Réseau de transport d'électricité

On-Line Security Assessment Based on Rules Learned Using Monte Carlo Simulations and HPC (An European TSO Perspective)

P. Panciatici (RTE)

Potential Impact of High-Performance Computing on the Power Grid, IEEE GM PES 2013, Vancouver

New tools are required to help European TSOs to make decisions:

- European Electricity Market: Large size system, all probable contingencies
- More intermittent generation: uncertainties must be taken into account
- More controllable devices: PSTs, HVDC links embedded in AC grid. More and more closed loop controls, SPS, corrective actions ….
  - ✓ More accurate modeling of all system's components including their *dynamic behavior*
- Dynamic Security Assessment (DSA) taking in account uncertainties

TSO DECISION MAKING PROCESSES

Decisions for hour H, day D in D-2 to H-1

- Some decisions must be made in advance (*they need time to be implemented) :*
  - ✓ Must run generators,
  - ✓ Cancellation of outage (maintenance work)
  - ✓ Procurement of ancillary services (active and reactive power reserves)

  These actions are generally costly for TSOs.

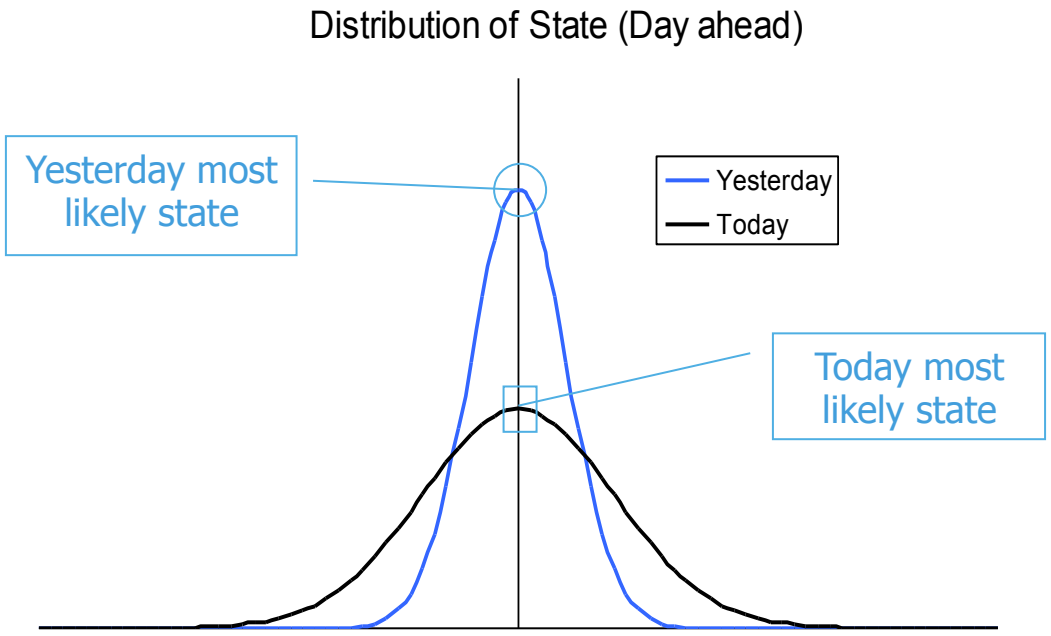
- Before the day head market closure (D-1, 6:00 P.M.)

- Traditionally, these decisions are made based on the most probable state for day (D) seen from (D-1)

TSO DECISION MAKING PROCESSES

"Uncertainties"

Increasing level of uncertainties



Decisions based on the most likely state of the system can't ensure the appropriate level of reliability

TSO DECISION MAKING PROCESSES

"Corrective" actions

- Corrective actions are post-fault actions implemented via automatic devices (SPS) or human actions (operating rules).

