Automatic License Plate Recognition by means of Machine Learning & Computer Vision

Tesi di Laurea in Ingegneria Elettronica

Candidato
Pietro Pennestrì
mat. 1694905

Relatore
Prof. A. Trifiletti

SAPIENZA
UNIVERSITÀ DI ROMA

CONTENTS

PREFACE

The aim of this thesis project is to develop an automatic car plate recognition system. A distinctive feature of this work is the combined use of **Computer Vision** and **Machine Learning** techniques.

Since optimization is the core of Machine Learning, some theoretical basis on unconstrained and constrained optimization algorithms are outlined in Chapter 1.

Moreover, for completeness, a quick introduction to Machine Learning is offered in Chapter 2. This introduction is far to be complete, but allows the reader to be acquainted with some basic definitions.

In Chapter 3 the edge detection problem is discussed. The focus on this problem is justified by its importances for the algorithm herein proposed.

Chapter 4 reports about the main phases and methods included in the proposed algorithm. Our approach progressively highlights vehicles areas. Then candidate areas of license plate are listed. This list is ordered according to values of a merit function herein proposed. The list items are then compared and matched with the results of the EAST (An **E**fficient and **A**ccurate **S**cene **T**ext Detector) trained network. Once the *best* candidate of Car Plate area has been detected, it is pre-processed and passed to `Tesseract` module for text recognition.

The scientific importance and practical usefulness of car plate detection is witnessed by the large amount of technical literature. Chapter 4 contains also a list of about 500 bibliographical references, just a glimpse of those available.

Finally, I wish to express my appreciation and gratitude to Prof. Alessandro Trifiletti for offering this thesis topic, for his support, discussion and freedom allowed. I wish to thank also Prof. Pietro Monsurrò for his expert introduction to Machine Learning.

Pietro Pennestrì
Roma, 27 Marzo 2019

1

REVIEW OF THEORY AND NUMERICAL OPTIMIZATION METHODS

There is no royal road to Geometry.

Euclid

Many models of neural networks rely upon optimization tecniques. In this chapter some mathematical foundation of basic optimization algorithms, used to train neural networks, will be discussed.

1.1. INTRODUCTION

In this chapter the theoretical base of optimization theory will be discussed. Initially the focus will be on the Lagrange multipliers method. This was introduced by Lagrange in his masterpiece *Mécanique Analitique*. The original purpose of the method was to solve problems of Statics of bodies subjected to constraints.

Then some common optimization techniques used in machine learning will be presented.

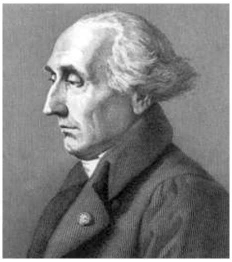


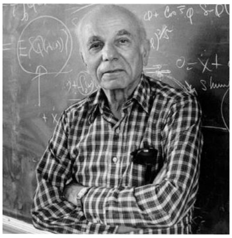
Figure 1.1: J.L. Lagrange (1736-1813)

The Lagrange's innovative approach allows to reduce problems of Mechanics to problems of Calculus, as well expressed by the following statement taken verbatim from the Preface of Lagrange:

> *On ne trouvera point de Figures dans cet Ouvrage. Les méthodes que j'y expose ne demandent ni constructions, ni raisonnemens géométriques ou mécaniques, mais seulement des opérations algébriques, assujéties à une marche réqulière et uniforme. Ceux qui aiment l'Analyse, verront avec plaisir la Mécanique en devenir une nouvelle brance, et me sauront gré d'en avoir étendu ainsi le domaine.*

The Lagrange multipliers method is not restricted to problems of Mechanics, but has a more general validity. As it will be shown, the requirements for the optimization of engineering systems makes this method a powerful tool.

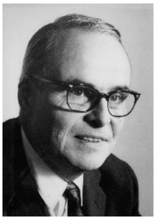
Starting from the second half of 20th century, significant adavancements on the solution of nonlinear constrained optimzation problems or *non linear programming* (NLP) are recorded.



Fritz John (1910-1994)

William Karush (1917-1997)

Harold Kuhn (1925-2014)



Albert Tucker (1905-1995)

Olvi Leon Mangasarian (1934-)

Figure 1.2: The founders of Non Linear Programming

One of the most well known optimum criteria is due to Harold Kuhn (1925-2014) and Albert Tucker (1905-1995) [2]. However, the necessary conditions required for the solution of the Lagrange multipliers problem with inequalities constraints only have been deduced three years before by Fritz John (1910-1994). In 1967 Mangasarian and Fromovitz [3] extend the conditions of optimum to the case of equality constraints.

1.2. UNCONSTRAINED OPTIMIZATION

In this section some definitions are introduced.

- a **relative minimum** or **local minimum** if

$$f\left(x^*\right) \leq f\left(x^* + h\right)$$

  for any value of h enough small;

- a **relative maximum** or **local maximum** if

$$f\left(x^*\right) \geq f\left(x^* + h\right)$$

for any value of h enough small;

- an **absolute minimum** or **global minimum** if
$$f\left(x^*\right) \leq f\left(x\right)$$
for any value of x, within the function domain;
- an **absolute minimum** or **global minimum** if
$$f\left(x^*\right) \geq f\left(x\right)$$
for any value of xl, within the function domain.

1.2.1. MULTI VARIABLE FUNCTION

Definition 1.2.1 (The r^{th} **differential of a function** $f(\mathbf{x})$)**.** If all the partial derivatives in $\mathbf{x}^*$ of function $f : \mathbb{R}^n \to \mathbb{R}$ exist and are continuous, then for $r \geq 1$ the polynomial

$$\mathrm{d}^r f(\mathbf{x}^*) = \underbrace{\sum_{i=1}^{n}\sum_{j=1}^{n}\dots\sum_{k=1}^{n}}_{\text{Somma rispetto a } r} h_i h_j \dots h_k \frac{\partial^r f(\mathbf{x}^*)}{\partial x_i \partial x_j \cdots \partial x_k} \tag{1.1}$$

is the r^{th} differential of $f(\mathbf{x})$ in $\mathbf{x}^*$.

The Taylor expansion of $f(\mathbf{x})$ in the neighborhood of $\mathbf{x}^*$ is expressed by:

$$\begin{aligned} f(\mathbf{x}) = & f(\mathbf{x}^*) + \mathrm{d}f(\mathbf{x}^*) + \frac{1}{2!}\mathrm{d}^2 f(\mathbf{x}^*) + \frac{1}{3!}\mathrm{d}^3 f(\mathbf{x}^*) \\ & + \dots + \frac{1}{n!}\mathrm{d}^{(n)} f(\mathbf{x}^*) + R_n(\mathbf{x}^*, \mathbf{h}) \end{aligned} \tag{1.2}$$

where $R_n(\mathbf{x}^*, \mathbf{h})$ is

$$R_n(\mathbf{x}^*, \mathbf{h}) = \frac{1}{(n+1)!}\mathrm{d}^{(n+1)} f(\mathbf{x}^* + \theta\mathbf{h})$$

with $\theta \in (0; 1)$ and $\mathbf{h} = \mathbf{x} - \mathbf{x}^*$.

Theorem 1.2.1 (**Necessary condition**)**.** *Let us denote by f a function $f : \mathbb{R}^n \to \mathbb{R}$ and $f \in C^1(A)$, with A an open set of $\mathbb{R}^n$. If $f(\mathbf{x})$ has an extremum value (maximum or minimum) for $\mathbf{x} = \mathbf{x}^* \in A$, then:*

$$\frac{\partial f(\mathbf{x}^*)}{\partial x_1} = \frac{\partial f(\mathbf{x}^*)}{\partial x_2} = \dots = \frac{\partial f(\mathbf{x}^*)}{\partial x_n} = 0 \tag{1.3}$$

Theorem 1.2.2 (**Sufficient condition**)**.** *A sufficient condition for $\mathbf{x}^*$ to be a point of maximum or minimum is that the Hessian matrix of $f(\mathbf{x})$ $\mathbf{H}(\mathbf{A}x)$, computed in $\mathbf{x}^*$, is*

1. *Positive definite, for $\mathbf{x}^*$ is a minimum.*
2. *Negative definite, for $\mathbf{x}^*$ is a minimum.*

Note. The theorem is not valid when $\mathbf{H}(\mathbf{x}^*)$ is semidefinite (positive or negative). In this case, the following theorem will be useful for the analysis of minima and maxima:

Theorem 1.2.3. *Let the partial derivatives of f of order $k \geq 2$ be continuous in the neighborhood of $\mathbf{x}^*$. If the following conditions are true:*

$$\mathrm{d}^r f(\mathbf{x}^*) = 0\,, \quad 1 \leq r \leq k-1 \tag{1.4a}$$

$$\mathrm{d}^k f(\mathbf{x}^*) \neq 0\,. \tag{1.4b}$$

the following cases can be enumerated:

1. *if k is even and $\mathrm{d}^k f(\mathbf{x}^*)$ is definite positive, $\mathbf{x}^*$ will be a point of relative minimum;*
2. *if k is even and $\mathrm{d}^k f(\mathbf{x}^*)$ is definite negative, $\mathbf{x}^*$ will be a point of relative maximum;*
3. *if k is odd no conclusion can be made about $\mathbf{x}^*$.*

1.3. CONSTRAINED OPTIMIZATION

In this section the optimization of functions subjected to equality constraints will be discussed.

Let:

$$f,g : \mathbb{R}^n \to \mathbb{R}$$
$$f,g \in C^1(A)$$

where A is an open set of $\mathbb{R}^n$

$$\text{Minimizzare } f = f(\mathbf{x}), \text{con } \mathbf{x} \in \mathbb{R}^n$$
$$\text{soggetta a}$$
$$g_i(\mathbf{x}) = 0, \quad i = 1,2,\ldots,m.$$

We will always assume that $m < n$. Otherwise, the problem is overdetermined and, in the majority of cases, there is not any solution.

GENERAL CASE ($m < n$)

Let us extend the previous analysis to the more general case of n variables and m constraints.

$$\text{Minimize } f(\mathbf{x})$$

subject to

$$g_j(\mathbf{x}) = 0, \quad (j = 1,2,\ldots,m)$$

The new objective function L has $(n+m)$ variables and is defined as follows:

$$L(x_1, x_2, \ldots, x_n, \lambda_1, \lambda_2, \ldots, \lambda_m) = f(\mathbf{x}) + \lambda_1 g_1(\mathbf{x}) + \ldots + \lambda_m g_m(\mathbf{x}) \tag{1.5}$$

NECESSARY CONDITIONS

The necessary conditions for L to have an extremum are:

$$\frac{\partial L}{\partial x_i} = \frac{\partial f(\mathbf{x})}{\partial x_i} + \sum_{j=1}^{m} \lambda_j \frac{\partial g_j(\mathbf{x})}{\partial x_i} = 0, \quad \text{per } i = 1,2,\dots,n \tag{1.6a}$$

$$\frac{\partial L}{\partial \lambda_j} = g_j(\mathbf{x}) = 0, \quad \text{per } j = 1,2,\dots,m \tag{1.6b}$$

The equations (1.6) form a system of $(n+m)$ equations with $(n+m)$ unknowns $x_1, x_2, \dots, x_n$ and $\lambda_1, \lambda_2, \dots, \lambda_m$

SUFFICIENT CONDITIONS

Theorem 1.3.1. *The sufficient condition for the function $f(\mathbf{x})$ to have a relative minimum (maximum) in $\mathbf{x}^*$ is that the quadratic function*

$$Q = \sum_{i=1}^{n} \sum_{j=1}^{m} \frac{\partial^2 L}{\partial x_i \partial x_j} \mathrm{d}x_i \mathrm{d}x_j \tag{1.7}$$

evaluated in $\mathbf{x} = \mathbf{x}^*$ is definite positive (negative), for all the values of $\mathrm{d}\mathbf{x}$ satisfying the constraints.

APPLICATION: SOLUTION OF AN UNDETERMINED SYSTEM OF LINEAR EQUATIONS

Let us denote by

$$\mathbf{Ax} = \mathbf{b} \tag{1.8}$$

a system of linear equations where $\mathbf{A}$ è is a rectangular matrix with **number of rows less than the number of columns**. The system will have an infinite number of solutions. However, we are looking for the one with minimum Euclidean norm.

The problem can be formulate ad sollows:

$$\min \mathbf{x}^\mathsf{T}\mathbf{x}$$

subject to the linear constraints $\mathbf{Ax} = \mathbf{b}$.

The **extended Lagrangean function** is initially formed:

$$L = \mathbf{x}^\mathsf{T}\mathbf{x} - \boldsymbol{\lambda}^\mathsf{T}(\mathbf{Ax} - \mathbf{b}) \ , \tag{1.9}$$

where $\boldsymbol{\lambda}$ is the vector of Lagrange multipliers.

