1.5)	95.11 (4)	94.89 (6)	95.33 (1.5)
pim	75.22 (1)	74.43 (4)	74.65 (2.5)	73.83 (5)	74.65 (2.5)	72.53 (6)
tao	96.80 (1)	96.77 (2)	96.68 (3)	96.61 (4)	96.57 (5)	91.22 (6)
thy	97.36 (1)	96.90 (3)	97.05 (2)	96.43 (5)	96.74 (4)	95.81 (6)
veh	69.34 (4)	69.23 (6)	69.74 (3)	70.21 (2)	69.31 (5)	71.79 (1)
wbcd	95.66 (5)	96.28 (3)	96.33 (1.5)	95.99 (4)	96.33 (1.5)	94.85 (6)
wdbc	91.04 (5)	91.33 (3)	91.62 (2)	91.97 (1)	90.63 (6)	91.09 (4)
wne	95.88 (4)	96.07 (3)	96.25 (2)	96.82 (1)	95.13 (6)	95.50 (5)
Rank	*3.00*	*4.08*	*2.67*	*3.17*	*4.29*	*3.79*
Pos	*2*	*5*	*1*	*3*	*6*	*4*

Results

- **Two key observations:**
  - BLX crossover enables XCS to fit complex boundaries more accurately
  - BLX may prevent XCS from over-fitting in complex domains

- **Fit complex boundaries: the TAO problem**

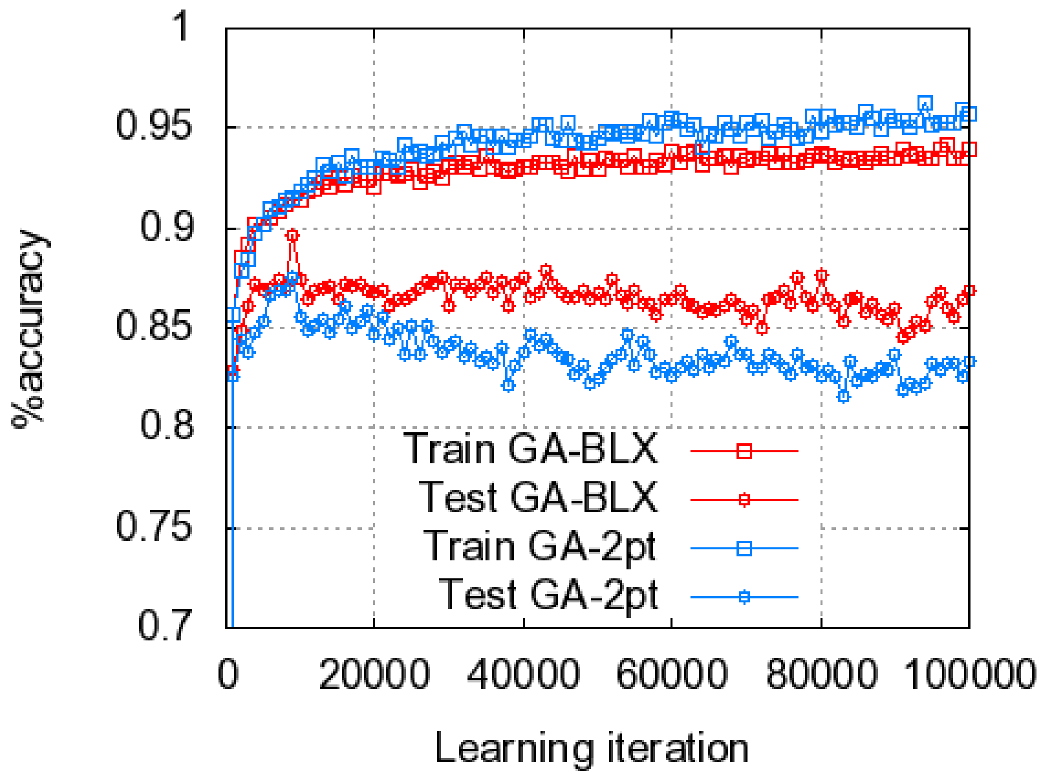


Domain | **Original XCS** | **XCS-GA BLX** | **XCS-ES BLX**

  - The freedom provided by BLX enables the system to create new classifiers that fit the curved boundaries

Results

- **Prevention from overfitting: The BAL problem**



- To increase the training accuracy, two-point crossover starts to over-fit the training examples in the BAL problem

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Conclusions

- **On average, BLX yields more accurate models than 2-point crossover**
- **BLX crossover enhances XCS-GA**
  - Morales et al. (2008) showed that XCS-ES resulted in more accurate models than XCS-GA.
  - BLX approaches XCS-GA results to XCS-ES results.
- **Two important observations:**
  - BLX helps fit curved boundaries.
  - BLX may prevent over-fitting.
- **The overall work clearly shows the importance of further research on GA operators.**

Further Work

- **Well, BLX is good! But, always?**
  - On average, yes!
  - Specific problems may not benefit from BLX

- **May evolution tell me when to use one operator or another?**
  - Existing studies on self-adaptation mutation for ternary rules
  - Search for evolution signals
  - Combine different operators
  - Let classifiers decide which operator to use
  - Characterize learning domains

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