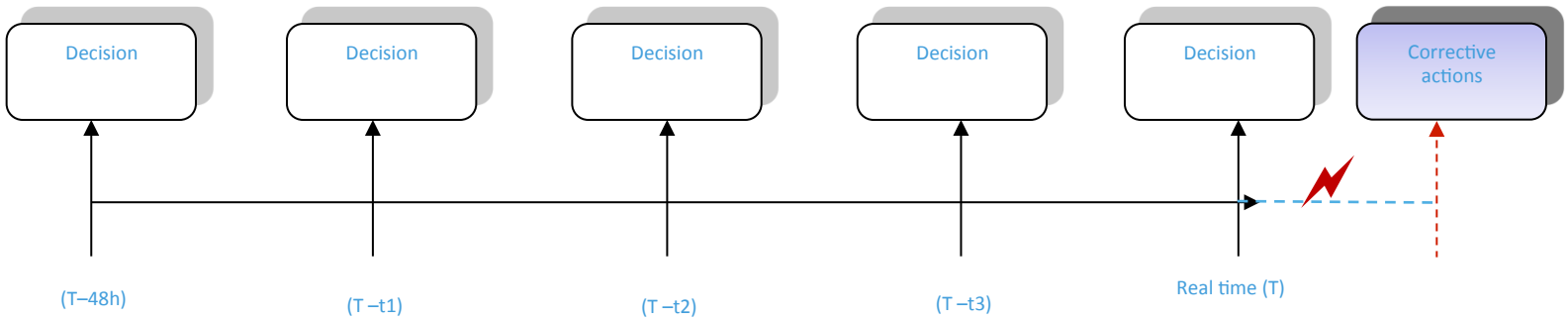
- More and more are used, based on controllable equipments: PST, HVDC converter.

- Priority is given to "corrective actions":
  - ✓ associated expected costs are very low, they act only if needed when a constraint is violated (low probability)
  - ✓ "Smarter" than preventive actions

TSO DECISION MAKING PROCESSES

New simulation/optimization problems

A complex multi stage decision making process:
Sliding window, from 2 days ahead to real time



- Minimizing costly strategic and preventive decisions taking into account uncertainties and corrective actions for a large system (large number of contingencies).

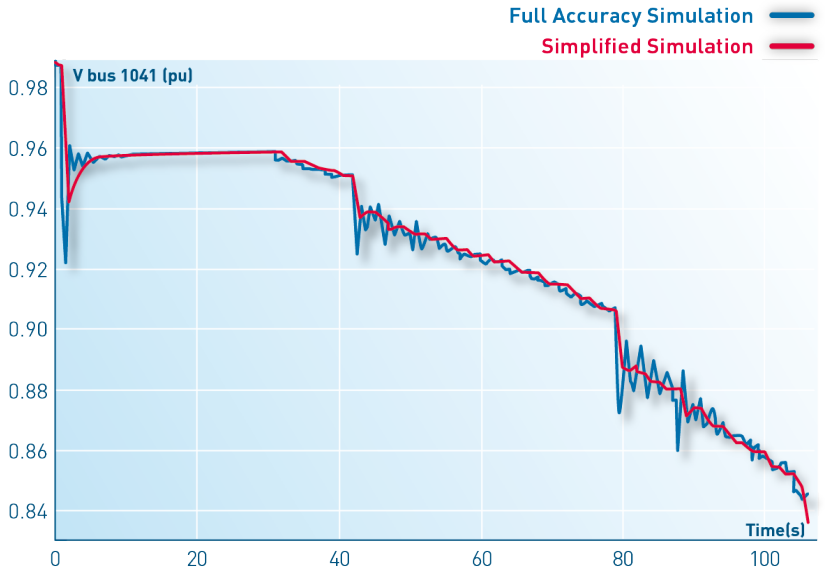
System dynamic behavior

- **Corrective actions and closed loop controls: post-fault steady state depends on the trajectory**

- **Possible unstable phenomena (less margin)**

✓ **Time domain simulation of the Pan-European model: a tough mathematical problem**

- Very large system (around 125.000 state variables)
- Non-linear, stiff, oscillating, poorly damped, discontinuous…



Online DSA with uncertainties for Pan-European Grid

Look head from D-1 to H-1

- **Probabilistic Dynamic Security Assessment**

✓ **This is an intractable problem:**

- Very large system (around 125.000 state variables)
- 5000 Contingencies
- Montecarlo: 1000 Samples (minimal)
- Time domain simulation per base case and contingency (duration: 5 min.):
  - Average optimistic computation time: 60 sec.