After the stationarity condition is applied

$$\frac{\partial L}{\partial \mathbf{x}} = 2\mathbf{x} - \mathbf{A}^\mathsf{T}\boldsymbol{\lambda} = \mathbf{0} \, ,$$

we obtain

$$\mathbf{x} = \frac{1}{2}\mathbf{A}^\mathsf{T}\boldsymbol{\lambda} \, . \tag{1.10}$$

By requiring

$$\frac{\partial L}{\partial \boldsymbol{\lambda}} = \mathbf{Ax} - \mathbf{b} = \mathbf{0} \tag{1.11}$$

and combining with (1.10) follows

$$\boldsymbol{\lambda} = 2\left(\mathbf{A}\mathbf{A}^{\mathsf{T}}\right)^{-1}\mathbf{b}\,,$$

or

$$\boxed{\mathbf{x} = \mathbf{A}^{\mathsf{T}}\left(\mathbf{A}\mathbf{A}^{\mathsf{T}}\right)^{-1}\mathbf{b}\,,} \tag{1.12}$$

the algebraic solution of our problem.

We observe that (1.12) corresponds with the definition of the *pseudoinverse* matrix with number of rows less than the number of columns.

Since $\mathbf{A}^{\mathsf{T}}\mathbf{A}$ is ill conditioned, its use in numerical calculations is not recommended.

1.4. NON LINEAR PROGRAMMING

The general non linear programming (NLP) problem is formulated in the form:

$$\begin{aligned} &\text{Minimize } \theta(\mathbf{x}) \text{ subject to the following constraints}\\ &g_i(\mathbf{x}) \le 0 \quad i \in M = \{1,2,\dots,m\}\\ &h_j(\mathbf{x}) = 0 \quad j \in K = \{1,2,\dots,k\} \end{aligned} \tag{1.13}$$

where $\theta(\mathbf{x})$, $g_i(\mathbf{x})$ e $h_j(\mathbf{x})$ are function defined in the n-dimensional Euclidean space E^n with continuous partial derivatives in E^n.

The optimality criteria can be divided in two categories:

- Necessary: If $\mathbf{x}^*$ is a solution of (1.13), the relations $\theta(\mathbf{x}^*)$, $g_i(\mathbf{x}^*)$ and $h_j(\mathbf{x}^*)$ sare considered necessary conditions.

- Sufficient: In some problems it is possible to establish a set of conditions that guarantee the relative estremality of a point $\mathbf{x}^*$.

We observe that these optimality criteria are form the theoretical bases for the solution of NLP problems.

The most famous necessary conditions of optimality are due to Kuhn and Tucker [2]. However, those more general due to Fritz John [1] do not require restrictive hypotheses on the constraints and have been discover three years earlier.

In his original paper Fritz John [1] solves Problem (1.13) excluding equality constraints. Mangasarian and Fromovitz [3] extend the conclusions of Fritz John to the case of presence of equality constraints without any attempt of conversion to inequality constraints.

Following the approach of Mangasarian and Fromovitz [3], the necessary conditions of Fritz John will be extended.

1.5. THE GENERALIZED NECESSARY CONDITIONS OF FRITZ JOHN

Theorem 1.5.1 (The generalized necessary conditions of Fritz John). *If* $\mathbf{x}^*$ *is a solution of problem* (1.13)*, then exist the vectors*

$$\bar{\mathbf{u}} = \left\{ \begin{array}{c} \bar{u}_0 \\ \bar{u}_1 \\ \vdots \\ \bar{u}_m \end{array} \right\}, \quad \bar{\mathbf{u}} \in E^{m+1} \qquad \bar{\mathbf{v}} = \left\{ \begin{array}{c} \bar{v}_1 \\ \bar{v}_2 \\ \vdots \\ \bar{v}_k \end{array} \right\}, \quad \bar{\mathbf{v}} \in E^{k} \tag{1.14}$$

such that

$$\left.\begin{array}{rl} \bar{u}_0 \nabla\theta(\mathbf{x}^*) + \sum\limits_{i=1}^{m} \bar{u}_i \nabla g_i\left(\mathbf{x}^*\right) + \sum\limits_{j=1}^{k} \bar{v}_j \nabla h_j\left(\mathbf{x}^*\right) & = 0 \\ \sum\limits_{i=1}^{m} \bar{u}_i g_i\left(\mathbf{x}^*\right) & = 0 \\ \bar{\mathbf{u}} & \geq 0 \\ \left[\begin{array}{c} \bar{\mathbf{u}} \\ \bar{\mathbf{v}} \end{array} \right] & \neq 0 \end{array}\right\} \begin{array}{c} \text{Condizioni Generalizzate} \\ \text{Necessarie di} \\ \text{Fritz John} \end{array} \tag{1.15}$$

1.6. QUALIFICATION OF EQUALITY AND INEQUALITY CONSTRAINTS

Theorem 1.6.1. *Let* $\mathbf{x}^*$ *be a solution of the NLP. A sufficient condition to satisfy the necessary conditions of Karush-Kuhn-Tucker (KKT)*

$$\nabla\theta\left(\mathbf{x}^*\right) + \sum_{i=1}^{m} \bar{u}_i \nabla g_i\left(\mathbf{x}^*\right) + \sum_{j=1}^{k} \bar{v}_i \nabla h_j\left(\mathbf{x}^*\right) = 0 \tag{1.16a}$$

$$\sum_{i=1}^{m} \bar{u}_i g_i\left(\mathbf{x}^*\right) = 0 \tag{1.16b}$$

$$u_i \geq M \quad i \in M \tag{1.16c}$$

is the existence of a vector $\mathbf{y} \in E^n$ *such that:*

1.

$$\mathbf{y}^{\top} \nabla g_i\left(\mathbf{x}^*\right) < 0 \quad i \in \overline{M} = \left\{ i |\ i \in M,\ g_i\left(\mathbf{x}^*\right) = 0 \right\} \neq \emptyset \tag{1.17a}$$

2.

$$\mathbf{y}^{\top} \nabla h_j\left(\mathbf{x}^*\right) = 0 \quad j \in K \tag{1.17b}$$

3. *be linear independent the*

$$\nabla h_j\left(\mathbf{x}^*\right) \quad \text{per } j \in K \tag{1.17c}$$

1.7. UNCOSTRAINED OPTIMIZATION: PROBLEM FORMULATION

Given a function $f : \mathbb{R}^n \in \mathbb{R}$ find the value $\mathbf{x}^*$, which minimazes $f(\mathbf{x})$. If A is an open set of $\mathbb{R}^n$ and if $f \in C^1 A$, then the point '$\mathbf{x}^*$, will be a stationary of $f(\mathbf{x})$ if the following conditions hold:

$$\left.\frac{\partial f}{\partial x_i}\right|_{\mathbf{x}=\mathbf{x}^*} = 0 \quad (i = 1, 2, \ldots, n) \tag{1.18}$$

Moreover, a stationary point $\mathbf{x}^*$ is a relative minimum if the Hessian matrix is positive definite, that is

$$\mathbf{H} = \nabla^2 f(\mathbf{x}) = \left[\left.\frac{\partial^2 f}{\partial x_i \partial x_j}\right|_{\mathbf{x}=\mathbf{x}^*} \right] = \text{positive definite} \tag{1.19}$$

If the function is not differentiable, conditions (1.18) and (1.19) do not apply. In all cases the generally understood notion of a minimum, namely, $f(\mathbf{x}^*) < f(\mathbf{x})$, can be used to identify a minimum point.

The optimization methods are of iterative nature. They all start with an initial trial solution $\mathbf{x}^{(0)}$ and search for the minimum in a sequential manner, as shown in the flowchart depicted in Figure 1.3

1.8. INDIRECT SEARCH (DESCENT METHOD)

Theorem 1.8.1. *The gradient vector rappresents the direction of stepeest ascent.*

Proof: Let $\mathbf{x}$ be a point of $\mathbb{R}^n$. A neighbouring point is represented by $\mathbf{x} + \mathrm{d}\mathbf{x}$, where the magnitude of $\mathrm{d}\mathbf{x}$ is represented by

$$\mathrm{d}\mathbf{x}^{\mathsf{T}}\mathrm{d}\mathbf{x} = (\mathrm{d}s)^2 = \sum_{i=1}^{n} (\mathrm{d}x_i)^2 \tag{1.20}$$

If $f + \mathrm{d}f$ denotes the value of the objective function at $\mathbf{x} + \mathrm{d}\mathbf{x}$, the variation $\mathrm{d}f$ associeted with $\mathrm{d}\mathbf{x}$ can be expressed as

$$\mathrm{d}f = \sum_{i=1}^{n} \frac{\partial f}{\partial x_i}\mathrm{d}x_i = \nabla f^{\mathsf{T}}\mathrm{d}\mathbf{x}\,. \tag{1.21}$$

$\mathrm{d}\mathbf{x}$ can be expressed as

$$\mathrm{d}\mathbf{x} = \mathbf{u}\,\mathrm{d}s \tag{1.22}$$

where $\mathbf{u}$ is a unit vector along the direction of $\mathrm{d}\mathbf{x}$.

Taking into account Eqs. (1.21), (1.22), the rate of change of f with respect to s, is expressed as:

$$\frac{\mathrm{d}f}{\mathrm{d}s} = \sum_{i=1}^{n} \frac{\partial f}{\partial x_i}\frac{\mathrm{d}x_i}{\mathrm{d}s} = \nabla f^{\mathsf{T}}\mathbf{u} \tag{1.23}$$

We are interested in finding the particular step $\mathrm{d}\mathbf{x}$, along which, the value of $\frac{\mathrm{d}f}{\mathrm{d}s}$ is maximum. According to definition of vector product, eq. (1.23) can also be expressed as:

$$\frac{\mathrm{d}f}{\mathrm{d}s} = \|\nabla f\|\,\|\mathbf{u}\|\cos\theta\,, \tag{1.24}$$

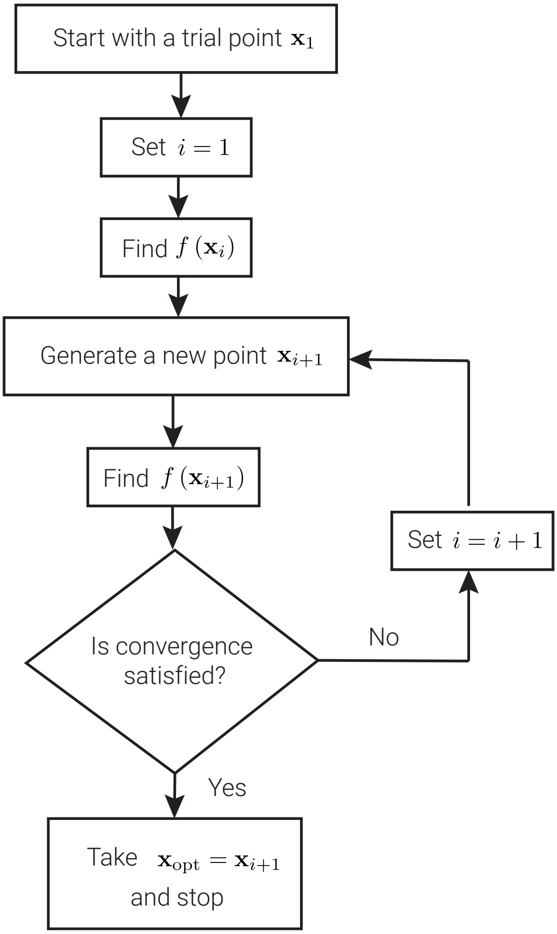


Figure 1.3: General iterative scheme of optimization

where θ is the angle formed by vectors ∇f and u. Eq. (1.24) is maximum (minimum) for $\theta = 0°$ ($\theta = 180°$). This proves, that the function value increases at a maximum rate in the direction of the gradient. ☐

Corollary 1.8.1.1. *The maximum rate of change at any point* $\mathbf{x}$ *is equal to the magnitude of the gradient.*

From a practical point of view, the gradient can be evaluated at point $\mathbf{x}_m$ with finite-differences formulas such as:

$$\left.\frac{\partial f}{\partial x_i}\right|_{\mathbf{x}_m} \approx \frac{f(\mathbf{x}_m + \Delta x_i \mathbf{u}_i) - f(\mathbf{x}_m)}{\Delta x_i}, \quad (i = 1, 2, \ldots, n) \tag{1.25}$$

$$\left.\frac{\partial f}{\partial x_i}\right|_{\mathbf{x}_m} \approx \frac{f(\mathbf{x}_m + \Delta x_i \mathbf{u}_i) - f(\mathbf{x}_m - \Delta x_i \mathbf{u}_i)}{2\Delta x_i}, \quad (i = 1, 2, \ldots, n) \tag{1.26}$$

where $\mathbf{u}_i$ is a vector of order n with all the componets equal to zero, except the i^{th} component which as a unit value.

