VorAIS: A Multi-Objective Voronoi Diagram-based Artificial Immune System

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Luis Martí[1,2] Arsene Fansi-Tchango[3] Laurent Navarro[3] Marc Schoenauer[1]

[1] TAO team, INRIA/LRI(CNRS & UPSud), Université Paris-Saclay, Paris, France.
[2] Universidade Federal Flumnense, Niterói (RJ) Brazil.
[3] ThereSIS, Thales Group, Paris, France.

Context

- Artificial Immune Systems have been derived from existing theories of the functioning of biological immune systems.
- They create a model that is able to discriminate between normal (self) and abnormal (non-self) objects.
- This feature makes AISs specially suited for dealing with problems related to anomaly and intrusion detection.

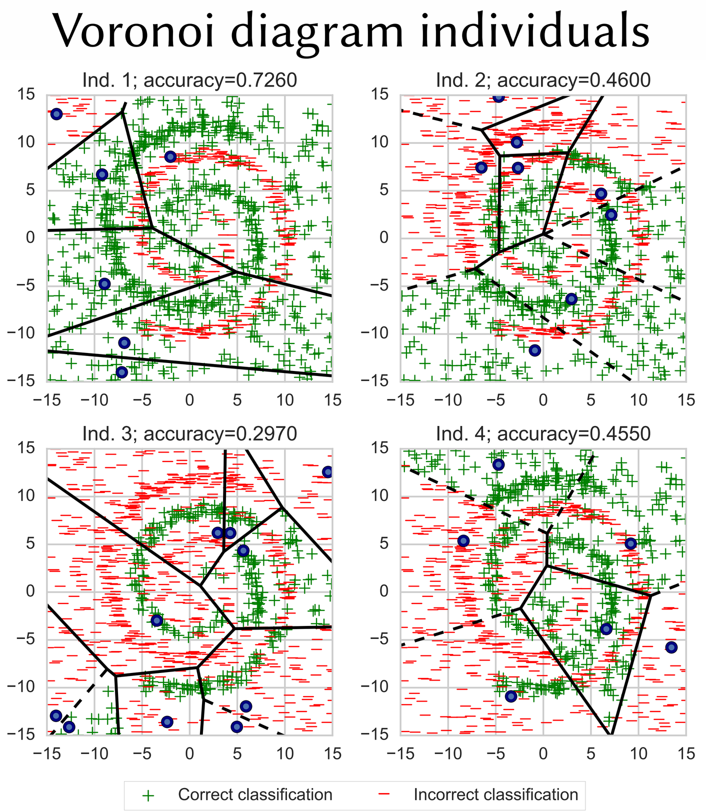
Voronoi diagram-based Artificial Immune System

VorAIS models the self/non-self using a Voronoi diagram that determines which areas of the problem domain correspond to self or to non-self.

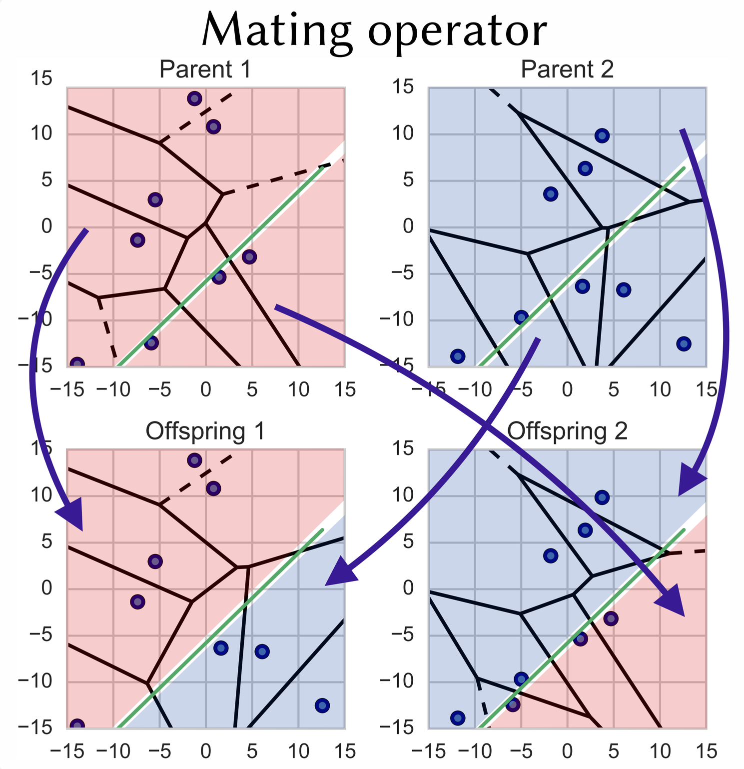
- Various classification metrics, like accuracy, recall, and specificity, must be taken into account.
- Multi-objective approach based on non-dominated sorting of NSGA-II.
- We introduce a mating operator as part of the AIS.