➡ Sequential Computation time: 9,5 years !!!

- **Using HPC?**

✓ **with 5 millions of cores => computation time: 60 sec.**

✓ **Mission critical IT system = private IT system**

- "1000 cores" seems a reasonable target => computation time: 3,5 days !!!

➡ Filtering/screening methods mandatory: target 15 min.

Filtering/screening methods

Look head from D-1 to H-1

- **Only a reduced number of contingencies and base cases are critical**
  (perhaps 20 among 5000 and 100 among 1000) => computation time 5 min.
  - ✓ **It seems possible to learn simple conservative rules to filter out a large number of contingencies and base cases.**

- **Idea: Perform offline Montecarlo simulations once a week to learn these simple conservative rules**
  - ✓ **Using a HPC facility > 10000 cores**
  - ✓ **During the iTesla project (2014) : 12 runs, between 12 and 24 hours.**

Filtering/screening method: Contingency ranking with respect to overloads in very large power systems taking into account uncertainty, preventive and corrective actions (TPWRS-00774-2012)

- Using a DC approximation: a sequence of very large Mixed Integer Linear Programming problems
- Ranking of contingencies severity into 4 clusters whatever the uncertainties
  1. Contingencies which don't require preventive or corrective actions
  2. Contingencies which require only corrective actions
  3. Contingencies which require corrective and preventive actions
  4. Contingencies for which the security of the system can't be ensured using the defined preventive and corrective control schemes
- We perform time domain simulation (DSA) only for contingencies in cluster 4 and 3.

