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Intelligence for Embedded Systems

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Intelligence for Embedded Systems

A Methodological Approach

Springer

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To Alessandro Maria, my Family
and those who came before

Preface

This book was written having in mind researchers, practitioners, and students willingly to *learn, understand, or perfect the fundamental mechanisms behind intelligence* and how they can be used *to design the future generation of embedded systems and embedded applications*.

Adaptation strategies, active and passive learning abilities, robustness capabilities, design of embedded, and distributed cognitive fault diagnosis systems, techniques for assessing the performance and constraints satisfaction in embedded applications are some fundamental aspects intelligent embedded systems and embedded applications need to face to deal with those uncertain, nonstationary, and evolving environments the real world is proposing.

The approach is *methodological*; as such, the presented methods are technology independent and can be suitably adapted to software, hardware, or both implementations, depending on the application constraints. Although it is not the focus of the book, presented methodologies can also be fruitfully used to guide the hardware/software co-design phase to define which parts of the application are more suitably implemented on a dedicated hardware and which ones found in software the most adequate implementation.

For its nature the book is crossing several disciplines, from measurements and metrology to machine learning, from computer science to probability and system identification. As such, *it is a book designed to build bridges among those fundamental areas for electronic engineers, computer scientists, and physicists*.

As it will be immediately clear the book was neither written with the goal to propose a tutorial for all topics covering a specific issue nor detailing and listing all papers and methodologies related to a given argument. Instead, the focus is on the formalization of a given problem, proposal of the most relevant strategies for addressing it, and discussions about "what is behind" the theory, the method, the approach. I consider the book successful if the reader grasps, after reading the main strategies, ideas and challenges behind intelligence and how intelligent methods can be—and should be—used to boost the next generation of embedded applications.

The book has been designed with the goal to fill a gap existing among disciplines a computer scientist, particularly the one designing embedded applications, will face in his/her working life.

It is the author's view that *many sections of the book should constitute teaching material within computer science and electronic engineer curricula* possibly, but not necessarily, within an embedded systems or a machine learning course. The material should be provided at the graduated or Ph.D. student level to optimally benefit from skills and knowledge gained in the undergraduate program.

The book is mostly self-contained. It is expected the reader to be familiar with the basics of mathematics (integrals, linear algebra, gradients, and partial derivatives) and hold the principles of probability and statistics (mean, variance, distributions) and operational research (function optimization). The reader must also be acquainted with the basics of computer sciences and the very basics of electronics, even though deep knowledge is not requested at this level. Having that in mind, also undergraduate students can take advantage of many of the presented topics. For instance, Chaps. 2, 3, 8, and 10 would constitute appropriate material to be taught within an undergraduate course on embedded systems or computer science, with the other chapters' contents used to give the flavor of what is behind. Material presented in the book chapters would constitute instead a full course on advanced embedded systems.

If *multidisciplinary* is the most appropriate adjective characterizing the book from the content point of view, the process behind its birth and writing is surely *globalized*. The book was conceived and moved its first steps in Paris, at the École Supérieure de Physique et de Chimie Industrielles (ESPCI), France, following the very welcome invitation of Prof. Gérard Dreyfus. Then, it grew in Italy, at the Politecnico di Milano, both at the Milan and the Lecco campuses, Italy. The first draft took body in Beijing, China, at the Chinese Academy of Sciences, Institute of Automation (CASIA), following a research experience carried out within the group of Prof. Dongbin Zhao. Refinements were carried out at the National Library in Florence, Italy, and the Institute for Infocomm Research (I^2R), A*STAR, Singapore, thanks to Dr. Huajin Tang who invited me for a short visit. Deep discussions and presentations where given, among others, at the Advanced Learning and Research Institute of the Università della Svizzera italiana, Switzerland, the Tsinghua University and the Peking University, China, the National University of Singapore, Singapore, the National Taiwan University in Taipei, Taiwan and the Los Alamos Labs, USA.

I am beholden to my family for having continuously supported me in this time-consuming editorial challenge.

