Call for Exploratory Projects in All Scientific Domains 2023
2023.15110.PEX

Status
Draft

Closes in
01.03.20

Application Global View

General data

Principal investigator
Francisco Manuel Gonçalves Coelho

Project title in portuguese
Indução de Stochastic Answer Set Programs por Meios Algébricos

Project title in english
Induction of Stochastic Answer Set Programs by Algebraic Means

Project acronym
IAM

Keywords in portuguese

Indução de Programas Lógicos   Programação Lógico-Probabilística   Programação de Conjunto de Resposta

Keywords in english

Inductive Logic Programming   Probabilistic Logic Programming   Answer Set Programming

Main scientific area

Scientific domain
Exact Sciences

Scientific area
Computer and Information Sciences

Scientific subarea
Computer Sciences

Evaluation panel
Computer and Information Sciences and Informatics

Timetable

Start date
01.09.2024

Duration (months)
18

Institutions

Principal contractor

Institution	Research Unit
Universidade de Évora	→ NOVA Laboratory for Computer Science and Informatics → Cátedra High Performance Computing

Institution description and its competencies for the development of the project

The University of Évora is a public University organized in 5 Schools: Arts, Sciences and Technology, Social Sciences, Health and human development, Nursing and the Institute for Advanced Studies and Research. Research and Development covers several areas through 18 Research Units, all of them submitted to international evaluation. The University of Évora has established 10 Chairs in Aerospace, Agriculture, Biodiversity, Heritage, Health, High Performance Computer, Iberian studies, UNESCO and Renewable Energies, participates in the National Roadmap of Strategic Research Infrastructures and has several research infrastructures in biodiversity, computer sciences, aerospace engineering, solar energy and heritage. The University fosters a close link with the community, enhanced through the creation of networks, the participation in the Science and Technology Park and by establishing protocols and co-promotion research projects. The main R&D areas are: Applied Mathematics; Chemistry; Culture; Education and Psychology; Healthcare; Geophysics; History; Environment and Sea; Linguistics and Literature; Materials and Surface Science; Social and Political Sciences and Science. The 300 running R&D projects are developed through national and international partnerships, under Horizon Europe, PRIMA, ERASMUS +, LIFE, Creative Europe, Digital Europe Programme, Cost Actions, EIT Health, EIT Urban Mobility, EEA Grants, INTERREG, PT2020, Alentejo2020, COMPETE2020, PRR, FCT or private funding.

Collaborative institutions

Country	Institution
PORTUGAL	Cátedra High Performance Computing

Institution description and its competencies for the development of the project

The High Performance Computing Chair (HPC) presents itself as a research and development (R&D) infrastructure dedicated to high performance computing that seeks to follow developments towards the digital transition, which enables a more efficient approach to national and European IT strategies, digital innovation for academia, companies and other public-private organizations.

This new research infrastructure, in partnership with the universities of Algarve, Nova de Lisboa and Porto, has as its main objective to promote professional training between academia and industry, enhancing the development and adoption of HPC, HPDA (High Performance Data Analytics) and AI (Artificial Intelligence) by different actors in the region and at national and international levels. At the same time, it enhances the use of local advanced computing infrastructures managed by the HPC-UÉ Center, such as the OBLIVION supercomputer

Research team ⌃

Principal investigator

Francisco Manuel Gonçalves Coelho   `Core`   PI   ⌃

Ciência ID
AF10-03F3-E074

Institution to which you are associated in the scope of the research project
Universidade de Évora

CV
Obtained in 25-02-2024 at 15:48:59 GMT

PI Narrative CV

Carreer profile
1993 Degree in Mathematics, FCUL

1997 MSc in Mathematics (Algebra), FCUL. About Hilbert's tenth problem and a computational model based on geometric constructions with ruler and compass.

1997 Teaching Assistant, Mathematics Department, UÉ.

2006 PhD in Informatics (Computer Science), UL. About deliberation by autonomous agents.

2006 Assistant Professor, Mathematics Department, UÉ.

2006-2021, Period of minor visible activity, dedicated to learn statistical AI. Here I started to think about the limitations and advantages of the statistical vs. logic AI approaches and how they can contribute to each other.

2006 Assistant Professor, Computer Science Department, UÉ.

2008 Article "The euclid abstract machine: Trisection of the angle and the halting problem". Develops the ideas about computing and geometry, started in the master's dissertation.

2010 Book "Teoria da Computação, Computabilidade e Complexidade" (Escolar Editora). For graduate students.

2015 Article "Probabilistic perception revision in AgentSpeak(L)". Initial study on the integration of logic and statistical AI.

2016 Book "Introdução à Matemática - Álgebra, Análise e Otimização" (LIDEL). For undergraduate students.

2017 Article "A method for regularization of evolutionary polynomial regression" (Applied Soft Computing). Proposes a method for learning polynomial models using genetic algorithms.

2021 Researcher at the chair "High Performance Computing" at UÉ. Organized and taught an introduction course to the Julia language, aimed at the digital humanities and social sciences.

2021 Integrated member of the NOVALINCS center. I have been researching the extension of the ASP language with probabilistic annotations.

2022 CPCA/A0 Project "JuPy". Small FCT founded project exploring the use of "high-level" languages (Julia, Python) in distributed computing and HPC systems.

2023 Work on the extension of ASP with probabilistic annotations, and respective induction by a set of data and background knowledge.

Contributions to Science and Society

Contributions to the generation of new ideas, tools, methodologies or knowledge

- 2021, Mentor of i-Days: Student competition to tackle health challenges, organized by EIT-Health and StartUB!C (Universidad de Barcelona), that took place in PACT, Évora. i-Days promote health innovation among university students through dozens of one-day and two-day programmes held in academic institutions around Europe.

