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A New Approach for Disruption Management in Airline Operations Control

Springer

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Subtly,
you brought something new to my life.
I hardly realized what it was
and its importance.
After all, it was just a distant star
that you decided to bring closer.
It seemed one among many,
but it had a special feature:
when I'm near it,
my heart glows with happiness.
I will keep it close, hoping
that you will never take it back from me.

António J. M. Castro

Preface

This book is a major outcome of the research performed during the Ph.D. studies of one of the authors under the supervision of a co-author and from the collective work that took place at the LIACC-DAIAS group at the Faculty of Engineering, University of Porto, Portugal.

For our study we followed the problem-oriented research methodology, i.e., we started from the problem description and sought the most appropriate techniques to solve it, trying to pursue, at the same time, an *out-of-the-box* thinking. By *out-of-the-box* thinking we mean to try to think beyond the requirements of the specific problem we were solving as of this moment in time, exploring alternative directions and involving a variety of aspects that, at this moment in time, might not be that relevant but, in the future, might become an asset.

Starting from an hypothesis that could have social impact, and that we can rephrase as follows: ”Can we automatically derive improved solutions for disruptive events at an airline control center, in such a way that other than the company, also the crew and the passenger interests are taken into account?”, our research lead us to a proposal general enough for being considered for the all plan-disruption class of problems.

By using a well understood paradigm as it is the case of Multi-Agent Systems, enhanced with generic protocols for agents' interaction, learning algorithms enabling continuous system improvement and parameterized utility functions, the proposed model is intended to be used by all those who are willing to solve unexpected problems that arise in dynamic environments and put previous established plans at risk. Application domains include, besides airlines control centers, all other kinds of transport systems, shop floor production plans, crisis management, robotics, etc.

We here advocate that the most flexible reasoning methodology for multi-faceted and dynamic situations includes decentralized cooperation among distributed, kind of autonomous computing entities, here acting as experts in different domains. Although contributing for a final joint commitment and better solutions to the problem at stake, these entities, or software agents, embed strategies for mutual convergence through negotiation mechanisms that enable them to learn with the experience.

The very kernel of what is described and shown in this book is that, for solving relevant and practical problems, we may elegantly intermingle sophisticated AI-based methodologies together with more classical programming to reach useful objectives. Multi-agent systems, negotiation protocols, reinforcement learning, are here put at work in the framework of a demanding practical every-day kind of application and present a solution that can be generalized for many kind of problems of the decentralized, distributed and dynamic type.

The work done was possible not only, but mainly, due to the dedicated work of Antonio Castro who, besides being an expert on the domain was willing to get a PhD thesis. It also capitalizes on the research work towards the development of adaptive negotiation protocols due to Ana Paula Rocha. More than ten years ago, Eugenio Oliveira had a vision on the importance of these technologies for relevant application domains if they could be appropriately integrated.

The result is not only this book but also the robust software system that we are now trying to put in place for social benefit.

Porto, Portugal,
March 2014

Antonio J. M. Castro
Ana Paula Rocha
Eugenio Oliveira

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Acronyms

ACARS	**Aircraft Communications Addressing and Reporting System**: A digital datalink system for transmission of short, relatively simple messages between aircraft and ground stations via radio or satellite.
ACMI	**Aircraft Crew Maintenance Insurance**: Also known as Wet Lease. The leasing of an aircraft including the crew members, maintenance and insurance.
AEA	**Association of European Airlines**: An association that includes 32 major airlines and that has been the voice of the European airline industry for over 50 years.
AMS	**Agent Management Services**: The core agent which keeps track of all JADE programs and agents in the system.
AOCC	**Airline Operations Control Center**: An airline entity responsible for monitoring and problem solving during the execution of the airline plan.
AOCP	**Airline Operations Control Problem**: The daily process of solving unexpected events that might disrupt the airline schedule (or plan) with the minimum cost and according to specific rules. See also Disruption Management below.
AOSE	**Agent Oriented Software Engineering**: A methodological approach for the development of software oriented or based on software agents.
ASAS	**Automatic or Semi-Automatic Systems**: A software system that replaces the functional part of an entity by computerized programs that work autonomously. In an automatic system, decision making is also undertaken by the system. In a semi-automatic system, the final decision is made by the human operator.
ASP	**Airline Scheduling Problem**: The process of creating the airline schedule (or plan) that covers all of the airline network, maximizing the revenue and minimizing the costs related to aircraft and crew members, in a specific period.
ATA	**Actual Time of Arrival**: The actual time of arrival of a flight.
ATC	**Air Traffic Control**: A service provided by ground-based controllers who direct aircraft on the ground (at airports for take-off and landing) and in the air.
ATD	**Actual Time of Departure**: The actual time of departure of a flight.
CDM	**Collaborative Decision Making**: Information about the aircraft/flight movement in several airports. It helps in making decisions.