VorAIS components

Voronoi diagram individuals



Mating operator



Mutation operator

function `mutate_voronoi`$(\mathcal{I}, p_s, p_f, p_t, p_+, p_-, \eta)$
- ▹ $\mathcal{I}$, individual to be mutated.
- ▹ $p_s \in [0,1]$, prob. of mutating a site.
- ▹ $p_f \in [0,1]$, prob. of mutating a site's feature.
- ▹ $p_t \in [0,1]$, prob. of changing the label of a site.
- ▹ $p_+ \in [0,1]$, prob. of adding a new site.
- ▹ $p_- \in [0,1]$, prob. of removing a site.
- ▹ $\eta \in (0,\infty]$, learning rate.

for all $S \in \mathcal{I}$ **do**
  if $U[0,1) < p_s$ **then**
    for all $x \in S$ **do**
      if $U[0,1) < p_f$ **then**
        $x \leftarrow$ `mutate_log_normal`(x, η)
    if $U[0,1) < p_t$ **then**
      $S.\ell \leftarrow$ `switch_label`$(S.\ell)$.
if $U[0,1) < p_+$ **then**
  $\mathcal{I} \leftarrow \mathcal{I} \cup \{$`random_site`$\}$.
if $U[0,1) < p_-$ **then**
  $i \leftarrow U[1, |\mathcal{I}|)$.
  $\mathcal{I} \leftarrow \mathcal{I} \setminus \{\mathcal{I}(i)\}$.
return $\mathcal{I}$, mutated individual.