- Co-author of "Lattice-Maker", a set of tools to present lattices of combinatorial games in LaTeX, used on the PhD thesis "Lattices related to Conway's construction", where I was member of the juri, and two papers where I'm co-author: DOI:10.1016/j.tcs.2014.01.025 (2014) and DOI:10.1007/s00182-020-00715-3 (2021).

- Author of "TeseUE", a LaTeX class to MSc dissertations and PhD thesis in Universidade de Évora, is currently used by many students.

- Co-author of "Genetic Algorithms for Polynomial Regression", R code to find the best polynomial regression using genetic algorithms, used in the journal paper DOI:10.1016/j.asoc.2017.05.047 (2017).

- Author of "Galaxity", a Java system to assess the correction of perceptions of AgentSpeak(L) agents using probabilistic methods, used in the conference paper DOI:10.1007/978-3-319-25524-8_44 (2015).

Contributions to the development of individuals and/or research teams

- 2023, 2024, coordinator and teacher of the online course "Programming in Julia for Digital Humanities", aimed to digital humanities and social sciences researchers, part of the training and dissemination activities of the HPC Centre and the HPC Chair.
- 2024, mentor of the mini-project "Automatic Differentiation", aimed at MSc and PhD students, at the Birla Institute of Technology and Science, Pilani, India, within the Asian and European Schools in Mathematics. Travel was supported by a CIMPA scholarship.
- 2024, teacher of the course "An Introduction to Julia for Scholars", aimed at MSc and PhD students and researchers, at the Birla Institute of Technology and Science, Pilani, India, within the Asian and European Schools in Mathematics. Travel was supported by a CIMPA scholarship.
- Since 2016, course director and teacher of "Introdução ao LaTeX" (Introduction to LaTeX), directed at students and

researchers, at U. Evora.

- 2016, Co-author of the book "Introdução à Matemática - Álgebra, Análise e Otimização"(LIDEL), ISBN:978-989-752-209-3, addressing core mathematical subjects (algebra, calculus and optimization) for social sciences university courses. Used in the course "Matemática Aplicada à Economia e Gestão", Universidade de Évora.
- 2010, co-author of the book "Teoria da Computação, Computabilidade e Complexidade", ISBN:978-972-592-281-1, where computation is explained starting with simple machines, addressing the computation limits such as the Halting Problem, polynomial equivalence and complexity. A draft version of this book was used in the course "Teoria da Computabilidade e Complexidade", Universidade de Évora.
- Since 2023, mentor of one BII Scholarship within the scope of the multi-annual financing of the R&D unit with reference UIDP/04516/2020, financed by national funds through the FCT/MCTES.
- Since 2022, supervisor of three ongoing PhD thesis on computer science.
- Since 2010, supervisor of six completed and three ongoing MSc dissertations about topics such as e-learning, virtual reality, serious games or game design.
- Since 2010, member of the juri in 13 academic examinations, including three as examiner.
- Since 2006, assistant professor at UÉ. Within this role I coordinated more than 26 courses, including mathematics and computer science, for graduation or MSc grades.

Contributions to the research community and the broader society

- Since 2022, reviewer for the "Applied Soft Computing" journal (Q1).
- Since 2021, participation in the "High Performance Computing Chair" of U. Évora, as member of the scientific team, technical-scientific board, coordinator of the "Programming in Digital Humanities" task and member of five work packages.
- Since 2011, member of several organizing and scientific committees of international scientific events. In the most recent, the international conference "Programming and Data Infrastructure in Digital Humanities", I was member of both the scientific and organizing committee.
- Since 1997, fifteen communications at scientific dissemination events, either at international conferences or invited to scientific lectures.
- 2024, 2023, 2010, visited higher education institutions in India, the Czech Republic and Timor-Lorosa'e to disseminate knowledge and to establish or reinforce cooperation between U. Évora and local HEI.
- 2010, 2016, Co-author of two pedagogical books, about Mathematics and Computer Science, aimed at higher education students, contributions to the dissemination of knowledge.
- Since 2016, course director and teacher of "Introdução ao LaTeX" (Introduction to LaTeX), directed at students and researchers, at U. Évora.
- 2023, 2024, An introduction course to the Julia language, for researchers in the areas of digital humanities and social sciences.
- 2023, Invited Talk, "Fronteiras da Inteligência Artificial", Festival da Ciência'23, U. Évora, aimed at societal engagement with science.
- 2024, An introduction course to the Julia language, for students on technical courses and researchers.
- 2024, A mini-project/introduction course to automatic derivation with Python, for students of technical courses.

Selected outputs and/or activities

Activity "Combinatorial Games Theory" and results

- Contributed to the development of "Lattice-Maker", a set of tools to present lattices of combinatorial games in LaTeX, available in the public repository <https://github.com/fmgc/Lattice-Maker>.
- Lattice-Maker was used by Cátia Dias on her PhD thesis "Lattices related to Conway's construction" where I was member of the juri, and in two international, indexed, jornal papers:
  - 2021, Carvalho, Dias, Coelho, Neto, Nowakowski, Vinagre, "On lattices from combinatorial game theory: infinite case", DOI:10.1007/s00182-020-00715-3
  - 2014, Carvalho, Santos, Dias, Coelho, Neto, Nowakowski, Vinagre, "On lattices from combinatorial game theory. Modularity and a representation theorem: Finite case", DOI:10.1016/j.tcs.2014.01.025

Activity "Polynomial Regression" and results

- Contributed to "Genetic Algorithms for Polynomial Regression", R code to find the best polynomial regression using genetic algorithms, available in the public repository <https://github.com/jpneto/GenAlgPoly>.
- This program was used in the international, indexed, journal paper
  - 2017, Coelho e Neto, "A method for regularization of evolutionary polynomial regression", DOI:10.1016/j.asoc.2017.05.047
- This is my most cited work, some of which two in 2023, six years after publishing.