1.9. RATE OF CHANGE OF A FUNCTION ALONG A DIRECTION

The rate of change of a function with respect to a parameter λ is expressed by

$$\frac{\mathrm{d}f}{\mathrm{d}\lambda} = \sum_{j=1}^{n} \frac{\partial f}{\partial x_j} \frac{\partial x_j}{\partial \lambda}. \tag{1.27}$$

Along a specified direction $\mathbf{s}_i$, any point $\mathbf{x}$ away from $\mathbf{x}^{(i)}$ can be expressed as

$$\mathbf{x} = \mathbf{x}^{(i)} + \lambda \mathbf{s}^{(i)} \tag{1.28}$$

Taking into account that

$$\frac{\partial x_j}{\partial \lambda} = \frac{\partial}{\partial \lambda}\left(x_j^{(i)} + \lambda s_j^{(i)}\right) = s_j^{(i)} \tag{1.29}$$

Eq. (1.27) is rewritten as follows

$$\frac{\mathrm{d}f}{\mathrm{d}\lambda} = \sum_{j=1}^{n} \frac{\partial f}{\partial x_j} s_j^{(i)} = \nabla f^{\mathsf{T}} \mathbf{s}^{(i)} \tag{1.30}$$

A necessary condition for the minimization of f respect to λ, is

$$\left.\frac{\mathrm{d}f}{\mathrm{d}\lambda}\right|_{\lambda=\lambda^*} = \nabla f^{\mathsf{T}}\big|_{\lambda^*} \mathbf{s}^{(i)} = 0 \tag{1.31}$$

Where λ^* is the sought optimal value of λ.

1.10. STEEPEST DESCENT (CAUCHY) METHOD

The steepestst descent method can be summarized in the following steps:

1. Set iteration counter $k = 0$ and pick and start with a given trial solution $\mathbf{x}^{(0)}$
2. Evaluate gradient $\nabla f(\mathbf{x}^{(k)})$ and set search direction
$$\mathbf{s}^{(k)} = -\nabla f(\mathbf{x}^{(k)}) \tag{1.32}$$
3. Determine from condition (1.31) the optimal step lenght λ^* in the direction of $\mathbf{s}^{(i)}$ and set
$$\mathbf{x}^{(k+1)} = \mathbf{x}^{(k)} + \lambda^* \mathbf{s}^{(k)} \tag{1.33}$$
4. Test $\mathbf{x}^{(k+1)}$ for optimality. If it is optimum stop the process, otherwise set $k = k+1$ and go to step 2.

1.11. NEWTON METHOD

A function $f(\mathbf{x})$ twice differentiable, can be approximated up to the second order as follows:

$$f(\mathbf{x}^{(k+1)}) \approx f(\mathbf{x}^{(k)}) + \nabla^{\mathsf{T}} f(\mathbf{x}^{(k)}) \Delta\mathbf{x}^{(k)} + \frac{1}{2}\left(\Delta\mathbf{x}^{(k)}\right)^{\mathsf{T}} \nabla^2 f(\mathbf{x}^{(k)}) \Delta\mathbf{x}^{(k)} \tag{1.34}$$

where $\Delta\mathbf{x}^{(k)} = \mathbf{x}^{(k+1)} - \mathbf{x}^{(k)}$.

If we minimaize the quantity $f(\mathbf{x}^{(k+1)}) - f(\mathbf{x}^{(k)})$ with respect to $\Delta\mathbf{x}^{(k)}$ we obtain:

$$\nabla f(\mathbf{x}^{(k)}) + \nabla^2 f(\mathbf{x}^{(k+1)}) \Delta\mathbf{x}^{(k)} = 0$$

or

$$\Delta\mathbf{x}^{(k)} = -\left[\nabla^2 f(\mathbf{x}^{(k)})\right]^{-1} \nabla f(\mathbf{x}^{(k)}) \,. \tag{1.35}$$

The direction of the steepest descent $\mathbf{s}^{(k)}$ is :

$$\mathbf{s}^{(k)} = -\left[\nabla^2 f(\mathbf{x}^{(k)})\right]^{-1} \nabla f(\mathbf{x}^{(k)}) \tag{1.36}$$

1.12. MARQUARDT METHOD

The steepest descent method has a slow convergence rate, but is less dependent on starting value. The Newton method, on the other hand, has a fast convergence, but is sensitive to the closeness of starting value to optimum value.

The Marquardt method attempts to take advantage, of steepest descent and Newton methods. In particular, the discussed method modifies the elements on the main diagonal of Hessian matrix as Follows:

$$\mathbf{H}_k = \mathbf{H}_k + \alpha_k \mathbf{I} \tag{1.37}$$

where $\mathbf{I}$ is the identity matrix and α_i a positive constant chosen to ensure the positive definiteness of $\mathbf{H}_k$.

When α_i is sufficiently large, $\alpha_i\,\mathbf{I}$ dominates $\mathbf{H}_k$ and the computation of inverse is simplified as follows:

$$\mathbf{H}_k^{-1} = (\mathbf{H}_k + \alpha_k \mathbf{I})^{-1} \approx \frac{\mathbf{I}}{\alpha_k} \tag{1.38}$$

In the first step of the iteration large values of $\alpha^{(k)}$ are chosen and the Marquardt method coincides with steepest descent method.

As the iterative process successfully progresses, the values of α are gradually decreased to zero and the correction vector $\Delta\mathbf{x}^{(k)}$ coincides with the one of Newton's method.

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2

REVIEW OF MACHINE LEARNING AND NEURAL NETWORKS

> *The neural network is this kind of technology that is not*
> *an algorithm, it is a network that has weights on it,*
> *and you can adjust the weights so that it learns.*
>
> Howard Rheingold

Neural networks are one of the most important tool used in Machine Learning to cast a model. In this chapter the main features of such tool will described together with some standard algorithms.

In this chapter the focus is on the meaning of commonly used terms adopted when developing applications based on artificial intelligence techniques.

By **artificial intelligence** it is usually meant the theory and development of computer systems able to perform tasks normally requiring human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages.

Machine learning and deep learning are brances of artificial intelligence. Following Kim [1], we can state that:

> "Deep Learning is a kind of Machine Learning, and Machine Learning is a kind of Artificial Intelligence."

Machine learning and **Deep learning** are often interchangeably used. However, as we will discuss, there is a significant theoretical difference between the two domains (see Figure 2.1).

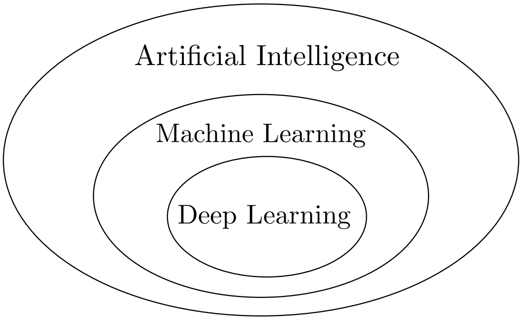

Figure 2.1: Relationship between Artificial Intelligence, Machine Learning and Deep Learning

2.1. MACHINE LEARNING

Machine Learning includes all the techniques that define a *model* out of *data*. The final result is a model useful for inference purposes. As depicted in Figure 2.2, such result is achieved through *training*, in a fashion similar to the human process.

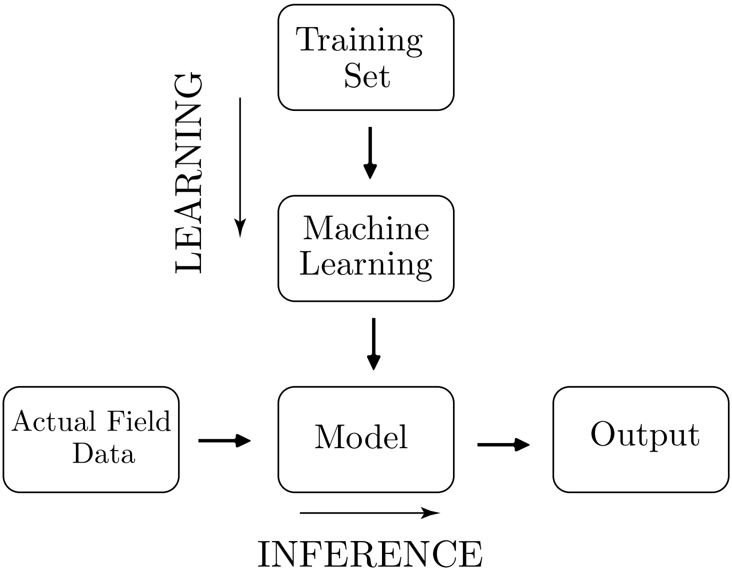

Figure 2.2: Machine Learning Process

Traditionally the modelling activity is based on the availability of analytical laws. However, there are many practical problems where analytical models are hardly available. A simple example of such problems is the handwriting recognition. For this class of problems, Machine Learning represents a viable solving tool.

2.1.1. THE PROCESSES OF MACHINE LEARNING

The main processes of Machine Learning are summarized in Figure 2.3. In particular we distinguish:

- **Learning**: use of training data for model definition;
- **Inference**: use of the model for prediction from field data.

It must be acknowledged that training and actual data field sets are different.

Figure 2.4: The Learning Process

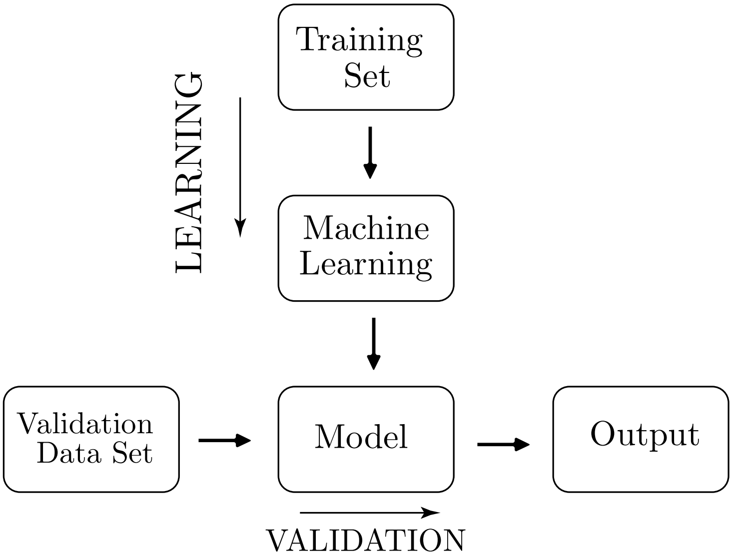

Figure 2.3: Learning and Inference Phases

The learning phase, as shown in Figure 2.4, can be divided in two steps:

- **training**;
- **validation**.

These require the splitting of the initially available data into a training and validation sets. During the training, different optimization algorithms are applied in order to achieve the best matching between the model output and the input training data. The model reliability is verified during validation. A subset of the initial dataset is excluded from the training and reserved for this purpose only.

A main concern of the learning phase is **overfitting**. The model complexity could be such that all the training data are perfectly matched. This may look like an ideal situation. However, the output could be prone to error due to model sensitivity to small data variations. A requested feature of a model is *generalizability*, *i.e.* the capability of providing accurate results in any situation. The following text excerpt [1] well explains the situation

> The Nobel prizewinning physicist Enrico Fermi was once asked his opinion of a mathematical model some colleagues had proposed as the solution to

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[1] `http://neuralnetworksanddeeplearning.com`

> an important unsolved physics problem. The model gave excellent agreement with experiment, but Fermi was skeptical. He asked how many free parameters could be set in the model. “*Four*" was the answer. Fermi replied: “*I remember my friend Johnny von Neumann used to say, with four parameters I can fit an elephant, and with five I can make him wiggle his trunk.*".

Models with a large number of free parameters can describe a wide range of phenomena. The agreement with the available data does not make it a good model. Likely there is enough freedom in the model to describe almost any data set of the given size, without capturing any genuine insights into the underlying phenomenon.

When that happens the model will work well only for the training data, but will fail to *generalize* to new situations.

One of the strategies against overfitting is **regularization**, a procedure aimed to simplify the model.

Validation is the process that reserves part of training data for testing the reliability and accuracy of the model.

Crossvalidation is a process based on the exchanging of the learning and the training data set (see Figure 2.5). At the end of k^{th} experiment the optimal result is obtained through average.