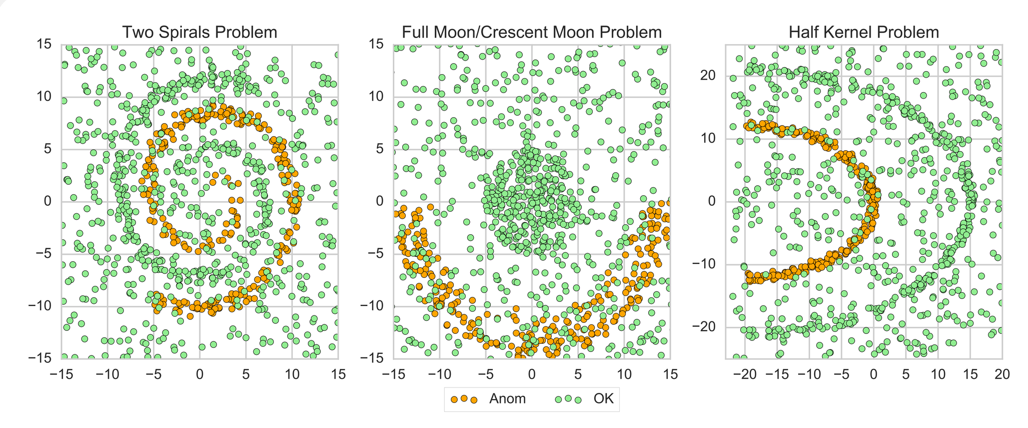
VorAIS outline

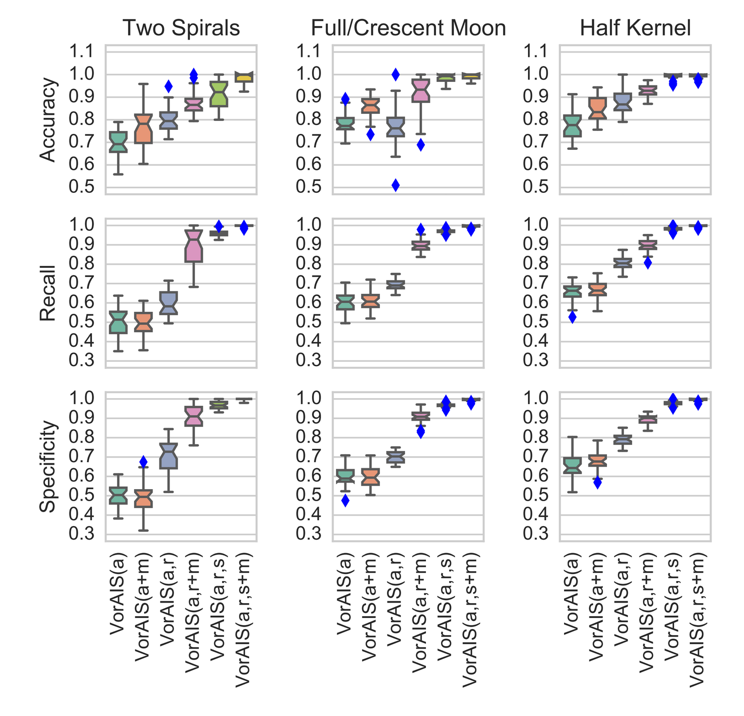
1. Create an initial random population $\mathcal{P}_0$ of n_{pop} individuals.
2. At iteration t, individuals in $\mathcal{P}_t$ are mated and mutated.
3. An offspring population, $\mathcal{P}_{\text{off}}$, with n_{off} individuals is created.
4. From $\mathcal{P}_t \cup \mathcal{P}_{\text{off}}$ the best n_{pop} individuals are selected using non-dominated sorting (with crowding distance).

Hyperparameters tuned by grid search (see PPSN paper).

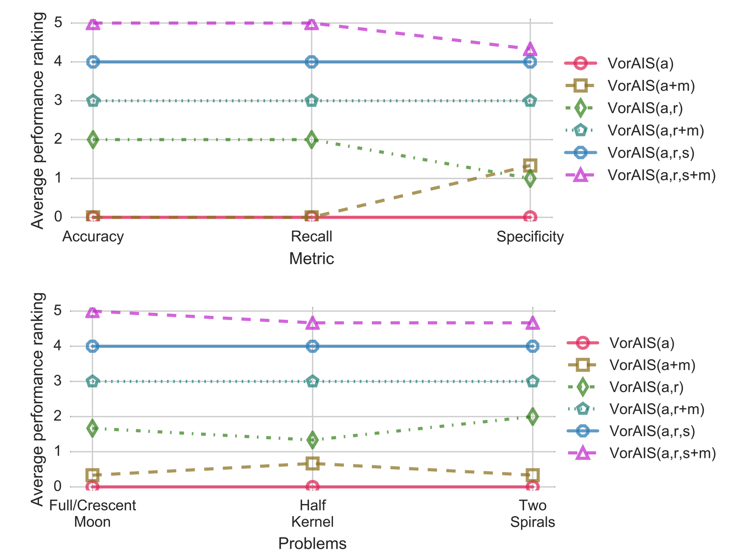
Preliminary study on test problems

- Influence of the mating operator (+m) and the use of the classification metrics (a, r and s, respectively), on two-dimensioal problems.