I also acknowledge the great contribution received by my collaborators in reviewing some chapters and run most of the experiments behind the introduced examples. At first I need to mention the precious collaboration of Dr. Manuel Roveri, then that of Dr. Maurizio Bocca, Dr. Giacomo Boracchi, Dr. Antonio Marullo, Mrs. Ouejdane Mejri, and Mr. Francesco Trovò, all from Politecnico di Milano, Italy.

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Acronyms

2cp	2's Complement
ACC	Anterior Cingulate Cortex
ADC	Analog to Digital Converter
AOA	Angle of Arrival
AR	Auto Regressive
ARL	Average Run Length
ARMAX	AutoRegressive Moving Average eXternal
ARX	AutoRegressive eXternal
BLB	Bag of Little Bootstraps
cdf	Cumulative Density Function
CDT	Change Detection Test
CI-CUSUM	Computational Intelligence CUSUM
CLT	Central Limit Theorem
CPM	Change Point Method
CPTM	Controlled Power Transfer Module
CUSUM	CUmulative SUM Control Chart
DCS	Discrete Controller Synthesis
DPR	Dynamic Partial Reconfiguration -FPGA
DV/FS	Dynamic Voltage/Frequency Scaling
ECM	Electronic Control Module
EM	ElectroMagnetic
FDS	Fault Diagnosis Systems
FFT	Fast Fourier Transform
FIR	Finite Impulse Response
FOA	Frequency of Arrival
FPGA	Field-Programmable Gate Array
FSM	Finite State Machine
FTSP	Flooding Time Synchronization Protocol
GPS	Global Positioning System
GPU	Graphics Processing Units
H-CDT	Hierarchical CDT
HMM	Hidden Markov Model
ICI	Intersection of Confidence Intervals
JIT	Just in Time

k-NN	k-Nearest Neighbors
LOO	Leave-One-Out
LPAC	Lateral Prefrontal and the Association Cortices
LTI	Linear Time Invariant
LTS	Lightweight Tree-based Synchronization
LUT	Look Up Table
M2M	Machine-to-Machine
MAPE(K)	Monitoring, Analysis, Planning, Execution, (Knowledge)
MEMS	Micro Electro-Mechanical Systems
MIPS	Million Instructions Per Second
MLE	Maximum Likelihood Estimation
MPPT	Maximum Power Point Tracker
MSE	Mean Squared Error
NTP	Network Time Protocol
OFC	Orbital preFrontal Cortices
PACC	Probably Approximately Correct Computation
pdf	Probability Density Function
ppm	Parts Per Million
QoS	Quality of Service
RBS	Reference Broadcast Synchronization
RSS	Received Signal Strength
RSSI	Received Signal Strength Indicator
SE	Squared Error
SEPIC	Single Ended Primary Inductor Converter
SNR	Signal to Noise Ratio
SPU	Sensing and Processing Units
TDOA	Time Difference of Arrival
TOA	Time of Arrival
UCEM	Uniform Convergence of Empirical Mean
UWB	Ultra-Wide Band
VM-PFC	Ventral-Medial PreFrontal Cortices
w.p.1	With Probability One

Symbols

$\mathbb{N}^d$	Space of natural d-dimensional vectors
$\mathbb{Z}^d$	Space of integer d-dimensional vectors
$\mathbb{Q}^d$	Space of rational d-dimensional vectors
$\mathbb{R}^d$	Space of real d-dimensional vectors
E	Expected value w.r.t. all random variables
E_x	Expected value w.r.t. x
$Var(x)$	Variance of x
$\lceil x \rceil$	Minimum integer greater or equal to x
$\|\cdot\|$	Norm operator
δx	Perturbation affecting x
$\mathcal{N}$	Gaussian distribution
$\circ$	Point-wise multiplication operator
$\bar{V}$	Structural risk
V_N	Empirical risk
ln	Natural logarithm
$O(\cdot)$	Big Oh notation
$trace(A)$	Trace of matrix A
$erf(\cdot)$	Error function
$\frac{\partial f(\theta,x)}{\partial \theta}\|_{\theta^o}$	Function $\frac{\partial f(\theta,x)}{\partial \theta}$ is evaluated in θ^o
$f(x)\|x$	$f(x)$ such that x