Activity "Perception Correction" and results

- Implemented "Galaxity", a Java system to assess the correction of perceptions of AgentSpeak(L) agents using probabilistic methods, and "jpgm", a small Java library to support simple probabilistic graphical models (pgm) computations used in Galaxity. These are available in the public repositories <https://bitbucket.org/mangon/galaxity> and <https://github.com/fmgc/jpgm>.
- "Galaxity" (and "jpgm") where used in the conference paper

- 2015, Coelho e Nogueira, "Probabilistic perception revision in AgentSpeak(L)", DOI:10.1007/978-3-319-25524-8_44

Activity "Stochastic Answer Set Programs" and results

- Started in 2023 and is currently my main research activity, a continuation of "Perception Correction" towards the combination of statistical ans logic AI. At this moment the outcomes of this activity are
  - BII scholarship, supported by "Financiamento Plurianual da unidade de I&D UIDP/04516/2020", co-supported by FCT, Portugal.
  - Draft programs, available in a public repository.
  - A paper, "An Algebraic Approach to Stochastic ASP", in co-authorship, recently submitted to a international conference.

Why would this grant be timely for me at this point in my career path and/or in my research?

2006, PhD thesis about deliberation.

Deliberation, selecting an action from perceptions and internal state, embodies the key challenges of AI, from computer vision to planning, learning, complexity or the frame problem. Each can be stated as a statistical problem (eg POMDP) or as a logical one (eg "plans" as formal expressions processed by symbolic rules).

Each has strengths and weaknesses. Statistical models require large amounts of data to train while inductive logic programs often result from background knowledge and small sets of examples but the former are robust to noise while the latter are fragile.

By then my research main interest become how to combine the strengths of statistical and logic AI.

2015, author of Galaxity, a system to play with correction of perceptions of logic agents using probabilistic methods; Described in **DOI:10.1007/978-3-319-25524-8_44**, a initial study on combining logic and statistical AI.

BDI agents often win planning competitions where, unlike real scenarios, perception is perfect. The Galaxity system introduces noise in the agent's perception and uses a HMM to estimate the probability of the real state. This is then tested in simulations, outperforming other agents also subject to noisy perceptions.

Despite the positive result, this is a shallow approach with no substantial theoretical base to support further work.

By then I have learned about probabilistic logic programming, the Sato semantics and Markov logic.

Also, my participation in the NOVALINCS research unit opened new opportunities.

Since 2023, mentor of a BII Scholarship about Stochastic Answer Set Programs (SASP), financed by national funds through FCT/MCTES: UIDP/04516/2020; NOVALINCS (UIDB/04516/2020).

Answer Set Programming (ASP) is a pure declarative logic language with excellent tool support and theoretical foundations (Gelfond and Lifschitz stable models). Semantics for probabilistic versions of ASP have been proposed but the problem is still very much open.

My, Bruno Dinis and Salvador Abreu approach is described in "An Algebraic Approach to Stochastic ASP", recently submitted to an international conference.

We address the problem of extending probability from total choices to stable models, and from there to general events. Possible applications include assigning a score to a logic program with respect to the empiric distribution of a dataset, which can be used by evolutionary algorithms searching optimal models of that dataset. From there we have induction of stochastic ASP.

This paper is the root to the research proposed with this project:

1. Investigate the structure and composition of SASP and transformation rules to **support program space search by evolutionary algorithms**.
2. Implement a library to **support SASP evaluation** using existing ASP systems.
3. Explore how distributed HPC systems can be used to **scale-up and speed-up the evaluation of SASP**.
4. Investigate the **application of SASP to theoretical and real-world problems**.

Members

Bruno Miguel Antunes Dinis   Core   Member   ⌃

Association
Accepted

Ciência ID
3E1F-A94E-D147

Institution to which you are associated in the scope of the research project
Universidade de Évora

CV
Obtained in 23-02-2024 at 15:10:13 GMT

Miguel Ângelo Pignatelli de Avillez Nunes Pereira   Core   Member   ⌄

Association
Waiting

Ciência ID
4110-30FC-E46E

Institution to which you are associated in the scope of the research project
Cátedra High Performance Computing

CV
-

SALVADOR LUÍS DE BETHENCOURT PINTO DE ABREU   Core   Member   ⌄

Association
Waiting

Ciência ID
C617-7ED4-8326

Institution to which you are associated in the scope of the research project
Universidade de Évora

CV
-

Hirings

(BIPD - 01) Post doctoral Research Grant   ⌄

Institution
Universidade de Évora

Tasks
Integration with existing ASP and ILP software frameworks (INT)   ·   12 person * month

Consultants
-

Research team CV synopsis

- **Francisco Coelho** completed his PhD in Informatics in 2006 at Universidade de Lisboa under the supervision of Helder Coelho on Artificial Intelligence. Is previous formation is on Mathematics, where he has a Master degree in Mathematics, specialty

on Artificial Intelligence. Is previous formation is on Mathematics, where he has a Master degree in Mathematics, specially Algebra, with a dissertation about Hilbert's tenth problem and about geometric computation, advised by Prof. Augusto Franco de Oliveira and Prof. José Félix Costa. Currently he is Assistant Professor at the Computer Science department of Universidade de Évora, where he has coordinated more than twenty courses and restructured or proposed other six, to the graduation and master degrees. He is supervising three PhD thesis and two MSc dissertations and has supervised other six completed MSc dissertations. He contributed with software and writing to papers covering a wide range of subjects but mostly about logic and statistical AI. He is integrated member of the Intelligent Systems of the research unit NOVALINCS and member of the scientific team of the High Performance Computing Chair.