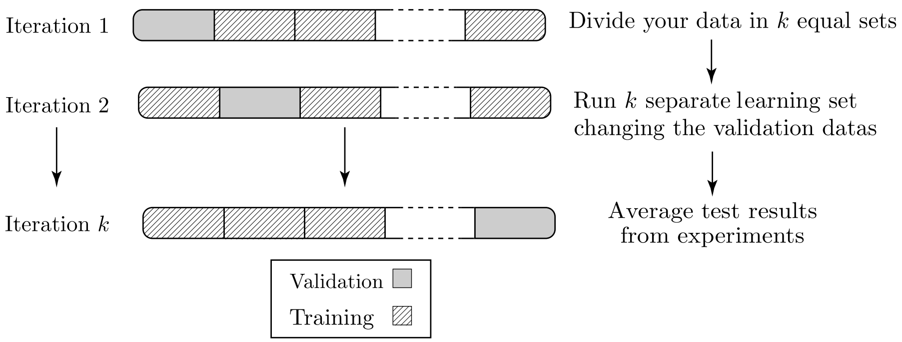

Figure 2.5: k-Fold Crossvalidation

2.1.2. TYPES OF MACHINE LEARNING

Depending on the training method, Machine Learning can be classified according to the following categories, also summarized in Table 2.1:

- **Supervised learning**,
- **Unsupervised learning**,
- **Reinforcement learning**

Table 2.1: Types of Machine Learning techniques

Type of Machine Learning	Data Set Structure
Supervised Learning	`{ input, correct output }`
Unsupervised Learning	`{ input }`
Reinforcement Learning	`{ input, some output, grade for this output }`

Supervised learning is the machine learning task of learning a function that maps an input to an output based on example input-output pairs [2].

In order to solve a given problem of supervised learning, one has to perform the following steps [2]:

1. Determine the type of training examples. Before doing anything else, the user should decide what kind of data is to be used as a training set. In case of handwriting analysis, for example, this might be a single handwritten character, an entire handwritten word, or an entire line of handwriting.
2. Gather a training set. The training set needs to be representative of the real-world use of the function. Thus, a set of input objects is gathered and corresponding outputs are also gathered, either from human experts or from measurements.
3. Determine the input feature representation of the learned function. The accuracy of the learned function depends strongly on how the input object is represented. Typically, the input object is transformed into a feature vector, which contains a number of features that are descriptive of the object. The number of features should not be too large, because of the curse of dimensionality; but should contain enough information to accurately predict the output.
4. Determine the structure of the learned function and corresponding learning algorithm.
5. Complete the design. Run the learning algorithm on the gathered training set. Some supervised learning algorithms require the user to determine certain control parameters. These parameters may be adjusted by optimizing performance on a subset (called a validation set) of the training set, or via cross-validation.
6. Evaluate the accuracy of the learned function. After parameter adjustment and learning, the performance of the resulting function should be measured on a test set that is separate from the training set.

Unsupervised Learning [3] is a branch of machine learning that learns from test data that has not been labeled, classified or categorized. Instead of responding to feedback, unsupervised learning identifies commonalities in the data and reacts based on the presence or absence of such commonalities in each new piece of data. The algorithms find

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[2] From https://en.wikipedia.org/wiki/Supervised_learning

[3] From https://en.wikipedia.org/wiki/Unsupervised_learning

and classify the relationship between elements in a data set mimicking human logic by searching structures, patterns and feature in available data set.

Unsupervised Learning is the task of reinforcement learning is to use observed rewards to learn an optimal (or nearly optimal) policy for the environment [2]. The correct input outpairs are not required in this case. The training data include input, some output and corresponding grade.

2.2. SUPERVISED LEARNING: CLASSIFICATION AND REGRESSION

IN supervised learning we distinguish two distinct operation:

- regression: the problem of predicting numerical continuous quantitivi output for a given input;
- classification: the probledm of predicting discrete class output for a given input.

More precisely, regression predictive modeling defines a mapping function f from input variables $\mathbf{x}$ to a *continuous*[4] output variables $\mathbf{y}$.

Given a datasets of age and income, an example of regression is to estimate income value from age or viceversa.

Conversely, classification predictive modeling defines a mapping function f from input variables $\mathbf{x}$ to *discrete* output variables $\mathbf{y}$.

The output variables consist of labels or categories. Thus, f predicts the class or category for a given $\mathbf{x}$.

A classic example is the Spam Filter problem, where the aim is to classify the mails into regular or spam.

Neural Networks are used to implement models in Machine Learning. Broadly, speaking an artificial neural network (ANN) can be interpreted as a signal processing system including elementary components, called artificial neurons or nodes, interconnected by links called connections which cooperate to solve a desidered computational task.

Often ANNs are considered simplified models of the human brain. Despite this view is exaggerated and misleading, one can establish somme correspondences.

2.3. BASIC OF ARTIFICIAL NEURONS

To continue with the comparison of ANN with human brain, when we acquire knowledge, connections of the neurons change. The human neurons do not store information, they process and transmit information to each other. The ANN imitates this mechanism of human brain (see Table 2.2).

In particular, the ANN is composed of nodes, that corresponds to neurons, and lines that correspond to dendrites.

The output signal from a cell is transmitted to other neurons by means of axons.

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[4] A continuous output variable is a real-value, such as an integer or floating point value.

Table 2.2: Functional similarities between human brain and ANN

Brain	Neural Network
Synapses	Inputs ($\mathbf{x}$)
Neurons	Nodes
Connections of neurons	Connection weights
Axons	Outputs ($\mathbf{y}$)

2.4. HYPERPLANES

In geometry a hyperplane is a subspace of one dimension less than its ambient space (e.g. in a 2 dimensional space, their hyperplanes are 1-dimensional lines).

From the previous example, we can deduce that an hyperplane can be described by the following equation:

$$\mathbf{w} \cdot \mathbf{x} = b \tag{2.1}$$

where $\mathbf{w} \neq \mathbf{0}$ and b is an arbitrary constant.

Hyperplanes are used for binary classification in linearly separable data. Let us define an hypothesis function h

$$h = \begin{cases} +1 & \text{if } \mathbf{w} \cdot \mathbf{x}_i + b \geq 0 \\ -1 & \text{if } \mathbf{w} \cdot \mathbf{x}_i + b < 0 \end{cases} \tag{2.2}$$

which can be redefined in a more compact way as:

$$\begin{aligned} h(\mathbf{x}_i) &= \operatorname{sign}(\mathbf{w} \cdot \mathbf{x}_i + b) \\ &= \operatorname{sign}(\mathbf{w} \cdot \hat{\mathbf{x}}_i) \end{aligned}$$

where

$$\begin{aligned} \hat{\mathbf{x}} &= \begin{bmatrix} b & \mathbf{w} \end{bmatrix}^\intercal \\ \hat{\mathbf{x}}_i &= \begin{bmatrix} 1 & \mathbf{x}_i \end{bmatrix}^\intercal \end{aligned}$$

2.5. THE PERCEPTRON - A BASIC NEURAL NETWORK

Let $\mathbb{D}$ represent a set of training samples $(\mathbf{x}_i, y_i)$ where y_i is the label of the sample and can assume 2 values (+1 or -1).

We wish to find a vector $\mathbf{w}$ such that

$$h(\mathbf{x}_i) = \operatorname{sign}(\mathbf{w} \cdot \mathbf{x}_i) = y_i \quad \forall \mathbf{x}_i \in \mathbb{D} \tag{2.3}$$

The perceptron learning algorithm can be summarized into the following steps:

1. choose a random vector $\mathbf{x}$;
2. If present, choose a random misclassified sample from $\mathbb{D}$ $(\mathbf{x}_m, y_m)$ and redefine $\mathbf{w}$ as follows:

$$\mathbf{w} \Rightarrow \mathbf{w} + y_m \mathbf{x}_m \tag{2.4}$$

3. Classify all the data with the updated value of **w**.
4. Repeat steps 2) and 3) until there is anot any missclassified data.

The idea behind the update rule of **w** can be explained by the following example: If $\text{sign}(\mathbf{w}\cdot\mathbf{x}_i) = -1$ for a missclassified data, this means that there is an angle $\theta > 90°$ between vectors **w** and $\mathbf{x}_i$. In order to get $\text{sign}(\mathbf{w}\cdot\mathbf{x}_i) = +1$ the angle betwwen **w** and $\mathbf{x}_i$ must be increased.

REFERENCES

[1] P. Kim. *MATLAB Deep Learning: With Machine Learning, Neural Networks and Artificial Intelligence.* Apress, 1 edition, 2017.

[2] S. Russell and P. Norvig. *Artificial Intelligence. A Modern Approach.* Pearson, 3rd edition, 2016.

3

COMPUTER VISION TECHNIQUES

> *If I have seen further it is by standing*
> *on the shoulders of giants.*
>
> Isaac Newton

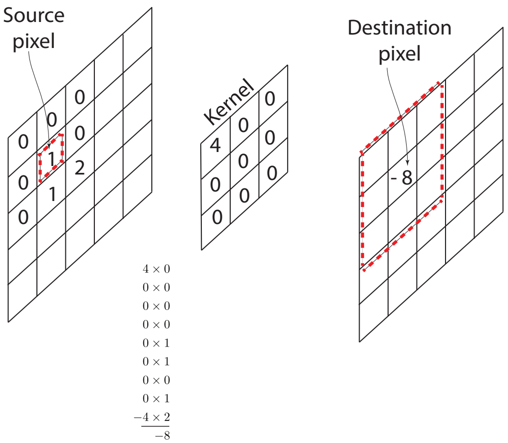
3.1. KERNEL IMAGE PROCESSING

The general expression of convolution is

$$g(x,y) = \left(w * f\right)(x,y) = \sum_{s=-a}^{a} \sum_{t=-b}^{b} w(s,t) f(x-s, y-t) \tag{3.1}$$

where $g(x,y)$ is the filtered image, $f(x,y)$ is the original image and w is the filter kernel.

Convolution is the processing of adding each element of the image to its local neighbors weighted by kernel.



3.2. IMAGE GRADIENT

An image gradient is a directional change of intensity or color in an image.

The definition of continuous one dimensional variable is given by the following expression:

$$\frac{df}{dx} = \lim_{\Delta x \to 0} \frac{f(x) - f(x - \Delta x)}{\Delta x} = f'(x) \tag{3.2}$$

If we deal with an image data, the smallest possible Δx is 1 (one pixel). Thus, for we can use the following expression for the approximation of derivative:

$$\frac{df}{dx} \approx \frac{f(x) - f(x-1)}{1} = f(x) - f(x-1) \tag{3.3}$$

Taking the difference between (x) and $(x-1)$ is only one of the following three possibilities available:

- $f(x) - f(x-1) \approx f'(x)$ Backward difference
- $f(x) - f(x+1) \approx f'(x)$ Forward difference
- $f(x+1) - f(x-1) \approx f'(x)$ Central difference

The derivative of an image has 2 dimensions. We can take the derivative in the x direction or in the y direction or together.

The following expressions define the gradient vector:
Given function $f(x, y)$

$$\text{Gradient vector } \nabla f(x,y) = \begin{bmatrix} \dfrac{\partial f(x,y)}{\partial x} & \dfrac{\partial f(x,y)}{\partial y} \end{bmatrix}^{\mathsf{T}} = \begin{bmatrix} f_x \\ f_y \end{bmatrix}$$

$$\left|\nabla f(x,y)\right| = \sqrt{f_x^2 + f_y^2}$$

$$\theta = \tan^{-1} \frac{f_y}{f_x}$$

To compute the derivative with respect ot x at a given point, the following steps are applied:

- use central differences
- average the derivative of the pixel with that of the row above and row below

$$\mathbf{G}_x = \frac{1}{3} \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix} * \mathbf{A} \tag{3.4}$$

$$\mathbf{G}_y = \underbrace{\frac{1}{3} \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}}_{\text{Derivative mask}} * \mathbf{A} \tag{3.5}$$

where $\mathbf{A}$ is the source image and $\mathbf{G}_x$, $\mathbf{G}_y$ are the two images containing at each point the horizontal and vertical derivative. (see also Prewit operator)

3.3. Histogram of oriented gradients (HOG)

HOG is a feature descriptor that is used to automatically detect objects from images. The HOG descriptor encodes the distribution of directions of gradients in localized portions of an image.

The object appearance and the shape within an image can be described by the histogram of edge directions.

The implementation of the HOG descriptors can be divided in 4 parts:

I GRADIENT COMPUTATION

The method requires to apply the following filter kernels:

$$f_x = \begin{bmatrix} --1 & 0 & 1 \end{bmatrix} \tag{3.6}$$

$$f_y = \begin{bmatrix} -1 \\ 0 \\ 1 \end{bmatrix} \tag{3.7}$$

Thus given an image I, the following convolution operations result in the derivatives of the image in the x and y directions:

$$I_x = I * f_x \tag{3.8}$$

$$I_y = I * f_y \tag{3.9}$$

The magnitude of the gradient and the orientation θ are given by the following expressions:

$$\theta_{i,j} = \tan^{-1} \frac{(I_y)_{i,j}}{(I_y)_{i,j}} \tag{3.10}$$

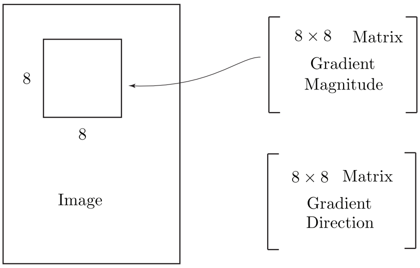
$$|g|_{i,j} = \sqrt{I^2_{x_{i,j}} + I^2_{y_{i,j}}} \tag{3.11}$$

If I is the given gray image represented by an $m \times n$ matrix, I_x and I_y are also $m \times n$ matrices. Thus, the gradient at pixel (i, j) will be

$$\begin{bmatrix} (I_x)_{i,j} \\ (I_y)_{i,j} \end{bmatrix} \tag{3.12}$$

II CELL ORIENTATION HISTOGRAM

The second step is the computation of the cell histogram. The given image is thus divided in cells of 8×8 pixels. This design choice arise from the fact that HOG descriptors were first used for pedestrian detection. In fact, in a scaled picture of 64 × 128, 8 × 8 cells are large enough to capture features such as face, top head, etc.