CDSP	**Cooperative Distributed Problem Solving**: A process of solving problems in a distributed way (physical, functional or spatial) in an environment where the entities are willing to cooperate, either because they have the same goal or because they are not able to solve the problem entirely by themselves.
CFMU	**Central Flow Management Unit**: A tool from EUROCONTROL that provides information about ATC slots.
DBQS	**Database Query System**: A system that allows a human operator to query a database and get information.
DF	**Directory Facility**: A yellow page service in JADE, where agents can publish their services.
DM	**Disruption Management**: A dynamic process of solving disruptions that affect an existing plan, in such a way that the impact and costs are minimized and, at the same time, complying with the required rules. See also Airline Operations Control Problem above.
DSS	**Decision Support System**: A computer-based information system that supports business or organizational decision-making activities.
EFB	**Electronic Flight Bag**: An electronic information management device that helps flight crews perform flight management tasks more easily and efficiently, in a paperless environment.
ETA	**Estimated Time of Arrival**: An estimated time of arrival for a flight.
ETD	**Estimated Time of Departure**: An estimated time of departure for a flight.
FAA	**Federal Aviation Administration**: An agency of the United States Department of Transportation with authority to regulate and oversee all aspects of civil aviation in the U.S.
GDP	**Gross Domestic Product**: The market value of all officially recognized final goods and services produced within a country in a given period of time.
GQN	**Generic Q-Negotiation**: An automated negotiation protocol proposed in this book that is an evolution of the Q-Negotiation protocol proposed by one of the authors.
HCC	**Hub Control Center**: An entity that some airlines have at their major or central airports (hubs) to help control the incoming and outgoing airline traffic. This entity typically exists when the airline operates a hub-and-spoke network.
HUB	**Hub-and-Spoke Network**: A system of connections arranged like a chariot wheel, in which all traffic moves along spokes connected to the hub at the center. Medium to large airline companies use this kind of network as a way of making a more efficient use of transportation resources. For example, aircraft are more likely to fly at full capacity, and can often fly routes more than once a day.

IATA	**International Air Transport Association**: IATA represents some 240 airlines comprising 84% of scheduled international air traffic. It is present in over 150 countries and has 101 offices around the globe.
IR	**Integrated Recovery**: A process that is able to recover all problem dimensions separately (not simultaneously). Usually sequentially and, as such, having a solving order.
MAS	**Multi-Agent System**: A software system composed of multiple interacting (intelligent) software agents.
MASDIMA	**Multi-Agent System for Disruption Management**: The advanced MAS prototype developed during this study that implements the approaches proposed by us.
MCS	**Movement Control System**: A software system to control the flight and aircraft information related to departures, takeoff, landing and arrival, amongst other information.
MTOW	**Maximum Takeoff Weight**: The maximum weight at which the pilot of the aircraft is allowed to attempt to take off, due to structural or other limitations.
MVT	**Aircraft Movement Message**: A message that includes information about the movement of an aircraft/flight. Typically the OOOI information.
NB	**Narrow Body**: An aircraft with a single aisle. Typically used to perform short to medium-range flights.
NOTAM	**Notice to Airmen**: Notifications to aircraft pilots of any hazards en route or at a specific location. The NOTAMs are usually provided by the aviation authority.
OOOI	**Out, Off, On and In**: For every flight/aircraft there are four important times to register: Out of gate time (gate departure), Off ground time (takeoff), On ground time (landing) and In gate time (gate arrival).
OR	**Operations Research**: Mathematical or scientific analysis of a process or operation, used for making decisions.
PIL	**Passenger Information List**: A list with the names, seats and other relevant information of the passengers on board of a flight.
PIR	**Partial Integrated Recovery**: A process that is able to recover at least two, but not all, of the problem dimensions, simultaneously or not.
RMA	**Remote Management Agent**: The agent in JADE which handles the GUI interface
SEF	**Portuguese Immigration Services**: The service responsible for give effect to the policy of immigration and asylum in Portugal, according to the provisions of the Constitution and the law and government guidelines.