- **Bruno Dinis** completed his PhD in Maths in 2013 at the University of Évora under the supervision of Imme van den Berg on Nonstandard Analysis. After his doctoral studies, he was a postdoc at the Faculdade de Ciências under the supervision of Fernando Ferreira, working on Proof Theory. Bruno Dinis is currently an Assistant Professor at the Universidade de Évora. Co-supervised 1 master's dissertation. He has written over 20 papers on several aspects of logic, for the most part in proof interpretations and its applications (proof mining).

- **Salvador** is Full Professor at the University of Évora (UE) School of Science and Technology since 2013, Senior Researcher at NOVA LINCS and President of the Scientific Council at the UE Institute for Research and Advanced Training (IIFA). He currently directs the PhD Program in Informatics at UE.
  He holds a Habilitation in Informatics from the University of Évora (2009), a PhD in Informatics from Universidade NOVA de Lisboa (1994), and a BSc in Informatics Engineering from Universidade Nova de Lisboa (1987).
  Salvador successfully supervised 9 doctoral theses and is currently directing 3. He was granted an IBM SUR award in 2013 and a JSPS Invitation Fellowship in 2015. He participates or participated as a project member or Principal Investigator in nationally and European funded projects, including OAR, AJACS, STAMPA, JEDI, HORUS, VAPS, BIOECOSYS, AI4EU, EUGREEN and PaCoMoCo.

Work plan ⌃

Abstract

Abstract in portuguese

[TODO]

> Análise do estado da arte

> Principais objetivos a atingir

A pontuação do SASP com relação às evidências torna possível induzir um SASP (ou seja, um modelo probabilístico) a partir de observações, com base e respeitando o Conhecimento Básico (BK) formalizado. Este tipo de modelos explicam as observações numa linguagem (de primeira ordem) que, em princípio, pode ser lida e interpretada por humanos, uma contribuição para o problema da Inteligência Artificial Explicável (XAI).

Outra vantagem potencial da nossa abordagem é que a indução de programas lógicos geralmente é obtida com pequenos conjuntos de dados.

Portanto, o motor deste projeto que enquadra as tarefas, marcos e objetivos principais é a utilização do SASP e o estudo da indução do SASP a partir de BK e observações.

A tarefa "Estrutura e Indução de SASP (SI)" tem como objetivo principal um estudo teórico para indução de SAPS. Continua o trabalho de [8], esclarecendo o papel dos elementos de estrutura e composição do SASP (por exemplo, programas estratificados ou recursivos, símbolos funcionais) nos modelos estáveis, a relação de equivalência de eventos e, a partir daí, procede ao estudo da indução. de SASP usando algoritmos de exploração de espaço de programa baseados em regras de transformação de programa (por exemplo, algoritmos genéticos).

O objetivo principal da tarefa "Integração com estruturas de software ASP e ILP (INT) existentes" é a implementação de ferramentas de software para usar e induzir SASP. Espera-se que esta tarefa beneficie da investigação teórica da tarefa anterior e dos seus resultados para serem utilizados, por investigadores não especialistas, em aplicações futuras.

O objetivo principal da tarefa "Computação de Alto Desempenho para Indução e Uso de SASPs (HPC)" é a aceleração e expansão do uso e indução de SASP usando sistemas HPC distribuídos. Deverá beneficiar do trabalho teórico da primeira tarefa e de alguns resultados da segunda tarefa. O resultado esperado desta tarefa é um conjunto de protótipos de programas e/ou bibliotecas explorando bases de conhecimento complexas ou grandes conjuntos de dados.

O objetivo principal da tarefa "Aplicações de SASPs (APP)" é a aplicação de SASP a problemas teóricos e do mundo real. Espera-se que esta tarefa beneficie das ferramentas de software da segunda e terceira tarefas. No final, devemos obter uma avaliação do

desempenho de SASPs codificados manualmente e induzidos em relação a problemas teóricos e do mundo real selecionados.

> Conhecimentos e habilidades disponíveis no grupo

Francisco Coelho é Professor Auxiliar na Faculdade de Ciências e Tecnologia da Universidade de Évora. Ele tem doutorado em Ciência da Computação e mestrado em Matemática. O seu principal trabalho de investigação trata da interação entre IA estatística e lógica e tem contribuído para/com software que apoia trabalhos de investigação nas áreas de aprendizagem automática, simulações baseadas em agentes e teoria combinatória dos jogos. Participou como Investigador Principal no projeto CPCA/A0/427668/2021, FCT, Portugal.

Bruno Dinis concluiu o doutoramento em Matemática em 2013 na Universidade de Évora sob orientação de Imme van den Berg em Nonstandard Analysis. Após o doutoramento, fez pós-doutoramento na Faculdade de Ciências sob orientação de Fernando Ferreira, trabalhando em Teoria da Prova. Bruno Dinis é atualmente Professor Auxiliar na Universidade de Évora. Coorientação de 1 dissertação de mestrado. Ele escreveu mais de 20 artigos sobre diversos aspectos da lógica, principalmente em interpretações de provas e suas aplicações (mineração de provas).

Salvador é Professor Catedrático da Faculdade de Ciências e Tecnologia da Universidade de Évora (UE) desde 2013, Investigador Sénior da NOVA LINCS e Presidente do Conselho Científico do Instituto de Investigação e Formação Avançada (IIFA) da UE. Foi-lhe atribuído um prémio IBM SUR em 2013 e uma JSPS Invitation Fellowship em 2015. Participa ou participou como membro do projeto ou investigador principal em projetos financiados a nível nacional e europeu, incluindo OAR, AJACS, STAMPA, JEDI, HORUS, VAPS, BIOECOSYS, AI4EU, EUGREEN e PaCoMoCo.