We are now ready to create an histogram of gradients in 8 × 8 cells. Each histogram contains 9 bins corresponding to angles $0^\circ, \quad 20^\circ, \quad 40^\circ, \quad \ldots \quad ,160^\circ$

The contributions of all the pixels in the 8 × 8 cells are added to create the 9 bin histogram

III BLOCK NORMALIZATION

Our descriptor should be independent to lighting variations. To achieve this feature, histograms must be normalized.

For this purpose:

1. Join together 4 cells as shown in the picture
2. Each histogram in the group can be interpreted as a vector

——— H1
——— H2
——— H3
——— H4

3. Join the four vectors to form a 36 × 1 vector $\mathbf{h}_i$
4. Normalize $\mathbf{h}_i$

IV HOG FEATURE VECTOR

Join all the $\mathbf{h}_i$ vectors to form the HOG feature vector.

3.4. EDGE DETECTION PROBLEM

An edge corresponds to a 0 order discontinuity in the intensity function of an image. Edge detectors are an important tool in computer vision. They simplify the image data in order to minimize the amount of data to be processed.

Given an image corrupted by acquisition noise, locate the edges most likely to be generated by scene elements and not by noise.

Intensity variations are also caused by noise, this produces a false edge detection.

The contours of potentially interesting scene elements, like solid objects, marks on surfaces, and shadows, all generate intensity edges.

The three steps of edge detection are:

1. Noise smoothing

2. Edge enhancement Edge location

Taking into account the definition of an edge it is possible in edge detection methods to distinguish the following categories:

- Gradient based methods: edges are regarded as local extrema of the gradient function;
- Laplacian based: edges are regarded as zero laplacian function.

One of the most used edge detector is the Canny edge detector.

3.4.1. GRADIENT BASED METHODS

Given an image let us consider its *intensity function* f (in the following we will initially consider f as a continuous function and then the discrete case will be discussed). At a given point (x_0, y_0), the rate of change $r_{f,theta}$ of the intensity function along the direction of θ can be computed as

$$r_{f,\theta} = \left.\frac{\partial f}{\partial x}\right|_{x=x_0} \cos\theta + \left.\frac{\partial f}{\partial y}\right|_{y=y_0} \sin\theta \tag{3.13}$$

The direction θ for which (3.13) is maximum (cite steepest descente) si

$$\theta^* = \arctan \frac{\frac{\partial f}{\partial y}}{\frac{\partial f}{\partial x}} \tag{3.14}$$

The rate of change has a magnitude of

$$|\nabla f| = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2} \tag{3.15}$$

It is clear that $\nabla f = |\nabla f| < \theta$.

A point in image is considered belonging to an edge if the gradient magnitude is greater than some defined treshold.

∇I cna be computed if the directional derivatives of f are known in two orthogonal directions.

Gradient based methods can be distinguished by:

a) methods used to approximate one dimensional derivatives;

b) directions used to compute the gradient;

c) manner in which they combine these approximations to form gradient magnitude.

In the following some gradient operators will be presented.

3.4.2. PREWIT OPERATOR

The main idea behind Prewit operator is the use of central finite differences:

$$\frac{\partial f(x,y)}{\partial x} \approx \frac{1}{2}\left[f(x+1,y) - f(x-1,y)\right] \tag{3.16}$$

This is equivalent to apply the following convolution kernel

$$\begin{array}{|c|c|c|}\hline -1 & 0 & 1 \\ \hline \end{array} \quad \begin{array}{|c|}\hline -1 \\ \hline 0 \\ \hline 1 \\ \hline \end{array} \tag{3.17}$$

We can improve robustness to noise by applying the following kernels

$$\underset{\partial/\partial x}{\begin{array}{|c|c|c|}\hline -1 & 0 & 1 \\ \hline -1 & 0 & 1 \\ \hline -1 & 0 & 1 \\ \hline \end{array}} \quad \underset{\partial/\partial y}{\begin{array}{|c|c|c|}\hline -1 & -1 & -1 \\ \hline 0 & 0 & 0 \\ \hline 1 & 1 & 1 \\ \hline \end{array}} \tag{3.18}$$

Let the matrix **A** represent the original B/W image and let G_x and G_y be two images which, at each position, contain the horizontal and vertical derivative approximations:

$$\mathbf{G}_x = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix} * \mathbf{A} \tag{3.19a}$$

$$\mathbf{G}_y = \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix} * \mathbf{A} \tag{3.19b}$$

It shoud be observed that the $\frac{1}{2}$ factor present in equation (3.16) could also be present in (**??**), but as long as this factor is nowhere applied, all gradient remain comparable in a relative way.

3.4.3. SOBEL OPERATOR

It is a 3 × 3 convolutional kernel defined as

$$\underset{\partial/\partial x}{\begin{array}{|c|c|c|}\hline -1 & 0 & 1 \\ \hline -2 & 0 & 2 \\ \hline -1 & 0 & 1 \\ \hline \end{array}} \quad \underset{\partial/\partial y}{\begin{array}{|c|c|c|}\hline -1 & -2 & -1 \\ \hline 0 & 0 & 0 \\ \hline 1 & 2 & 1 \\ \hline \end{array}} \tag{3.20}$$

$$\mathbf{G}_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} * \mathbf{A} \tag{3.21a}$$

$$\mathbf{G}_y = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix} * \mathbf{A} \tag{3.21b}$$

3.5. LAPLACIAN BASED EDGE

In Laplacian based method edges are identified by zero-crossing in the second derivative of the image.

Consider the following Taylor expansion

$$\begin{aligned} f(x+h) &= f(x) + hf'(x) + \frac{1}{2}h^2 f''(x) + \frac{1}{3!}h^3 f'''(x) + o\left(h^4\right) \\ f(x-h) &= f(x) - hf'(x) + \frac{1}{2}h^2 f''(x) - \frac{1}{3!}h^3 f'''(x) + o\left(h^4\right) \end{aligned}$$

Therefore, considered that

$$f(x+h) + f(x-h) = 2f(x) + h^2 f''(x) + o\left(h^4\right)$$

the second derivative is

$$f''(x) \approx \frac{f(x+h) + f(x-h) - 2f(x)}{h^2} \tag{3.22}$$

and the Laplacian kernel can thus be represented as

$$\begin{aligned} \nabla^2 =& \nabla_x^2 + \nabla_y^2 = \begin{bmatrix} 0 & 0 & 0 \\ 1 & -2 & 1 \\ 0 & 0 & 0 \end{bmatrix} + \begin{bmatrix} 0 & 1 & 0 \\ 0 & -2 & 0 \\ 0 & 1 & 0 \end{bmatrix} \\ &= \underbrace{\begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix}}_{\text{Laplacian filter}} \end{aligned} \tag{3.23}$$

3.6. LAPLACIAN OF GAUSSIAN LOG

This technique can be divided in two steps:

1) The image is smoothed with a Gaussian filter to suppress/reduce noise, before Laplacian filter.

2) The Laplacian os the smoothed image is computed.

Let $f(x,y)$ represent the intensity function of an image and let G_σ represent a 2D Gaussian kernel

$$G_\sigma = \frac{1}{2\pi\sigma^2} \mathrm{e}^{-\left(\frac{x^2+y^2}{2\sigma^2}\right)} \tag{3.24}$$

$$\Delta\left[G_\sigma(x,y) * f(x,y)\right] = \underbrace{\left[\Delta G_\sigma(x,y)\right]}_{\text{Laplacian of Gaussian}} * f(x,y) \tag{3.25}$$

3.7. CANNY EDGE DETECTOR

Canny edge detector can be divided into the following steps:

SMOOTHING

Since all digital images are affected with noise, the input image I is convolved with a Gaussian smoothing filter G

$$S[i,j] = I[i,j] * G[i,j,\sigma] \tag{3.26}$$

where σ controls the degree of smoothing.

IMAGE GRADIENT

From smoothed image S, the gradient is computed using finite differences

$$P[i,j] \approx \frac{S[i,j+1] - S[i,j] + S[i+1,j+1] - S[i+1,j]}{2} \tag{3.27}$$

$$Q[i,j] \approx \frac{S[i,j] - S[i+1,j] + S[i,j+1] - S[i+1,j+1]}{2} \tag{3.28}$$

where matrices **P** and **Q** represent the image derivatives in the x and y direction, respectively.

For each pixel of the smoothed image S gradient magnitude M and the gradient direction θ are computed

$$M[i,j] = \sqrt{P[i,j]^2 + Q[i,j]^2} \tag{3.29}$$

$$\theta[i,j] = \mathrm{ATAN2}\left(\frac{Q[i,j]}{M[i,j]}, \frac{P[i,j]}{M[i,j]}\right) \tag{3.30}$$

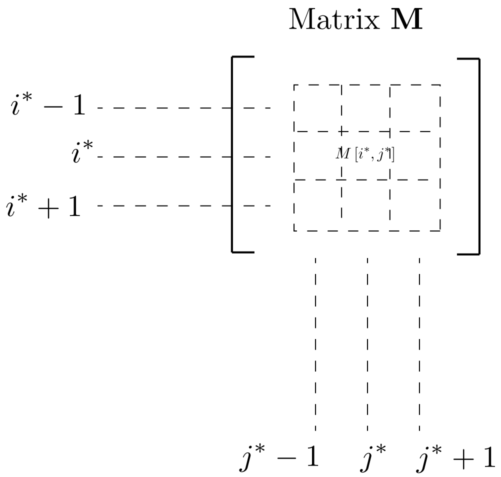
NON MAXIMA SUPPRESSION

Let us define a function SECTOR(θ) defined as follows:

$$\mathrm{SECTOR}(\theta) = \begin{cases} 0 & \text{if } \theta \in [0, 22.5°] \text{ or } \theta \in [337.5°, 360°] \text{ or } \theta \in [157.5°, 202.5°] \\ 1 & \text{if } \theta \in [22.5°, 77.5°] \text{ or } \theta \in [202.5°, 247.5°] \\ 2 & \text{if } \theta \in [77.5°, 112.5°] \text{ or } \theta \in [247.5°, 292.5°] \\ 3 & \text{if } \theta \in [112.5°, 157.5°] \text{ or } \theta \in [292.5°, 337.5°] \end{cases} \tag{3.31}$$

The computed angles θ are assigned to a sector with the function SECTOR.

The magnitude matrix **M** is then inspected with a 3 × 3 neighborhood matrix. The central element $M[i^*, j^*]$ of the neighborhood matrix is then compared along the direction computed by the function $\mathrm{SECTOR}(\theta[i^*, j^*])$ with its two neighbors. $M[i^*, j^*]$ is set to zero only if it is lower than one of its neighbors.



The following example will clarify the procedure:

1. If SECTOR$(\theta[i^*,j^*]) = 0$, $M[i^*,j^*]$ is computed with $M[i^*,j^*+1]$, $M[i^*,j^*-1]$
2. If SECTOR$(\theta[i^*,j^*]) = 1$, $M[i^*,j^*]$ is computed with $M[i^*-1,j^*+1]$, $M[i^*+1,j^*-1]$
3. If SECTOR$(\theta[i^*,j^*]) = 2$, $M[i^*,j^*]$ is computed with $M[i^*-1,j^*]$, $M[i^*+1,j^*]$
4. If SECTOR$(\theta[i^*,j^*]) = 3$, $M[i^*,j^*]$ is computed with $M[i^*-1,j^*-1]$, $M[i^*+1,j^*+1]$

The results of nonmaxima suppression are stored in a matrix **N**.
TRESHOLDING The matrix **N** is processed with a double tresholding algorithm. At the beginning two edge images are produced and every pixel below the tresh level τ in **N** will be set to 0.

1) $\mathbf{T}_1$ is the matrix generated with tresh level τ_1

1) $\mathbf{T}_2$ is the matrix generated with tresh level τ_2

We assume $\tau_1 > \tau_2$ (usually $\tau_2 \approx 2\tau_1$).