SIR	**Simultaneously Integrated Recovery**: A process that is able to recover all problem dimensions simultaneously. Here, all dimensions are of equal importance since there is no solving order.
SITA	**Société Internationale de Télécommunications Aéronautiques**: Provider of global information and telecommunication solutions for the air transport industry.
STA	**Schedule Time of Arrival**: The original arrival time of a flight.
STD	**Schedule Time of Departure**: The original departure time of a flight.
WB	**Wide Body**: An aircraft with two passenger aisles, also known as a twin-aisle aircraft. Typically used to perform long-range flights.
ULD	**Unit Load Device**: A pallet or container used to load luggage, freight, and mail on a aircraft.

Nomenclature

Sets

A	Set of attribute names of a dimension.
Ac	Set of aircraft in a specific time.
$Airp$	Set of airports.
As	Set of activities in a specific time.
CA	Set of attributes of a competence.
CD	Set of attribute domains of a competence.
CS	Set of candidate solutions of a respondent agent.
Cw	Set of crew members in a specific period of time.
Edg	Set of flights in graph G.
Fl	Set of flights in a specific period of time.
I	Set of attribute domains of a dimension.
J	Set of negotiation attributes.
L^o	An ordered set of negotiation messages in $NegP^o$ (OA negotiation process).
L^{Ra}	An ordered set of negotiation messages in $NegP^{Ra}$ (RA negotiation process).
O	Set of organizer agents (in a negotiation).
PA	Set of problem domain attributes.
Pxd	Set of disrupted passengers in a flight.
R	Set of respondent agents (in a negotiation).
R_a	Set of respondent agents in a negotiation $NegP^o$ (organizer agent negotiation process.
R_b	Set of respondent agents in a negotiation $NegP^{Ra}$ (respondent agent negotiation process.
RT	Set of restrictions.
Sac	A Solution Set for the aircraft problem as seen by the *aircraft specialist* agent.
Scw	A Solution Set for the crew problem as seen by the *crew specialist* agent.
Spx	A Solution Set for the passenger problem as seen by the *passenger specialist* agent.
V	Set of attribute score functions of a dimension.
Vrt	Set of airports in graph G.
VP	Set of preferred attribute values of a dimension.

Tuples

AT	A q-learning action.
AV	Partial-Solution attribute values.
C	Competence of an agent.
d	Dimension of a problem.

F	Feedback for each attribute of each dimension.
G	A graph used by the *passenger specialist* agent.
IP	Interaction Protocol in the negotiation model NegMod.
$NegMod$	Our Negotiation Model.
$NegP^{o}$	A negotiation process from the point of view of an organizer agent.
$NegP^{Ra}$	A negotiation process from the point of view of an organizer agent.
P	Problem to be solved.
ps	Partial-solution.
Q	State, action and Q-Value of the Q-learning algorithm.
S	Solution to a problem.
ST	A q-learning state.

Elements of Sets and Tuples or Indexes

a	An agent (in general).
ac	A specific element of the set Ac.
as	A specific element of the set As.
at	An action, i.e., an element of the n-tuple AT.
b	Another agent (in general).
cw	A specific element of the set Cw.
f	A feedback.
fl	A specific element of the set Fl.
i	Index of a dimension.
j	An index of an element of a set or tuple; An issue or attribute.
o	An organizer agent.
pa	An attribute (in general) from the problem domain.
pxd	A specific element of the set Pxd.
r	A respondent agent.
rt	A restriction.
sac	A specific element of the set Sac.
scw	A specific element of the set Scw.
spx	A specific element of the set Spx.
st	A state, i.e., an element of the n-tuple ST.

Variables

ad	A disrupted aircraft included in the set Ac.
asd	A disrupted activity included in the set As.
c	A comment by the organizer agent to a proposal presented by a respondent agent.
cwd	A disrupted crew member included in the set Cw.
ev	Evaluation assigned by the organizer agent to a proposal.
fd	A disrupted flight included in the set Fl.
id	An identifier of something.
m	Total number of attributes on a partial-solution; Total number of attributes on a dimension; Total number of respondent agents.
n	Total number of dimensions in a problem; Total number of partial-solutions in a solution; Total number of organizer agents.

p Total number of proposals received; Total number of proposals sent.
rw A reward (value of) in the q-learning algorithm.
s Total number of requests and informs received.
t An instance of time or a round in a negotiation.
uv Utility value of a proposal/solution for the agent that sent it..
V^P Value of an offer according to a score function.
V_j^i The score value of issue j in dimension i.
V_o^t Evaluation made by agent o does at round t.
w Total number of attributes (in general).
W_j^i Weight of issue j in dimension i.
α_i Weight of dimension i.