Miguel Avillez [TODO]

> Estratégia e metodologias a utilizar

O caminho estratégico

> Novidade e os resultados esperados

Abstract in english
[DRAFT]

> Analysis of the state of the art

> Main goals to be addressed

Scoring SASP with respect to evidence makes possible to induce a SASP (i.e., a probabilistic model) from observations, based and respecting formalized Background Knowledge (BK). Such kind of models explain the observations in a (first order) language that, in principle, can be read and interpreted by humans, a contribution to the problem of Explainable Artificial Intelligence (XAI).

Another potential advantage of our approach is that induction of logic programs is usually achieved with small datasets.

Therefore, the driver of this project that frames the tasks, milestones and main objectives is the use of SASP and the study of induction of SASP from BK and observations.

Task "Structure and Induction of SASP (SI)" main goal is a theoretical study for induction of SAPS. It continues the work of [8] by clarifying the role of SASP structure and composition elements (e.g., stratified or recursive programs, functional symbols) in the stable models, the equivalence relation of events and, from there, proceed to the study of induction of SASP using program space exploration algorithms based on program transformation rules (e.g., genetic algorithms).

Task "Integration with existing ASP and ILP software frameworks (INT)" main goal is the implementation of software tools to use and induce SASP. This task is expected to benefit from the theoretical research of the previous task and its results to be used, by non-specialist researchers, in future applications.

Task "High Performance Computing for Induction and Use of SASPs (HPC)" main goal is the speed-up and scale-up of use and induction of SASP using distributed HPC systems. It should benefit from the theoretical work of the first task and from some

output of the second task. The expected outcome of this task is set of prototype programs and/or libraries exploring complex knowledge bases or large datasets.

Task "Applications of SASPs (APP)" main goal is the application of SASP to theoretical and real-world problems. This task is expected to benefit from the software tools from the second and third tasks. In the end, we should get an assessment of the performance of hand-coded and induced SASPs with respect to selected theoretical and real-world problems.

> Knowledge and skills available in the group

Francisco Coelho is Assistant Professor at Universidade de Évora, School of Science and Technology. He has a PhD in Computer Science and MSc in Mathematics. His main research work deals with the interplay of statistical and logic AI and he has contributed to/with software supporting research work in the areas of machine learning, agent based simulations and combinatorial game theory. He participated as Principal Investigator in the project CPCA/A0/427668/2021, FCT, Portugal.

Bruno Dinis completed his PhD in Maths in 2013 at the University of Évora under the supervision of Imme van den Berg on Nonstandard Analysis. After his doctoral studies, he was a postdoc at the Faculdade de Ciências under the supervision of Fernando Ferreira, working on Proof Theory. Bruno Dinis is currently an Assistant Professor at the Universidade de Évora. Co-supervised 1 master's dissertation. He has written over 20 papers on several aspects of logic, for the most part in proof interpretations and its applications (proof mining).

Salvador is Full Professor at the University of Évora (UE) School of Science and Technology since 2013, Senior Researcher at NOVA LINCS and President of the Scientific Council at the UE Institute for Research and Advanced Training (IIFA). He was granted an IBM SUR award in 2013 and a JSPS Invitation Fellowship in 2015. He participates or participated as a project member or Principal Investigator in nationally and European funded projects, including OAR, AJACS, STAMPA, JEDI, HORUS, VAPS, BIOECOSYS, AI4EU, EUGREEN and PaCoMoCo.

Miguel Avillez [TODO]

> Strategy and methodologies to be used

The strategic path

> Novelty and the expected results

Abstract for publication

Abstract for publication in portuguese

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Abstract for publication in english

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State of the art and objectives

A major limitation of logical representations in real world applications is the implicit assumption that the background knowledge (BK) is perfect. This assumption is problematic if data is noisy, which is often the case. Probabilistic Logic Programming (PLP) is one ongoing effort to address this problem by extending the syntax and semantics of logic programs in order to have them

one ongoing effort to address this problem by extending the syntax and semantics of logic programs in order to have them represent and operate probability distributions (see [11]).

Current systems for PLP, such as ProbLog [5], P-log [3], LP^MLN [6], or cplint [7], derive a probability distribution from a program. However, for Answer Set Programs (ASP) [12] with probabilistic facts, the characterization of a probability distribution on the program's domain is not straightforward (see [1, 2, 3, 4]).

In [8] we address the problem of extending probability from the total choices of an ASP program to its stable models and, from there, to general events. Our approach is algebraic in the sense that it relies on an equivalence relation over the set of events and uncertainty is expressed with variables and polynomial expressions. In that work we show how SASP can represent arbitrary bayesian networks and therefore express any probability distribution of discrete random variables.

This representation of arbitrary bayesian networks conferes to SASP the capability to deal with a very large collection of probability problems and tasks. However, the problem of obtaining such SASP, besides hand-coded, remains open.

In our system some unknowns are represented by numeric parameters that can be estimated later from further information, e.g., evidence. This approach, delaying the assignment of certain parameters, enables later refinement and scoring a partial program from additional evidence.

In turn, scoring of SASP (i.e., models of a probabilistic phenomenon) is a key feature required to the application of evolutionary algorithms. From here we can explore how to induce SASP from BK and evidence.

The calculus of the score of an SASP with respect to evidence was already introduced and illustrated in [8]. It remains to investigate the application of this process to induction of SASP from BK and evidence.