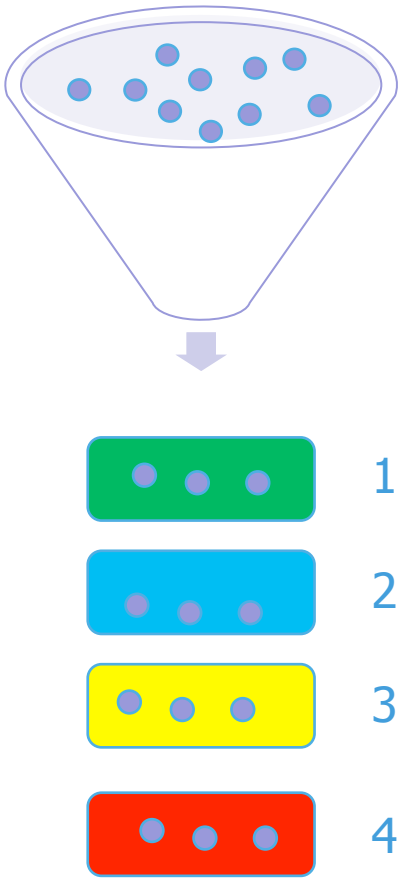
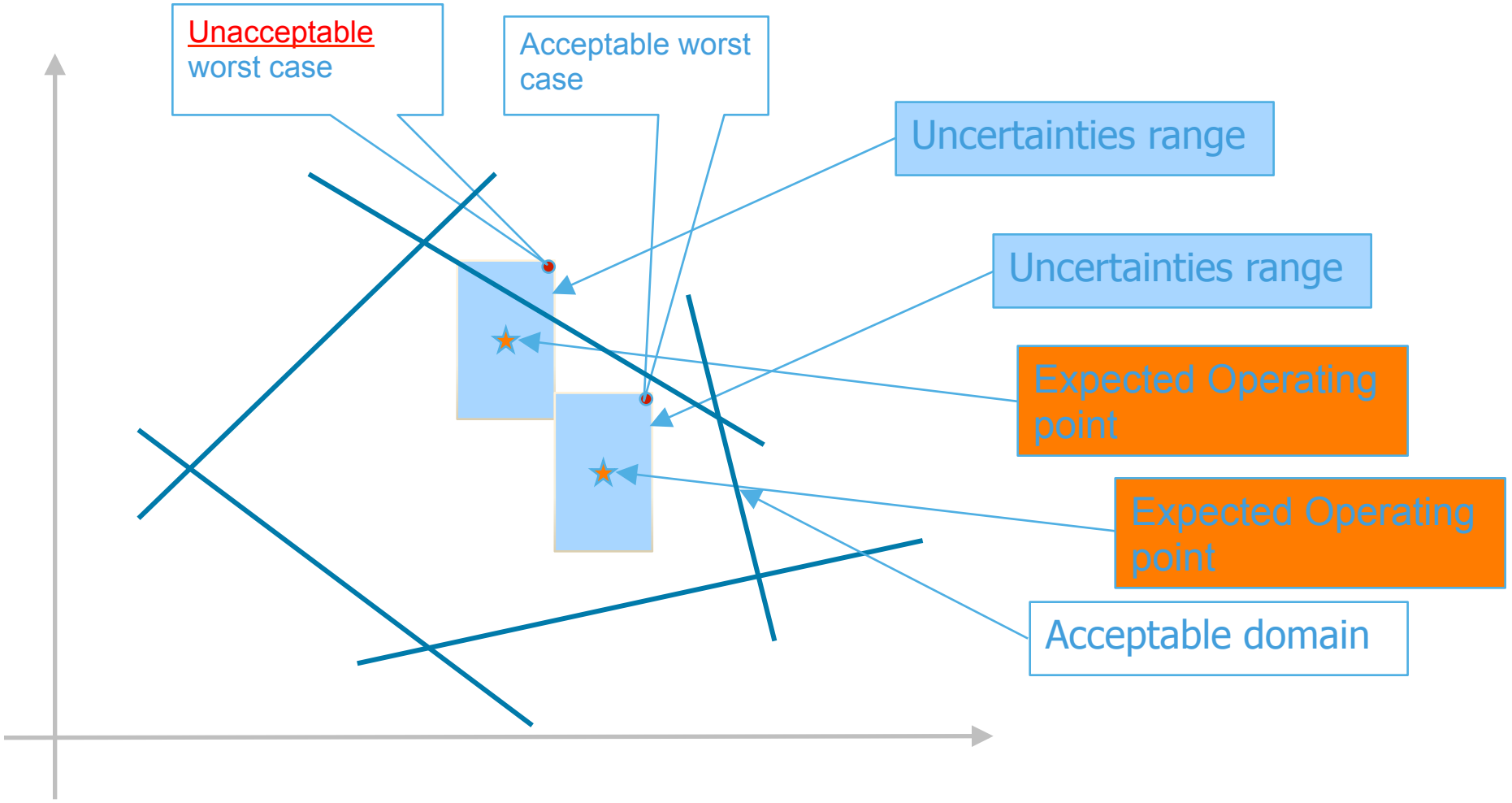