Since $\mathbf{T}_2$ was formed with an higher tresh level, it will contain fewer *false edges* and therefore pixels contained in $\mathbf{T}_2$ will be considered by the algorithm *pure edges*. The algorithm will then examine points (elements) $\neq 0$ in $\mathbf{T}_1$ matrix. Given a point of $\mathbf{T}_1$ denoted by $\mathbf{T}_1[i^*,j^*]$ if a pure edge is found in a 8-neighbours of $\mathbf{T}_1[i^*,j^*]$, then $\mathbf{T}_1[i^*,j^*]$ will be considered an edge too.

REFERENCES

[1] F. van der Heijden. *Image based measurement systems*. John Wiley & Sons, 1994.

4

AUTOMATIC PLATE RECOGNITION SYSTEM

> *We can only see a short distance ahead,*
> *but we can see plenty there that needs to be done.*
>
> Alan Turing

This chapter contains the outline of the proposed algorithm.

4.1. INTRODUCTION

Purpose of this thesis project is the development of an automatic car plate recognition system based on the combined use of **Computer Vision** and **Machine Learning** techniques. To increase both flexibility and success rate, the system integrates different computational approaches. Great care has been taken to make the system independent of the different national features such as color.

4.2. SOFTWARE AND TOOLS

This project has been entirely developed in `Python 3` and uses the following open-source software libraries:

- OpenCV `https://opencv.org`
- NumPy `http://www.numpy.org/`
- Tesseract 4 `https://github.com/tesseract-ocr/`
- Imutils. `https://github.com/jrosebr1/imutils`

For the part of **Machine Learning** the following trained networks have been used:

Figure 4.1: (Left) Recognition of an Indian car plate, (Right) Recognition of an Italian (European) car plate

- MobileNetSSD (Google) https://github.com/tensorflow/models/tree/master/research/object_detection
- EAST https://github.com/oyyd/frozen_east_text_detection.pb

4.3. SYSTEM ARCHITECTURE

The picture in Figure 4.2 depicts the proposed system architecture.

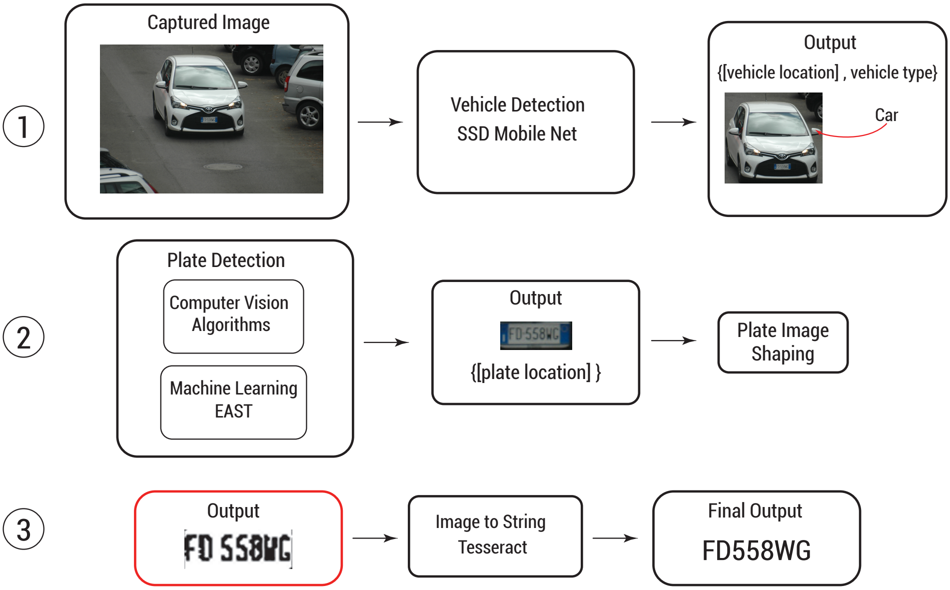


Figure 4.2: System Architecture

The first step in our system, given an input image, is to localize and classify vehicles with the help of **SSD** (**S**ingle **S**hot MultiBox **D**etector) which is a Machine Learning method for object recognition from digital images.

The theoretical bases of this method are available from the following web page:

- SSD: Single Shot MultiBox Detector `https://arxiv.org/abs/1512.02325`

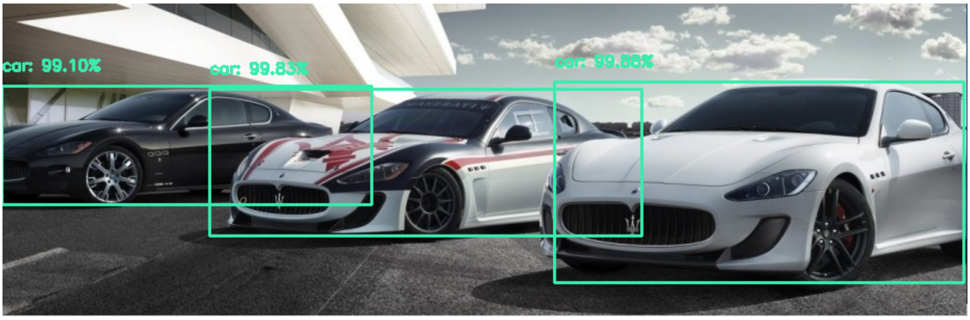
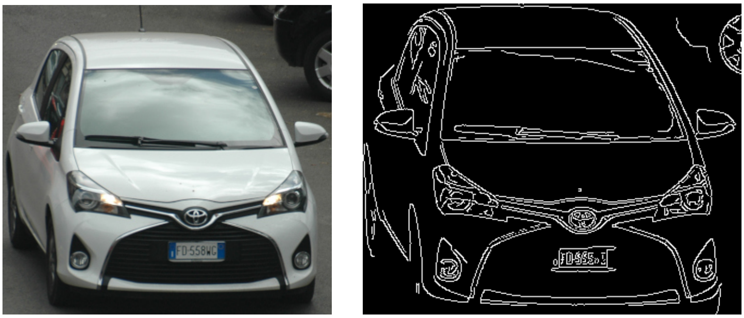


Figure 4.3: Application of SSD: Examples of results

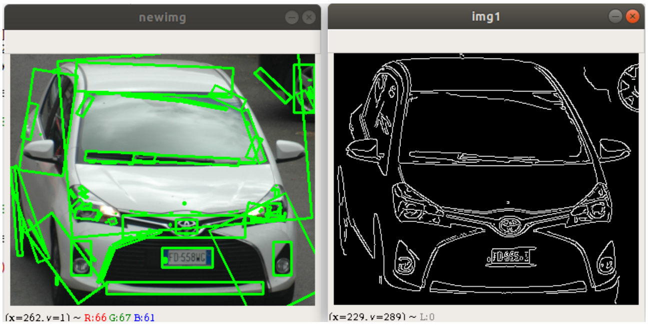
Currently there is not a flawless car plate recognition system. Since the outcome is affected by many factors (light, optics, meteo, etc.) different methodologies and techniques are available in technical literature. To increase success rate our system integrates different techniques of compute vision and machine learning. The final outcome is a selection from the breeding of results from different approaches.

4.4. APPLICATION OF COMPUTER VISION TECHNIQUES

Our system detects the vehicle shape edges by means of the Canny algorithm



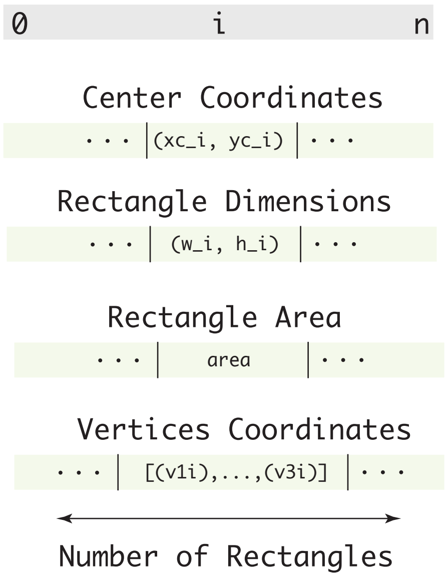
The image edges are extracted by means of the `OpenCV`: `cv2.findContours` procedure Afterwards the rectangles are identified.



(x=262, y=1) ~ R:66 G:67 B:61

(x=229, y=289) ~ L:0

A rectangle search procedure (named `findRect`) has been coded. It requires as input the binary image and gives as output the following arrays:



```
Center Coordinates
 ... | (xc_i, yc_i) | ...

Rectangle Dimensions
 ... | (w_i, h_i) | ...

Rectangle Area
 ... | area | ...

Vertices Coordinates
 ... | [(v1i),...,(v3i)] | ...
```

4.5. INDEXES OF MERIT

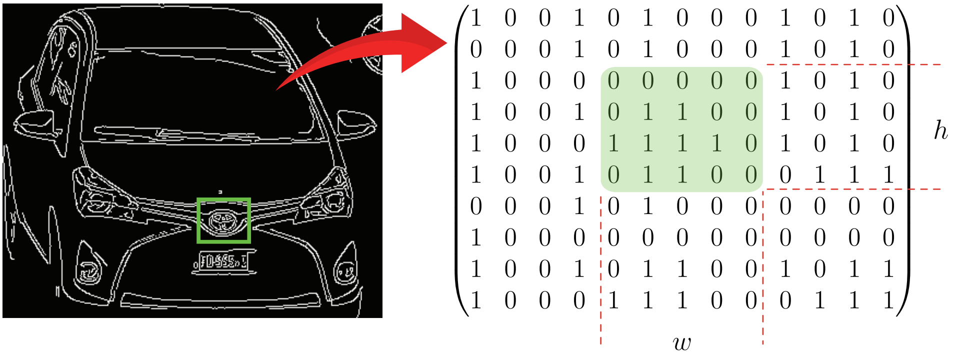
The rectangles detected within the image are classified according to the following criteria:

- density (number of edges included);
- lengths ratio;
- rectangle angular position;
- position.

4.5.1. DENSITY

The density ρ of a portion of a binary image is defined according to the following equation:

$$\rho = \frac{\text{N}^\circ \text{ elements} \neq 0}{wh} \tag{4.1}$$



$$\begin{pmatrix}
1&0&0&1&0&1&0&0&0&1&0&1&0\\
0&0&0&1&0&1&0&0&0&1&0&1&0\\
1&0&0&0&0&0&0&0&0&1&0&1&0\\
1&0&0&1&0&1&1&0&0&1&0&1&0\\
1&0&0&0&1&1&1&1&0&1&0&1&0\\
1&0&0&1&0&1&1&0&0&0&1&1&1\\
0&0&0&1&0&1&0&0&0&0&0&0&0\\
1&0&0&0&0&0&0&0&0&0&0&0&0\\
1&0&0&1&0&1&1&0&0&1&0&1&1\\
1&0&0&0&1&1&1&0&0&0&1&1&1
\end{pmatrix}$$

Figure 4.4: Example of binary Image

For each rectangle spotted within the figure, the density is computed and the corresponding value stored in the array (`density_marks`). The values of `density_marks` elements are then normalized.

```
density_marks = | ··· | V_density | ··· |
```

```
0 ≤ V_density ≤ 1
```

4.6. LENGTHS RATIO

For each rectangle the side lengths ratio $r = \frac{w}{h}$ is computed and a merit value $V_{\text{ratio}}(r)$ assigned:

$$V_{\text{ratio}}(r) = \begin{cases} 0, & \text{se } \; r \geq 2E_r \\ \dfrac{-1}{E_r^2}(r - E_r)^2 + 1, & \text{se } \; r < 2E_r \end{cases} \tag{4.2}$$

where E_r is the expected plate ratio.

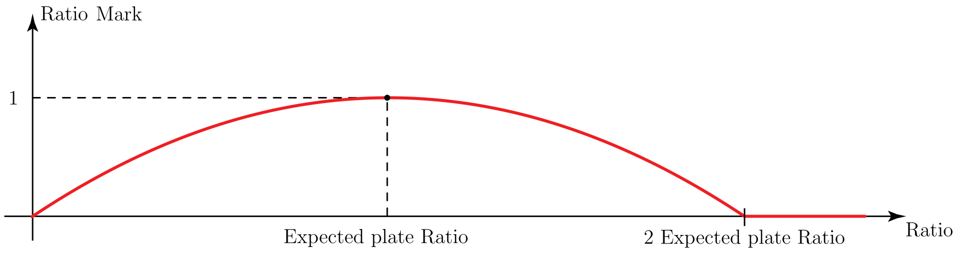


Figure 4.5: Visual representation of $V_{\text{ratio}}(r)$

4.6.1. POSITION

With some few exceptions, the abscissa x_c of the car plate center should be in the neighborhhod of the vehicle simmetry axis as depicted in Figure 4.6.