Ideas of this paper have a partial, limited, implementation, available in a public repository, that results from the work of a BII scholarship, supported by NOVALINCS "Financiamento Plurianual da unidade de I&D UIDP/04516/2020" and co-supported by Fundação para a Ciência e a Tecnologia (FCT), Portugal.

In the general Induction of Logic Programs (ILP) setting (see [11, 13]) the goal is to algorithmically obtain a (target) logic program. For that, (1) BK (e.g., obtained from experts) is provided in the form of a logic program, describing objects and (first-order) relations of a domain and (2) observations are organized as positive evidence, that should be inferred from the target program, and negative evidence, that should not be inferred from the target program. Moreover, the target program must be (logically) consistent with the BK. ILP is a form of Machine Learning (ML) that offers significant advantages over numeric based ML:

- For one, ILP address the problem of Explainable Artificial Intelligence (XAI) because, unlike the large-dimensional vector based models of numeric ML, logic programs are human-readable in the sense that their declarative nature describes what objects are in the domain, their structure, properties and relations.
- Second, ILP describes phenomena with related instances while numeric ML is limited to a single (tabulated) relation where different instances (lines) are independent given the model.
- Third, often a target program is generated from a small set of observations, while, in general, numeric ML models require large datasets to achieve significant accuracy.
- At last, expert knowledge, expressed in the BK, can be utilized to structure the target program, i.e., to model the observations. Again, this is a feature hard to achieve with numeric ML models.

Drawbacks of ILP include the computational complexity of inducing the target program and the general difficulty of logic programs to deal with noisy data. While the later is being addressed by PLP in general and SASP in particular, the computational complexity of induction remains an important challenge that we propose to investigate with this project.

In summary, with this project we aim to continue our exploration on how SASP represent probability distributions, how to use them to model probabilistic phenomena and how they can be induced from BK and evidence.

More specifically, this project's objectives are to investigate:

- The role of program structure and composition in the use of PASP to model probabilistic phenomena.
- Program transformation rules and space exploration algorithms for SASP.
- The performance of hand-coded and induced SASP models on selected theoretic and real world cases.

Research plan and methods

[DRAFT]

Identify whether the work plan requires advanced computer resources to be provided by FCT
Yes

Identify whether the work plan requires space in a research data repository to be provided by the FCT
Yes

Bibliographic references

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Past publications

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Tasks

SUMMARY OF COSTS BY INSTITUTION

Universidade de Évora

1. Structure and Induction of SASP (SI)	4 440,00 €
2. Integration with existing ASP and ILP software frameworks (INT)	30 835,00 €
3. Applications of SASPs (APP)	2 220,00 €
Total	**37 495,00 €**

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1   **Structure and Induction of SASP (SI)**   12 months   From 01.09.2024 to 31.08.2025 ⌃

Members

Persons / Month	Allocated
2	Bruno Miguel Antunes Dinis Universidade de Évora
2	Francisco Manuel Gonçalves Coelho Universidade de Évora
1	SALVADOR LUÍS DE BETHENCOURT PINTO DE ABREU Universidade de Évora

Task description and expected results

Objectives

Understand the role of Stochastic Answer Set Programs (SASP) structure and composition elements (e.g., stratified or recursive programs, functional symbols) on the stable models, event classes, respective probability and SASP scoring with respect to evidence (i.e., a dataset).

Understand what are the best choices for program transformation and combination rules for induction of SASP from Background Knowledge (BK) and evidence using evolutionary program space exploration algorithms (e.g., genetic algorithms).

Methodologies and approaches

List structure elements (e.g., stratified programs, recursive rules, functional symbols) and explore the respective effects on the stable models and event classes.

Modify the definition of event classes and study the effect on event probability and score function in modeling probabilistic processes

Define SASP transformation and combination rules to study and characterize the resulting properties of evolutionary program space exploration algorithms for the induction of SASP from BK and evidence.

Expected results

Assessment on the effects of SASP structures and composition elements on stable models, event classes, respective probability and SASP scoring with respect to evidence for the use of SASP in modeling probabilistic processes.

Assessment of SASP transformation and combination rules and the resulting properties of evolutionary program space exploration algorithms for the induction of SASP from BK and evidence.

Preconditions from other tasks

None. This is an initial task, a continuation of already done research.

Results to other tasks

The use of SASP in modeling probabilistic processes, because it studies the elements utilized in the computation of the event classes and respective probabilities.

The induction of SASP from BK and evidence, because it studies program transformation and combination rules utilized in evolutionary program space exploration algorithms.

Role of each partner and institution

Universidade de Évora: Principal contractor.

Justification for the resources

For deliverable "SI Paper 1": A member should present the results of this task in an international conference or journal.

For deliverable "SI Paper 2": A member should present the results of this task in an international conference or journal.

Deliverables and delivery dates

Paper accepted in international conference or journal, by 2025-03-01

Paper accepted in international conference or journal, by 2025-09-01

Overall cost justification of the task

Registration in international conference (x2)....1400.00€

Travel to international conference (x2)..............1000.00€

Per diem international conference (x3x2).........1152.00€

Budgets

Institution	Amount requested
Universidade de Évora	4 440,00 €

2	**Integration with existing ASP and ILP software frameworks (INT)**	12 months	From 01.12.2024 to 30.11.2025	∧

Members

Persons / Month	Allocated
2	Francisco Manuel Gonçalves Coelho Universidade de Évora
12	BIPD - 01 Post doctoral Research Grant Universidade de Évora

Task description and expected results

Objectives

Support the application of SASP for modeling probabilistic processes and induce SASP from Background Knowledge (BK) and evidence.