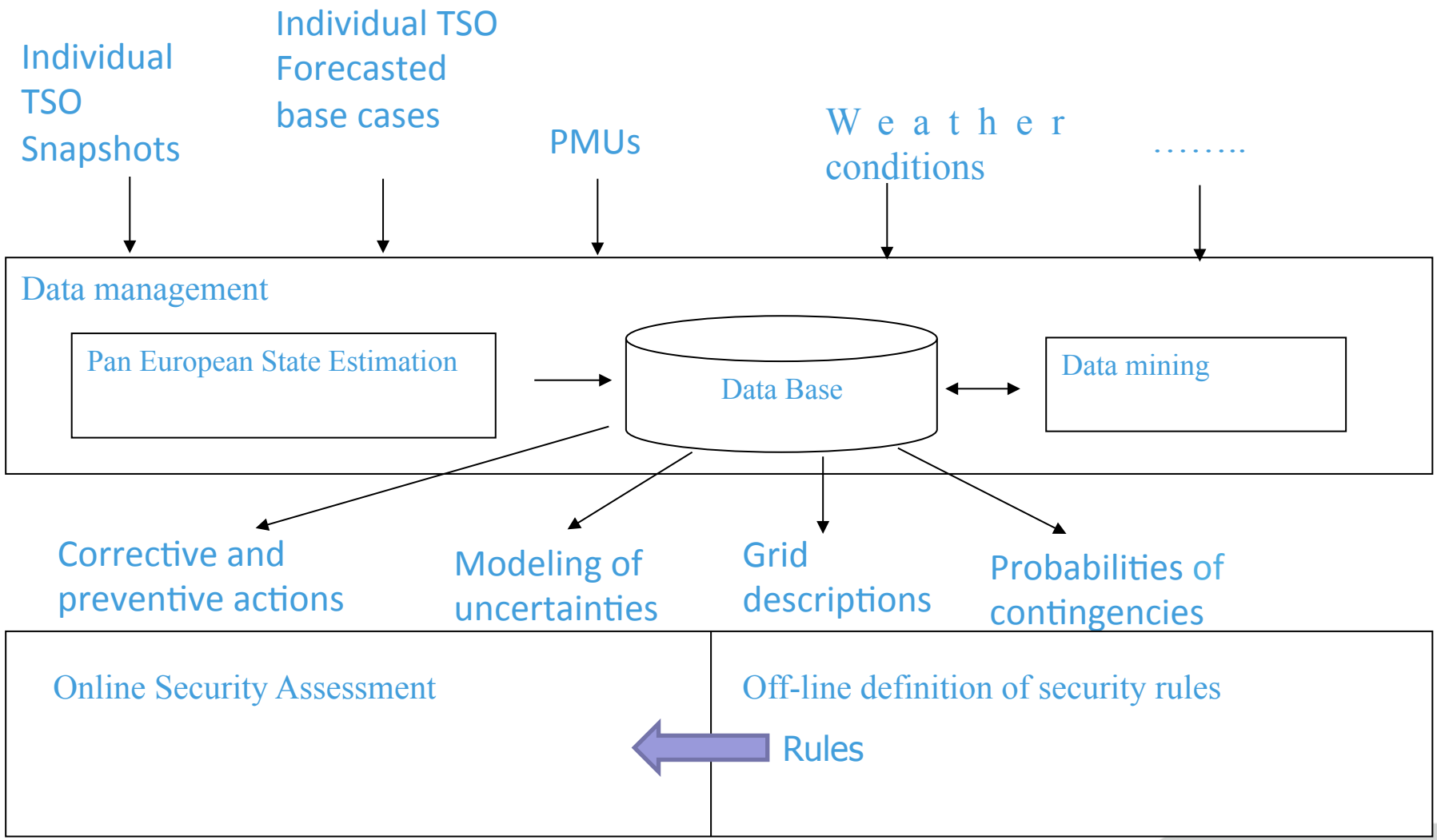
Illustration of the main idea of the method

based on a "worst case" approach



Pan European Toolbox architecture (*i*TESLA project)

Data management | Online security assessment / Off-line definition of rules



Off-line definition of security rules

Enhanced Monte Carlo: Important Sampling *based on HPC (>10 000 cores)*

✓ 10000 samples of stochastic variables based on modeling of uncertainties provided by data mining

✓ Splitting in subsets of 500 samples

For each contingency (among 5000) : *parallel processing*
  For each subset (among 200):
    For each sample (among 500) : *parallel processing*
      if (Base case not already built) then
        Built a realistic base case (Optimization)
      endif
      if ($\mathbf{C_c}$: the case is not similar to a case already analyzed) then
        Time Domain Simulation (N_{tds})
        Labeling as acceptable or unacceptable
      endif
    end-sample
  end-subset
  Learning of similarity rules per contingency ($\mathbf{C_c}$)
end-contingency

✓ Learning of simple conservative security rules per contingency for online analysis ("oblique" decisions trees)

We hope:

$N_{tds} << 5.10^3.10^4$
(50 10^6)