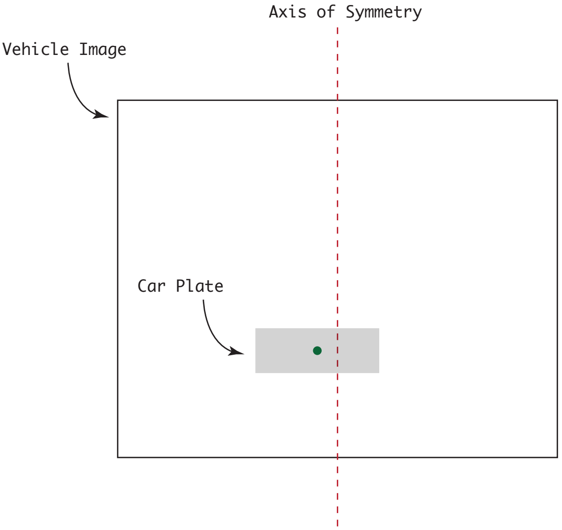


Figure 4.6: Car Plate Position

For each rectangle, a mark V_{position} is assigned proportional to the closeness of the car plate center to the car symmetry axis:

$$V_{\text{ratio}}(r) = \begin{cases} 0, & \text{se } x_c \geq w \\ \frac{-4}{w^2}(x_c - \frac{w}{2})^2 + 1, & \text{se } 0 < x_c < w \end{cases} \tag{4.3}$$

4.6.2. ANGULAR POSITION OF THE RECTANGLE

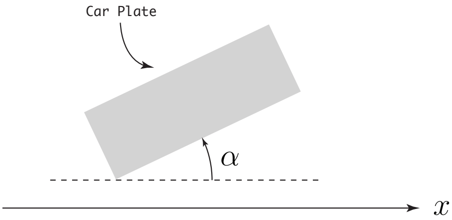


Figure 4.7: Car Plate Orientation

The mark assigned to the rectangle angular position is computed by means of the following equation:

$$V_{\text{position}} = -(\cos\alpha - 1)^2 + 1 \tag{4.4}$$

4.6.3. THE OVERALL MERIT VALUE

To take into account the previous single parameter ranking, for each rectangle an overall merit function f is evaluated by means of the following equation:

$$f = \frac{1}{2} V_{\text{density}} V_{\text{orientation}} \left(V_{\text{ratio}} + V_{\text{position}} \right) \tag{4.5}$$

The list of rectangles is then ordered according to the ranking based on the overall merit value. The top of the list rectangle is the one with the highest mark and should contain the car plate.

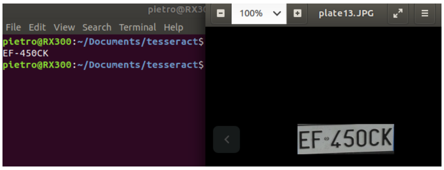
4.6.4. SEARCH OF ALPHANUMERIC CHARACTERS & CAR PLATE LOCALIZATION

The vehicle image is scanned with the neural network **EAST** (2017) (*An **E**fficient and **A**ccurate **S**cene **T**ext Detector*) to recognize the presence of alphanumeric characters within digital images. The neural network locates the areas (rectangles) where alphanumeric characters are recognized. The following algorithm is then executed:

- A check is made if the rectangles enumerated by the EAST network are inside those from the procedure `findRect` (Canny Rects), with mark different than zero. If there are 2 Canny Rect, containing the same EAST Rect, only the one with smallest area is considered.

- In case of positive matching, the indexes of the two rectangles (Canny Rect and EAST Rect) are stored into the new array `east_inside_canny`.

The rectangle with the highest mark within the array `east_inside_rect` will be the the best candidate (*winner*) to contain the car plate alphanumeric characters. The area within the *winner* rectangle, after few adjustment such as deskewing and histogram equalization, is scanned by means of `Tesseract` for alphanumeric characters recognition.



```
pietro@RX300:~/Documents/tesseract$
EF-450CK
pietro@RX300:~/Documents/tesseract$
```

Figure 4.8: Tesseract Result

4.7. CONCLUSIONS & DEVELOPMENT

In this thesis project, it has been developed a new software system for car plate character recognition. All the procedures are coded in `Python` and require open source libraries only. The current success rate for detection is greater than 85%.

In future some feature could be added to this project such as:

- Addition of model and color recognition modules.
- Hardware choice and camera interface.
- Remote device control and web interface.

4.8. CODE

In the following a **Beta Version** of the Python code developed to detect a Car Plate is attached.

```python
#!/usr/bin/env python
# -*- coding: utf-8 -*-
#
#  main.py
#
#  Copyright 2019 pietro pennestri' pietro.pennestri@gmail.com
#
#  This program is free software; you can redistribute it and/or modify
#  it under the terms of the GNU General Public License as published by
#  the Free Software Foundation; either version 2 of the License, or
#  (at your option) any later version.
#
#  This program is distributed in the hope that it will be useful,
#  but WITHOUT ANY WARRANTY; without even the implied warranty of
#  MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
#  GNU General Public License for more details.
#
#  You should have received a copy of the GNU General Public License
#  along with this program; if not, write to the Free Software
#  Foundation, Inc., 51 Franklin Street, Fifth Floor, Boston,
#  MA 02110-1301, USA.
#
#

import cv2
import imutils
```

```
from imutils.object_detection import non_max_suppression
import numpy as np
import sys
######################################################################
#                getVehicles                  #
######################################################################
def getVehicles(imageFile,minConfidence):
  CLASSES = ["background", "aeroplane", "bicycle", "bird", "boat",
  "bottle", "bus", "car", "cat", "chair", "cow", "diningtable",
  "dog", "horse", "motorbike", "person", "pottedplant", "sheep",
  "sofa", "train", "tvmonitor"]
  detected_vehicles=[]
  locations=[]
  net = cv2.dnn.readNetFromCaffe('./models/MobileNetSSD_deploy.prototxt.txt', './models/MobileNetSSD_deploy.caffemodel')
  image = cv2.imread(imageFile)
  (h, w) = image.shape[:2]
  blob = cv2.dnn.blobFromImage(cv2.resize(image, (300, 300)), 0.007843, (300, 300), 127.5)

  net.setInput(blob)
  detections = net.forward()
  for i in np.arange(0, detections.shape[2]):
    confidence = detections[0, 0, i, 2] # extract the confidence
    idx = int(detections[0, 0, i, 1]) # extract the index of the class label
    # focus only on car "bus", "car", "motorbike" with confidence > input confidence
    if (confidence > minConfidence  and (idx==7 or idx==6 or idx==14) ):
      box = detections[0, 0, i, 3:7] * np.array([w, h, w, h])
      whereIsIt = box.astype("int") # startX, startY, endX, endY
      whatIsIt=CLASSES[idx]
      locations=locations+[whereIsIt]
      detected_vehicles=detected_vehicles+[whatIsIt]

  return detected_vehicles, locations



######################################################################
#                         east detector                         #
######################################################################
def east(image,min_confidence):
  orig = image.copy()
  (H, W) = image.shape[:2]
  (resized_image_width,resized_image_height)=(int(320),int(320))
  ratio_width = W / float(resized_image_width)
  ratio_height = H / float(resized_image_height)

  image = cv2.resize(image, (resized_image_width, resized_image_height))
  (H, W) = image.shape[:2]

  layerNames = [
    "feature_fusion/Conv_7/Sigmoid",
    "feature_fusion/concat_3"]

  # load the pre-trained EAST text detector
  net = cv2.dnn.readNet('./models/frozen_east_text_detection.pb')
  avg_color_per_row = np.average(image, axis=0)
```

```
avg_color = np.average(avg_color_per_row, axis=0)
avg_color_turple=(avg_color[2],avg_color[1],avg_color[0]) #BGR

blob = cv2.dnn.blobFromImage(image, 1.0, (W, H), avg_color_turple, swapRB=True, crop=False)

net.setInput(blob)
(scores, geometry) = net.forward(layerNames)

(numRows, numCols) = scores.shape[2:4]
rects = []
confidences = []

# loop over the number of rows
for y in range(0, numRows):
  # extract the scores (probabilities), followed by the geometrical
  # data used to derive potential bounding box coordinates that
  # surround text
  scoresData = scores[0, 0, y]
  xData0 = geometry[0, 0, y]
  xData1 = geometry[0, 1, y]
  xData2 = geometry[0, 2, y]
  xData3 = geometry[0, 3, y]
  anglesData = geometry[0, 4, y]
  for x in range(0, numCols):
    if scoresData[x] < min_confidence:
      continue
    (offsetX, offsetY) = (x * 4.0, y * 4.0)
    angle = anglesData[x]
    cos = np.cos(angle)
    sin = np.sin(angle)
    h = xData0[x] + xData2[x]
    w = xData1[x] + xData3[x]
    endX = int(offsetX + (cos * xData1[x]) + (sin * xData2[x]))
    endY = int(offsetY - (sin * xData1[x]) + (cos * xData2[x]))
    startX = int(endX - w)
    startY = int(endY - h)

    rects.append((startX, startY, endX, endY))
    confidences.append(scoresData[x])

# apply non-maxima suppression to suppress weak, overlapping bounding
# boxes
boxes = non_max_suppression(np.array(rects), probs=confidences)
converted_boxes=[]
centers=[]
for (startX, startY, endX, endY) in boxes:
  # scale the bounding box coordinates based on the respective ratios
  startX = int(startX * ratio_width)
  startY = int(startY * ratio_height)
  endX = int(endX * ratio_width)
  endY = int(endY * ratio_height)
  converted_boxes=converted_boxes+[[startX, startY, endX, endY]]
  centerX=0.5*(startX+endX)
  centerY=0.5*(startY+endY)
  centers=centers+[(centerX,centerY)]
return converted_boxes, centers
```

```

########################################################################
#               findRect                          #
########################################################################

def findRect(img_binary):
  selected_rects=0
  dimensions=[]
  areas=[]
  centers=[]
  rectangles=[]
  #cnts = cv2.findContours(img_binary.copy(), cv2.RETR_EXTERNAL, cv2.CHAIN_APPROX_SIMPLE)
  cnts = cv2.findContours(img_binary.copy(), cv2.RETR_EXTERNAL, cv2.CHAIN_APPROX_NONE)
  cnts = imutils.grab_contours(cnts)
  for cnt in cnts:
    #  cv2.minAreaRect(). It returns a Box2D structure which contains following details
    #  ( center (x,y), (width, height), angle of rotation ).
    rect = cv2.minAreaRect(cnt)
    center=rect[0]
    rect_dimensions=np.asarray(rect[1])
    width=rect_dimensions[0]
    height=rect_dimensions[1]

    if(height>width):
      width,height=height,width

    box = cv2.boxPoints(rect)
    dimensions=dimensions+[(width,height)]
    areas=areas+[width*height]
    centers=centers+[center]
    rectangles=rectangles+[box]
  return rectangles, centers, dimensions , areas


#######################################################################
#      Detect Rectangular Shape                  #
#######################################################################
def detectRectShape(c):
  # initialize the shape name and approximate the contour
  shape = "unidentified"
  peri = cv2.arcLength(c, True)
  approx = cv2.approxPolyDP(c, 0.04 * peri, True)
  if len(approx) == 4:
    # compute the bounding box of the contour and use the
    # bounding box to compute the aspect ratio
    (x, y, w, h) = cv2.boundingRect(approx)
    ar = w / float(h)
    # a square will have an aspect ratio that is approximately
    # equal to one, otherwise, the shape is a rectangle
    if (ar >= 0.95 and ar <= 1.05):
      return False , None , None
    else :
      return True , ar, int(w*h)
  else:
```

```
        return False , None, None

##############################################################
#          normalizeList                  #
##############################################################
def normalizeList(thelist):
    i=0
    max_elem=max(thelist)
    while(i<len(thelist)):
        if(thelist[i]!=0):
            thelist[i]=thelist[i]/max_elem
        i=i+1
    return thelist

def removeIndexFromList(index2remove,thelist):
    i=0
    list2return=[]
    for elem in thelist:
        if(i!=index2remove):
            list2return=list2return+[elem]
        i=i+1
    return list2return


def orderVertexes(rectangle):
    vertexes_x=[]
    vertexes_y=[]
    for vertex in rectangle:
        vertexes_x=vertexes_x+[vertex[0]]
        vertexes_y=vertexes_y+[vertex[1]]

    first_y_maximum=max(vertexes_y)
    first_y_maximum_index=vertexes_y.index(first_y_maximum)
    pop_vertexes_y=removeIndexFromList(first_y_maximum_index,vertexes_y)
    second_y_maximum=max(pop_vertexes_y)

    if(second_y_maximum==first_y_maximum):
        copy_vertexes_y=vertexes_y
        copy_vertexes_y[first_y_maximum_index]=copy_vertexes_y[first_y_maximum_index]+1
        second_y_maximum_index=copy_vertexes_y.index(second_y_maximum)
    else:
        second_y_maximum_index=vertexes_y.index(second_y_maximum)

    first_y_minimum=min(vertexes_y)
    first_y_minimum_index=vertexes_y.index(first_y_minimum)
    pop_vertexes_y=removeIndexFromList(first_y_minimum_index,vertexes_y)
    second_y_minimum=min(pop_vertexes_y)

    if(second_y_minimum==first_y_minimum):
        copy_vertexes_y=vertexes_y
        copy_vertexes_y[first_y_minimum_index]=copy_vertexes_y[first_y_minimum_index]+1
        second_y_minimum_index=copy_vertexes_y.index(second_y_minimum)
    else:
        second_y_minimum_index=vertexes_y.index(second_y_minimum)