Methodologies and approaches

Implement, test, benchmark and document:

- SASP intermediate representation and a parser.
- Integration with existing, state of the art, Answer Set Program (ASP) tools such as Potassco and cplint for the computation of the stable models.
- Instrumental functions such as: event belongs to class, class probability, event probability.
- Support for SASP combination and transformation.
- Integration with existing, state of the art, evolutionary explorations tools (e.g. genetic algorithms).
- Command-line programs to support basic usage such as: list classes, query the probability of an event or class, induce SASP.

Expected results

A basic set of tools, including a library and command-line programs, to use Stochastic Answer Set Programs (SASP) for modeling probabilistic processes and induce SASP from Background Knowledge (BK) and evidence.

Preconditions from other tasks

From task SI:

- Insights on the relation of SASP structure and composition elements and the computation of classes, and element and

class probability.

- Insights on the effects of SASP transformation and combination rules on evolutionary program space exploration algorithms.

Results for other tasks

The software tools required by task APP to use and/or induce SASP on large problems.

Role of each partner and institution

Universidade de Évora, Principal contractor.

Justification for resources

The implementation volume and complexity requires a full-time post-doc student working over a year, using a suitable laptop.

The student should present the results of this task in an international conference or journal.

Deliverables and delivery dates

A report on progress, documenting the implementation, testing, benchmarking and documentation of the tools, by 2025-06-01.

Paper accepted in international conference or journal, by 2025-12-01.

Overall cost justification of the task

Registration in international conference...........700.00€

Travel to international conference.....................500.00€

Per diem international conference (x3).............576.00€

Laptop (i7, 32GB ram, 1TB SSD, 15").................2660.00€

Post-doc scholarship (BPD) (12 x 1686,00€)...20232.00€

Budgets

Institution	Amount requested
Universidade de Évora	30 835,00 €

3	**Applications of SASPs (APP)**	12 months	From 01.03.2025 to 28.02.2026	∧

Members

Persons / Month	Allocated
2	Francisco Manuel Gonçalves Coelho Universidade de Évora
1	Miguel Ângelo Pignatelli de Avillez Nunes Pereira Cátedra High Performance Computing
1	SALVADOR LUÍS DE BETHENCOURT PINTO DE ABREU Universidade de Évora

Task description and expected results

Objectives

Use Stochastic Answer Set Programs (SASP) for modeling probabilistic processes and induce SASP from Background Knowledge (BK) and evidence in the context of theoretic scenarios (toy problems) described in the relevant literature (e.g., Stochastic Plan Generation, Logic/Statistic Puzzles) as well as to a selected real world cases (e.g., virtual machine migration and server consolidation in data-centers).

Methodologies and approaches

Compile a set of theoretic and real-world problems.

Gather information in the form of background knowledge (e.g., from experts) and data (positive and negative examples) on

Gather information in the form of background knowledge (e.g., from experts) and data (positive and negative examples) on selected problems.

Evaluate the performance of hand-coded and induced SASPs on that set of problems.

Compare with state-of-the-art results.

Expected results

Assessment of the performance of hard-coded and induced SASPs on selected theoretical and real-world problems.

A list of advantages and problems in the application of SASP.

Preconditions from other tasks

From task SI:

- Insights on the relation of SASP structure and composition elements and the computation of classes, and element and class probability.
- Insights on the effects of SASP transformation and combination rules on evolutionary program space exploration algorithms.

From task INT:

- Libraries, programs, and respective documentation.

Results for other tasks

None. This is a final task.

Role of each partner and institution

Universidade de Évora: Principal contractor.

High Performance Computing Chair: Research unit.

Justification for the needed resources:

A member should present the results of this task in an international conference.

Deliverables and delivery dates

A report on progress, documenting the performance of the hand-coded and induced PASP models on the selected problems, by 2025-09-01.

A paper accepted in an international conference or journal, by 2026-03-01.

Overall cost justification of the task

Registration in international conference.......700.00€

Travel to international conference................500.00€

Per diem international conference (x3).........720.00€

Budgets

Institution	Amount requested
Universidade de Évora	2 220,00 €

Project timeline and management

Milestone list

Date	Designation	Description	Tasks
01.03.2025	SI Paper 1	A paper accepted in an international conferences or journals, describing the effects of structures and composition elements on SASP on stable models, event classes, and respective probability.	1. Structure and Induction of SASP (SI)

01.06.2025	INT Report	A report on progress, documenting the implementation, testing, benchmarking and documentation of the tools.	2. Integration with existing ASP and ILP software frameworks (INT)
01.09.2025	SI Paper 2	A paper accepted in an international conference or journal, describing program transformation rules and space exploration algorithms for SASP.	1. Structure and Induction of SASP (SI)
01.09.2025	APP Report	A report on progress, documenting the performance of the hand-coded and induced PASP models on selected problems.	3. Applications of SASPs (APP)
01.12.2025	INT Paper	A paper accepted in an international conference or journal, describing the performance of the implemented tools on hand-coded and induced SASP.	2. Integration with existing ASP and ILP software frameworks (INT)
01.03.2026	APP Paper	A paper accepted in an international conference or journal, documenting the performance of the hand-coded and induced PASP models on selected problems.	3. Applications of SASPs (APP)

Timeline

timeline.pdf

Obtained on 27-02-2024 at 21:55:52

Description of the management structure

[DRAFT]

Financial and Administrative Management

The Administrative Services of the University of Évora are responsible for project's financial and administrative management, through its Projects Management Division (DGP). This office is organized in two areas: (i) financial contracts and administrative management and (ii) administrative support to R&D units. They are deep experienced in managing several different financial programs such as Portuguese Government Structural Funds (Portugal 2020, FCT) and Community Funds, such as Erasmus+, H2020, HORIZON EUROPE or Creative Europe.