Miscellaneous

CL Communication language of a negotiation model.
CV A scoring function that evaluates the preferred solutions (partial) according to the competence of an agent.
DL Domain language of a negotiation model.
E Environment of a negotiation model.
RF A List of request and inform tuples received during the inter-respondent agents negotiation.
$O_{r\to o}^t$ Offer from a respondent agent r to an organizer agent o at round t; vector of values proposed by agent r to agent o at round t.
$O_{r\to o}^t[j]$ Value of attribute j presented by agent r to agent o at round t.
$Q(st,at)$ The Q-value (in the q-learning algorithm) that corresponds to the execution of action at when at state st.
RI Rules of interaction of an IP (Interaction Protocol).
$Rw_r^{t+1}(O_{r\to o}^t)$ A function that calculates a reward (q-learning) that agent r receives at round $t+1$ after presenting a proposal O to agent o in the previous round t.
SM Sequence of messages exchanged during a negotiation process.
$U_o(O_{r\to o}^t)$ Utility of offer o for an organizer agent o.
V^i Score function for dimension i.

Air Transport Metrics

$\overline{CC}$ Average of Crew Costs in m.u.
$\overline{CCrcv}$ Average of Crew Cost Recovery Ratio.
$\overline{CCmin}$ Average of Crew Cost per Minute of the original problem flight delay.
$\overline{CwD}$ Average of Crew Delays in minutes.
$\overline{FC}$ Average of Aircraft and Flight Costs in m.u.
$\overline{FCrcv}$ Average of Flight Cost Recovery Ratio.
$\overline{FCmin}$ Average of Flight Cost per Minute of the original problem flight delay.
$\overline{FD}$ Average of Flight Departure Delays in minutes.
$\overline{FD15min}$ Average Number of Flights with Departure Delays greater than 15 minutes.

$p\left(\overline{FD15min}\right)$ Percentage of the Number of Flights with Departure Delays greater than 15 minutes.
$\overline{FDrcv}$ Average of Flight Departure Delay Recovery Ratio.
$\overline{PC}$ Average of Passenger Costs in m.u.
$\overline{PCmin}$ Average of Passenger Cost per Minute of the original problem flight delay.
$\overline{PD}$ Average of Passenger Trip Time Delays in minutes.

Negotiation Outcome Metrics

GF Global Fairness of the negotiation winner solutions.
$\overline{Ua/c}$ Average of the Aircraft partial-solutions Utility of the Negotiation Winner Solutions for the Aircraft Agent.
$\overline{Ucrew}$ Average of the Crew partial-solutions Utility of the Negotiation Winner Solutions for the Crew Agent.
$\overline{Upax}$ Average of the Passenger partial-solutions Utility of the Negotiation Winner Solutions for the passenger Agent.
$\overline{Usup}$ Average of the Negotiation Winner Solutions Utility for the Supervisor Agent.
$\overline{Usw}$ Average Utilitarian Social Welfare of the Negotiation Winner Solutions for the Supervisor Agent.

Protocol Performance Metrics

$\overline{Mprb}$ Average Number of Messages per Problem, exchanged by agents during the negotiation.
$\overline{Msg}$ Average Number of Messages Exchanged by agents during the negotiation.
$\overline{NR}$ Average Number of Negotiation Rounds to Reach an Agreement.
$\overline{NT}$ Average Negotiation Time.
$\overline{ST}$ Average Negotiation Search Time.

Solution Quality Metrics

$\overline{A/Cact_{ei}}$ Arithmetic Average of the percentage of times that an action i was used to solve the aircraft part of a problem in the experimental run e.
$A/Cqual$ Aircraft Solution Quality.
$\overline{CRWact_{ei}}$ Arithmetic Average of the percentage of times that an action i was used to solve the crew part of a problem in the experimental run e.
$CRWqual$ Crew Solution Quality.
$\overline{PAXact_{ei}}$ Arithmetic Average of the percentage of times that an action i was used to solve the passenger part of a problem in the experimental run e.
$PAXqual$ Passenger Solution Quality.
$ITGqual$ Integrated Solution Quality, i.e., the quality of the solution that includes the three dimensions of the problem: aircraft, crew and passenger.

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