```

```
  upper_vertexes=[(vertexes_x[first_y_maximum_index],first_y_maximum),(vertexes_x[second_y_maximum_index],second_y_maximum)]
  lower_vertexes=[(vertexes_x[first_y_minimum_index],first_y_minimum),(vertexes_x[second_y_minimum_index],second_y_minimum)]


  #Define Vertexes
  if(upper_vertexes[0][0]<upper_vertexes[1][0]):
    v0=upper_vertexes[0]
    v1=upper_vertexes[1]
  else:
    v0=upper_vertexes[1]
    v1=upper_vertexes[0]

  if(lower_vertexes[0][0]<lower_vertexes[1][0]):
    v2=lower_vertexes[0]
    v3=lower_vertexes[1]
  else:
    v2=lower_vertexes[1]
    v3=lower_vertexes[0]

  # v2 upper left, v3 upper right, v0 lower left, v1 lower right
  return [v0,v1,v2,v3]

def isPointinRect(point, rectangle ,rectArea):
  #(p.s. l'area del rettangolo in generale viene ricavata grazie alle coordinate
  # dei suoi estremi tuttavia per ogni rettangolo conosciamo la sua area ....)
  rectangle=orderVertexes(rectangle)
  v0=rectangle[0]
  v1=rectangle[1]
  v2=rectangle[2]
  v3=rectangle[3]

  area0=0.5*abs(np.linalg.det( np.array([[v0[0], v0[1], 1], [point[0], point[1], 1],[v1[0], v1[1], 1]]) ))
  area1=0.5*abs(np.linalg.det( np.array([[v0[0], v0[1], 1], [point[0], point[1], 1],[v2[0], v2[1], 1]]) ))
  area2=0.5*abs(np.linalg.det( np.array([[v1[0], v1[1], 1], [point[0], point[1], 1],[v3[0], v3[1], 1]]) ))
  area3=0.5*abs(np.linalg.det( np.array([[v2[0], v2[1], 1], [point[0], point[1], 1],[v3[0], v3[1], 1]]) ))

  if (area0 + area1 + area2 + area3-rectArea<=1):
    return 1
  else:
    return 0



def rectCosOrientation(rect):
  rect=orderVertexes(rect)
  start_vertex=rect[0]
  distances=[]
  for vertex in rect:
    if(vertex!=start_vertex):
      distance=((start_vertex[0]-vertex[0])**2+(start_vertex[1]-vertex[1])**2)**0.5
      distances=distances+[distance]
```

```python

  min_index=np.argmax(distances)
  max_index=np.argmin(distances)
  distances[min_index]=0
  distances[max_index]=0
  end_vertex=rect[np.argmax(distances)+1]
  orientation_vector=[start_vertex[0]-end_vertex[0], start_vertex[1]-end_vertex[1]]
  cos_orientation=orientation_vector[0]/(orientation_vector[1]**2+orientation_vector[0]**2)**0.5
  return cos_orientation

#input image
image_path = sys.argv[1]
image = cv2.imread(image_path)
expected_plate_ratio=11/52


detected_vehicles, vehicles_locations=getVehicles(image_path,0.20)
print('I have found '+str(len(detected_vehicles))+' vehicles.')



for vehicle_location in vehicles_locations:
  lowerX=int(vehicle_location[0])
  lowerY=int(vehicle_location[1])
  upperX=int(vehicle_location[2])
  upperY=int(vehicle_location[3])
  vehicle_image=image[lowerY:upperY , lowerX:upperX]
  vehicle_image_gray=cv2.cvtColor(vehicle_image, cv2.COLOR_BGR2GRAY)
  vehicle_image_canny = cv2.Canny(vehicle_image_gray,100,200)
  vehicle_image_width=upperX-lowerX
  rectangles, centers, dimensions ,areas=findRect(vehicle_image_canny)

  text_rectangles, text_centers=east(vehicle_image,0.5)

  for (startX, startY, endX, endY) in text_rectangles:
    cv2.rectangle(vehicle_image, (startX, startY), (endX, endY), (255, 0, 0), 2)

  ratio_marks=[]
  orientation_marks=[]
  position_marks=[]
  density_marks=[]

  for rectangle, dimension, area, center in zip(rectangles, dimensions, areas, centers):
    width=dimension[0] #width is always the largest dimension
    height=dimension[1]
    if (width>5 and height>5):
      #rectangles_ratio_cp=rectangles_ratio_cp+[abs((width/height)-plate_ratio)]
      v=orderVertexes(rectangle)
      rect_x_max=max([v[0][0],v[1][0],v[2][0],v[3][0]])
      rect_x_min=min([v[0][0],v[1][0],v[2][0],v[3][0]])
      rect_y_max=max([v[0][1],v[1][1],v[2][1],v[3][1]])
      rect_y_min=min([v[0][1],v[1][1],v[2][1],v[3][1]])
      rect_matrix=vehicle_image_canny[int(rect_y_min):int(rect_y_max) , int(rect_x_min):int(rect_x_max)]
      if(rect_matrix.shape[0]==0 or rect_matrix.shape[1]==0):
```

```
            density_marks=density_marks+[0]
        else:
            area=rect_matrix.shape[0]*rect_matrix.shape[1]
            density_mark=np.count_nonzero(rect_matrix == 255)/area
            density_marks=density_marks+[density_mark]
        plate_ratio=height/width

        if(plate_ratio >=2*expected_plate_ratio):
            ratio_mark=0
        else:
                ratio_mark=-(1/expected_plate_ratio**2)*(plate_ratio-expected_plate_ratio)**2 +1
                ratio_mark=area*ratio_mark

        ratio_marks=ratio_marks+[ratio_mark]
        cos_orientation=rectCosOrientation(rectangle)
        orientation_mark=-(cos_orientation)**2+2*abs(cos_orientation)
        orientation_marks=orientation_marks+[orientation_mark]

        position_mark=-(4/vehicle_image_width**2)*(center[0]-vehicle_image_width/2)**2 + 1
        position_marks=position_marks+[position_mark]

    else:
        ratio_marks=ratio_marks+[0]
        orientation_marks=orientation_marks+[0]
        position_marks=position_marks+[0]
        density_marks=density_marks+[0]



ratio_marks=normalizeList(ratio_marks)
orientation_marks=normalizeList(orientation_marks)
density_marks=normalizeList(density_marks)

marks=[]
for ratio_mark, orientation_mark ,position_mark, density_mark in zip(ratio_marks, orientation_marks, position_marks, density_marks):
    mark=density_mark*(1/2)*orientation_mark *(ratio_mark + position_mark)
    #mark=density_mark*(1/2)*ratio_mark  *(orientation_mark + position_mark)
    marks=marks+[mark]


marks_argsort = np.argsort(marks)
marks_argsort = marks_argsort[::-1]


east_inside_canny=[] # [(east_rect_index,minimum_area_canny_rect_index)]

#check if east rect is inside canny rect
j=0
for (startX, startY, endX, endY) in text_rectangles:
    minimum_area_canny_rect_index=None
    i=0
    for index in marks_argsort:
        if (marks[index]!=0 ):
            ck1=isPointinRect((startX,startY), rectangles[index]  ,areas[index])
```

```
      ck2=isPointinRect((startX,endY), rectangles[index]  ,areas[index])
      ck3=isPointinRect((endX,startY), rectangles[index], areas[index])
      ck4=isPointinRect((endX, endY), rectangles[index],  areas[index])
      if (ck1 and ck2 and ck3 and ck4):
        #rectangle=np.int0(rectangle)
        #cv2.drawContours(vehicle_image,[rectangle],0,(0,255,0),2)
        if (minimum_area_canny_rect_index is not None):
          if(areas[i]<areas[minimum_area_canny_rect_index]):
            minimum_area_canny_rect_index=index
        else:
          minimum_area_canny_rect_index=index
    i=i+1
  if (minimum_area_canny_rect_index is not None):
    east_inside_canny=east_inside_canny+[(j,minimum_area_canny_rect_index)]
  j=j+1

#check for duplicates in east_inside_canny
if (east_inside_canny):
  selected_canny_rects=[]
  selected_east_rects=[]
  for turple in east_inside_canny:
    selected_canny_rects=selected_canny_rects+[turple[1]]
    selected_east_rects=selected_east_rects+[turple[0]]

  east_inside_canny=[]
  check_list=[]
  for selected_canny_rect, selected_east_rect in zip(selected_canny_rects, selected_east_rects):
    if (not selected_canny_rect in check_list):
      east_inside_canny=east_inside_canny+[(selected_east_rect,selected_canny_rect)]
      check_list=check_list+[selected_canny_rect]

if(len(east_inside_canny)==1):
  print ('Exit 1')
  rectangle=rectangles[east_inside_canny[0][1]]
  rectangle=np.int0(rectangle)
  cv2.drawContours(vehicle_image,[rectangle],0,(0,255,0),2)

elif(len(east_inside_canny)==0):
  print ('Exit 2')
  expected_plate_ratio=11/43
  mser = cv2.MSER_create()
  gray = cv2.cvtColor(vehicle_image, cv2.COLOR_BGR2GRAY)
  vis = vehicle_image.copy()
  #detect regions in gray scale image
  regions, _ = mser.detectRegions(gray)
  hulls = [cv2.convexHull(p.reshape(-1, 1, 2)) for p in regions]
  selected_hulls=[]
  for contour in hulls:
    mask = np.zeros((vehicle_image.shape[0], vehicle_image.shape[1], 1), dtype=np.uint8)
    cv2.drawContours(mask, [contour], -1, (255, 255, 255), -1)
    text_only = cv2.bitwise_and(vehicle_image, vehicle_image, mask=mask)
    text_only_gray=cv2.cvtColor(text_only, cv2.COLOR_BGR2GRAY)
    thresh = cv2.threshold(text_only_gray,1,255,cv2.THRESH_BINARY)[1]
    thresh_area=np.count_nonzero(thresh == 255)
```

```
      # find contours in the thresholded image and initialize the
      # shape detector
      cnts = cv2.findContours(thresh.copy(), cv2.RETR_EXTERNAL, cv2.
    CHAIN_APPROX_SIMPLE)
      cnts = imutils.grab_contours(cnts)
      # loop over the contours
      for c in cnts:
        isRect=detectRectShape(c)
        #if(isRect[0] and min(isRect[2],thresh_area)/max(isRect[2],thresh_area) >=
    0.95 ):
        if(isRect[0] and  abs(isRect[2]-thresh_area)<10):
          cv2.drawContours(mask, [contour], -1, (0, 255, 0))
          contour_image_intersection= cv2.bitwise_and(vehicle_image, vehicle_image,
    mask=mask)
          canny = cv2.Canny(contour_image_intersection,100,200)
          canny_area=np.count_nonzero(canny == 255)
          if(canny_area!=0):
            selected_hulls=selected_hulls+[contour]

    rectangles=[]
    ratio_marks=[]
    for contour in selected_hulls:
      rect = cv2.minAreaRect(contour)
      rectangles=rectangles+[cv2.boxPoints(rect)]
      rect_dimensions=np.asarray(rect[1])
      width=rect_dimensions[0]
      height=rect_dimensions[1]
      if (width >1 and height > 1 ):
        plate_ratio=height/width
        if(plate_ratio>=2*expected_plate_ratio):
          ratio_mark=0
        else:
          ratio_mark=-(1/expected_plate_ratio**2)*(plate_ratio-expected_plate_ratio)
    **2 +1
          ratio_mark=ratio_mark*width*height
      else:
        ratio_mark=-1

      ratio_marks=ratio_marks+[ratio_mark]

    print(ratio_marks)
    if ratio_marks:
      rect_index= np.argmax(ratio_marks)
      rectangle=np.int0(rectangles[rect_index])
      cv2.drawContours(vehicle_image,[rectangle],0,(0,255,0),2)
      cv2.polylines(vehicle_image, selected_hulls, 1, (0, 0, 255))
    else:
      print('No Plate could be detected')

  elif(len(east_inside_canny)>1):
    print('Exit 3')
    rectangle=rectangles[east_inside_canny[0][1]]
    rectangle=np.int0(rectangle)
    cv2.drawContours(vehicle_image,[rectangle],0,(0,255,0),2)


  # Visual Output
```

```
cv2.imshow('img1',vehicle_image_canny)
cv2.imshow('img',vehicle_image)
cv2.waitKey(0)
```

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