Learning of similarity rules for important sampling

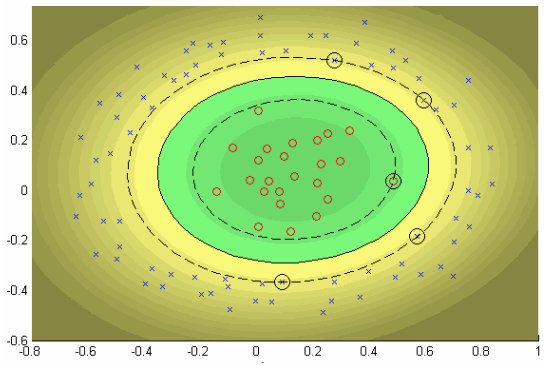
Support Vector Machine and probability of misclassification

Boundaries: h(x) = 0 / x=parameters, y = acceptable(+1) / unacceptable(-1)

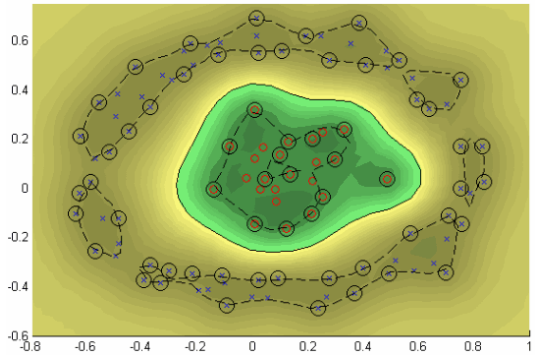
$$h(x) = \sum_{k=1}^{n} \alpha_k * y_k K(x_k, x) + b* = g(x) + b* = 0$$

Gaussian Kernel: $K(x_i, x_j) = \exp\left(-||x_i - x_j||^2/\sigma\right)$

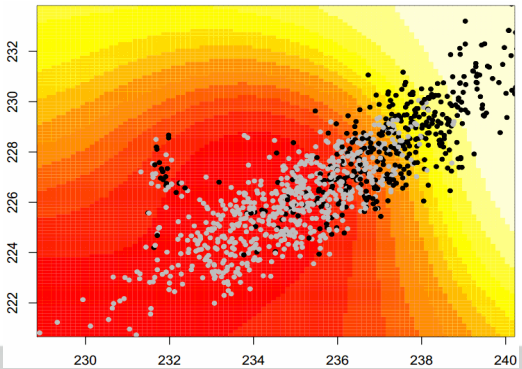
σ small: precise boundaries but risk of over learning

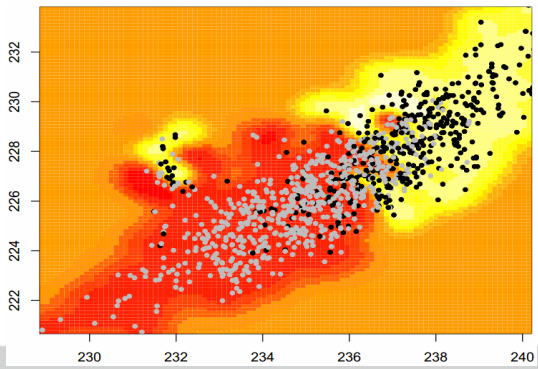


$\sigma = 10$



$\sigma = 0.1$





Probability of misclassification: Logistic regression

$$\log \frac{\mathbb{P}(Y=1|x)}{\mathbb{P}(Y=0|x)} = \beta_1.h(x) + \beta_2$$

For a new sample (x):
If (prob. of misclassification > p_{is})
then
    Analyze the new sample
endif
Typically: p_{is} = 1%

HPC facility: size, cost, performance and confidentiality

Accessible during the project not for operational use (anticipation of future offers)

- **Ongoing discussion with CEA:**
  - ✓ access to Curie thin nodes machine: 80000 cores *(ranked: 15, top500 June 2013)*

Provider	Ratio = cost/perf. (lower is better)	Available cores
Curie thin nodes	40	80640
Bifi – Universidad Zaragoza	66	3072
Google Compute Engine	80	> 600000
Amazon Web Services	83	> 50000
Bull eXtreme Factory	103	4032
Windows Azure	105	> 10000
Rackspace	344	> 10000
Vcodyne	501	7680

THANKS FOR YOUR ATTENTION!

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