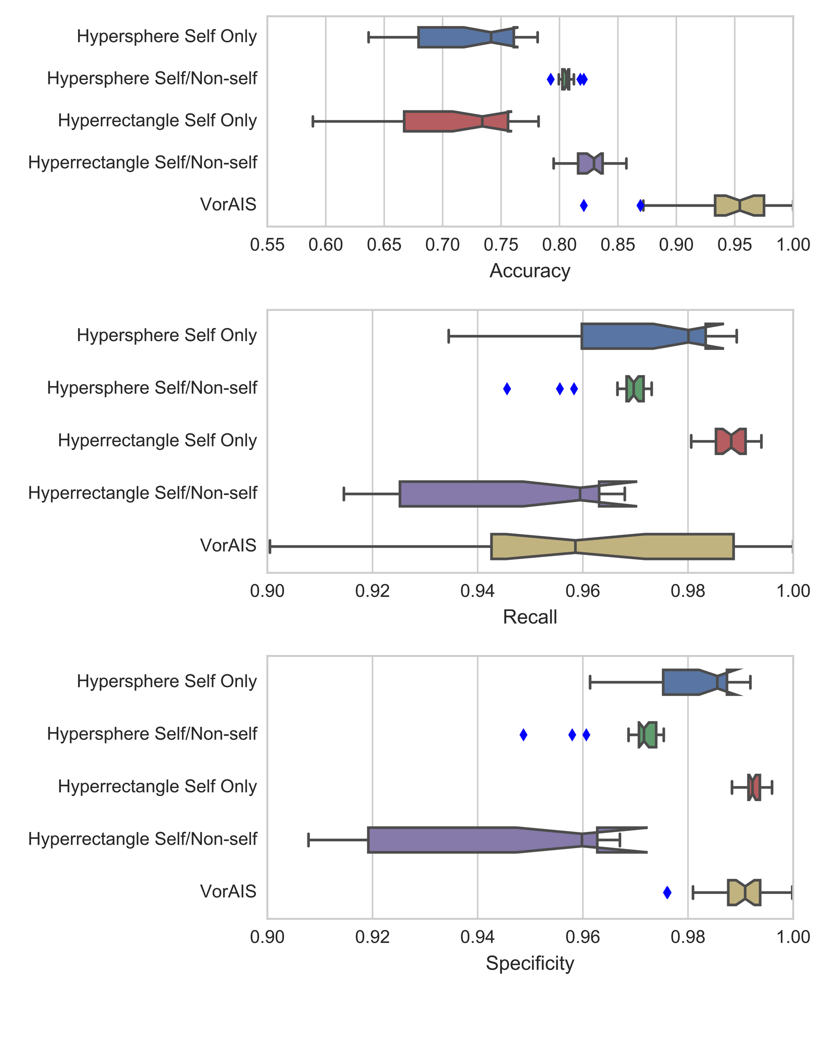


Bergmann-Hommel tests grouped by problem and metric.



NSL KDD'99 anomaly detection problem

- Compare VorAIS with other AISs in a computer network anomaly detection benchmark problem.
- NSL-KDD'99 has 41 —38 numeric and 3 categorical— features and one class attribute describing the nature of the events.



Bergmann-Hommel tests.

	NSA_{sp}	NSA^+_{sp}	NSA_{re}	NSA^+_{re}	VorAIS
Accuracy					
NSA_{sp}	×	−	∼	−	−
NSA^+_{sp}	+	×	+	−	−
NSA_{re}	∼	−	×	−	−
NSA^+_{re}	+	+	+	×	−
VorAIS	+	+	+	+	×
Recall					
NSA_{sp}	×	+	−	+	∼
NSA^+_{sp}	−	×	−	+	∼
NSA_{re}	+	+	×	+	+
NSA^+_{re}	−	−	−	×	−
VorAIS	∼	∼	−	+	×
Specificity					
NSA_{sp}	×	+	−	+	−
NSA^+_{sp}	−	×	−	+	−
NSA_{re}	+	+	×	+	+
NSA^+_{re}	−	−	−	×	−
VorAIS	+	+	−	+	×

Final remarks

- We have obtained a performance comparable with the state of the art but adequate classification performance is not enough.
- It is necessary to create a compact representation of the 'normal' data.
- We developed custom objective functions that rely on volume-based approaches.

L. Martí, A. Fansi-Tchango, L. Navarro, and M. Schoenauer, *Anomaly detection with the Voronoi diagram evolutionary algorithm*,in Proceedings of the 14th International Conference on Parallel Problem Solving from Nature (PPSN XIV), Edinburgh, UK: Springer, 2016.