It is DGP's main task to fulfill all the necessary operations, provide administrative support and reassure the good execution of R&D Units budgets and respective Projects. Furthermore, it is accountable for the execution of all legal and required financial reports.

Each project is the responsibility of a project officer with expertise and experience in project management and finance. The project officer acts as a link between the Responsible Researcher and the rest of the financial team. Is also responsible to process all expenses fulfilling all the current national and European legislations.

The project officer is also in charge of the liaison with FCT (Science and Technology National Agency), European Commission and other donors by elaborating and delivering the financial reports and respective requests for payments, including reassuring all necessary procedures to the validation of expenditures.

The University of Évora owns an information system that allows the researcher to follow the project's financial implementation on a permanent basis.

Ethical issues

Are there Ethics Issues identified in this project?
No

Ethical declarations you consider appropriate
-

Justification
-

2030 Agenda

Framework of the application for the United Nations SDG 2030 Agenda

SDG Goal 9: Industry, Innovation and Infraestructures

Framework justification

Application of this project include the optimization in the use of existing infrastructure, therefore in accordance to **Target 9.b:** *Support domestic technology development, research and innovation in developing countries, including by ensuring a conducive policy environment for, inter alia, industrial diversification and value addition to commodities.* **Indicator 9.b.1:** *Proportion of medium and high-tech industry value added in total value added.*

Other projects

CPCA/A0/427668/2021   Fundação para a Ciência e a Tecnologia - FCT, I.P.   ⌃

PI

Francisco Coelho (PI)

Project status

Completed

Project title (in English)

JuPy | High Level Languages on HPC

Principal contractor

High Performance Computing Chair

Total funding

185,00 €

Start date	Duration (months)
21.01.2022	3

Main objectives of the project that you consider relevant for this application

- Knowledge and experience acquired about implementing and executing programs in a distributed HPC system.
- Technical and scientific cooperation relationships established between the PI and the management team of the "Oblivion | HPCUE" cluster.

Attachments

-

Indicators   ⌃

Expected output indicators

Description	2024	2025	2026	Total
A - Publications	0	0	0	

A · Publications	0	0	0	
Books	0	0	0	**0**
Book chapters	0	0	0	**0**
Papers in international journals	0	0	0	**0**
Papers in national journals	0	0	0	**0**
B · Communications	0	0	0	
Communications in national meetings	0	0	0	**0**
Communications in international meetings	0	3	1	**4**
C · Reports	0	2	0	**2**
D · Organization of seminars and conferences	0	0	0	**0**
E · Advanced training	0	0	0	
PhD theses	0	0	0	**0**
Master´s theses	0	0	0	**0**
Others	0	1	0	**1**
F · Models	0	0	0	**0**
G · Software	0	0	0	**0**
H · Pilot plants	0	0	0	**0**
I · Prototypes	0	1	1	**2**
J · Patents	0	0	0	**0**
K · Others	0	0	0	
API documentation	0	1	1	**2**
Library documentation	0	1	1	**2**
	0	0	0	**0**

Release

Promotion actions of the scientific activity planned in the project

- Publication in international conferences or journals.
- Public repositories with software and documentation, datasets and models.

Budget

Principal contractor

Universidade de Évora

Item	2024	2025	2026	Total
Human Resources ⌄	1 686,00 €	18 546,00 €	0,00 €	**20 232,00 €**
Missions ⌄	0,00 €	0,00 €	0,00 €	**0,00 €**

Scientific and technical instruments and equipment ⌄	2 660,00 €	0,00 €	0,00 €	**2 660,00 €**
Subcontracts ⌄	0,00 €	0,00 €	0,00 €	**0,00 €**
Patents registration ⌄	0,00 €	0,00 €	0,00 €	**0,00 €**
Demonstration, Promotion and Dissemination ⌄	0,00 €	5 328,00 €	1 776,00 €	**7 104,00 €**
Adaptation of buildings and facilities ⌄	0,00 €	0,00 €	0,00 €	**0,00 €**
Purchase of goods and services ⌄	0,00 €	0,00 €	0,00 €	**0,00 €**
Overheads	1 086,50 €	5 968,50 €	444,00 €	**7 499,00 €**
Total	**5 432,50 €**	**29 842,50 €**	**2 220,00 €**	**37 495,00 €**

Global budget

Item	2024	2025	2026	Total
Human Resources	1 686,00 €	18 546,00 €	0,00 €	**20 232,00 €**
Missions	0,00 €	0,00 €	0,00 €	**0,00 €**
Scientific and technical instruments and equipment	2 660,00 €	0,00 €	0,00 €	**2 660,00 €**
Subcontracts	0,00 €	0,00 €	0,00 €	**0,00 €**
Patents registration	0,00 €	0,00 €	0,00 €	**0,00 €**
Demonstration, Promotion and Dissemination	0,00 €	5 328,00 €	1 776,00 €	**7 104,00 €**
Adaptation of buildings and facilities	0,00 €	0,00 €	0,00 €	**0,00 €**
Purchase of goods and services	0,00 €	0,00 €	0,00 €	**0,00 €**
Overheads	1 086,50 €	5 968,50 €	444,00 €	**7 499,00 €**
Total	**5 432,50 €**	**29 842,50 €**	**2 220,00 €**	**37 495,00 €**

Funding plan

Item	2024	2025	2026	Total
FCT Financing	5 432,50 €	29 842,50 €	2 220,00 €	**37 495,00 €**
Self Funding	0,00 €	0,00 €	0,00 €	**0,00 €**
Other public funding	0,00 €	0,00 €	0,00 €	**0,00 €**
Other private funding	0,00 €	0,00 €	0,00 €	**0,00 €**
Total	**5 432.50 €**	**29 842.50 €**	**2 220.00 €**	**37 495.00 €**