Horizon 2020

Call: H2020-MSCA-IF-2017

(Marie Skłodowska-Curie Individual Fellowships)

Topic: MSCA-IF-2017

Type of action: MSCA-IF-EF-ST

(Standard EF)

Proposal number: 799557

Proposal acronym: PolyBar

Deadline Id: H2020-MSCA-IF-2017

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How to fill in the forms?

The administrative forms must be filled in for each proposal using the templates available in the submission system. Some data fields in the administrative forms are pre-filled based on the previous steps in the submission wizard.

This proposal version was submitted by **Valentin BLOT** on **14/09/2017 16:55:22** Brussels Local Time. Issued by the Participant Portal Submission Service.

Proposal ID **799557** *Acronym* **PolyBar**

1 - General information

Topic	MSCA-IF-2017
Call Identifier	H2020-MSCA-IF-2017
Type of Action	MSCA-IF-EF-ST
Deadline Id	H2020-MSCA-IF-2017

Acronym	PolyBar
Proposal title	A new approach to polymorphism through bar recursion

Note that for technical reasons, the following characters are not accepted in the Proposal Title and will be removed: < > " &

Duration in months	24
Scientific Area	ENG

Please select up to 5 descriptors (and at least 3) that best characterise the subject of your proposal, in descending order of relevance.

Descriptor 1	*Theoretical computer science, formal methods*
Descriptor 2	*Software engineering, operating systems, computer languages*
Descriptor 3	*Mathematical aspects of Computer Science*
Descriptor 4	*Mathematical logic and set theory*
Free keywords	*lambda-calculus, realizability, bar recursion*

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Abstract

Parametric polymorphism is an ubiquitous paradigm in programming. It permits writing generic algorithms that can be used on several datatypes, thus reducing the duplication of code and producing safer software. System F is a very simple polymorphic programming language suited to the theoretical study of polymorphism. From the point of view of mathematical logic, System F corresponds to the theory of second-order Peano arithmetic (PA2), which in turn is a sub-theory of first-order Peano arithmetic with the axiom of countable choice (PA-AC). On the other hand, PA-AC can be computationally interpreted using the non-polymorphic programming language System T extended with the bar recursion operator (System TBR).
The PolyBar project will turn the logical translation of PA2 to PA-AC into a computational translation from System F to System TBR. This translation will improve the state-of-the-art by extending the use of well-known proof techniques to polymorphic programming languages and promote the use of these languages in environments where safety is important, like medical software or autonomous car systems. Computer programmers will be able to use the sophisticated features of polymorphism and still prove correctness properties on their programs.
The PolyBar project will be carried out by the experienced researcher who worked during his PhD thesis on computational interpretations of PA-AC using System TBR, and recently gave the first connections with PA2 and System F. The experienced researcher will collaborate with a supervisor who has a strong background in type theories (including System F) and in correspondences between various mathematical theories and programming languages. Working in France, where System F was discovered and is still a subject of intense research by many experts in the field, the experienced researcher will make the beneficiary benefit from his experience in the UK, which has a strong community on recursion theory and denotational semantics.

Remaining characters 6

Has this proposal (or a very similar one) been submitted to a Horizon 2020 Marie Skłodowska-Curie Individual Fellowship call, with the same supervisor and future host institution (and partner organization for Global Fellowships)? (•) Yes ( ) No

Please give the proposal reference or contract number.	
740252	

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Declarations

1) The applicant (future beneficiary) declares to have the explicit consent of all partner organisations (if applicable) on their participation and on the content of this proposal.	☒
2) The information contained in this proposal is correct and complete.	☒
3) This proposal complies with ethical principles (including the highest standards of research integrity — as set out, for instance, in the European Code of Conduct for Research Integrity — and including, in particular, avoiding fabrication, falsification, plagiarism or other research misconduct).	☒

4) The applicant (future beneficiary) hereby declares:

- it is fully eligible in accordance with the criteria set out in the specific call for proposals; and	☒
- it has the financial and operational capacity to carry out the proposed action.	☒

The applicant (future beneficiary) is only responsible for the correctness of the information relating to his/her own organisation. Where the proposal to be retained for EU funding, the applicant (future beneficiary) will be required to present a formal declaration in this respect.

According to Article 131 of the Financial Regulation of 25 October 2012 on the financial rules applicable to the general budget of the Union (Official Journal L 298 of 26.10.2012, p. 1) and Article 145 of its Rules of Application (Official Journal L 362, 31.12.2012, p.1) applicants found guilty of misrepresentation may be subject to administrative and financial penalties under certain conditions.

Personal data protection
The assessment of your grant application will involve the collection and processing of personal data (such as your name, address and CV), which will be performed pursuant to Regulation (EC) No 45/2001 on the protection of individuals with regard to the processing of personal data by the Community institutions and bodies and on the free movement of such data. Unless indicated otherwise, your replies to the questions in this form and any personal data requested are required to assess your grant application in accordance with the specifications of the call for proposals and will be processed solely for that purpose. Details concerning the purposes and means of the processing of your personal data as well as information on how to exercise your rights are available in the privacy statement. Applicants may lodge a complaint about the processing of their personal data with the European Data Protection Supervisor at any time.

Your personal data may be registered in the Early Detection and Exclusion system of the European Commission (EDES), the new system established by the Commission to reinforce the protection of the Union's financial interests and to ensure sound financial management, in accordance with the provisions of articles 105a and 108 of the revised EU Financial Regulation (FR) (Regulation (EU, EURATOM) 2015/1929 of the European Parliament and of the Council of 28 October 2015 amending Regulation (EU, EURATOM) No 966/2012) and articles 143 - 144 of the corresponding Rules of Application (RAP) (COMMISSION DELEGATED REGULATION (EU) 2015/2462 of 30 October 2015 amending Delegated Regulation (EU) No 1268/2012) for more information see the Privacy statement for the EDES Database).

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List of participants

#	Participant Legal Name	Country
1	UNIVERSITE PARIS DIDEROT - PARIS 7	France

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Proposal ID **799557**	*Acronym* **PolyBar**	*Short name* **UNIVERSITE PARIS DIDEROT-PARIS7**

2 - Administrative data of participating organisations

Future Host Institution

PIC	***Legal name***
999865525	*UNIVERSITE PARIS DIDEROT - PARIS 7*

Short name: UNIVERSITE PARIS DIDEROT-PARIS7

Address of the organisation

Street RUE THOMAS MANN 5

Town PARIS

Postcode 75205

Country France

Webpage www.univ-paris-diderot.fr

Legal Status of your organisation

Research and Innovation legal statuses

Public body ..... yes
Non-profit ..... yes
International organisation ..... no
International organisation of European interest ..... no
Secondary or Higher education establishment ..... yes
Research organisation ..... yes
Small and Medium-sized Enterprises (SMEs) ..... no
Academic Sector ..... yes

Legal person ..... yes

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Proposal ID **799557** *Acronym* **PolyBar** *Short name* **UNIVERSITE PARIS DIDEROT-PARIS7**

Department(s) carrying out the proposed work

Department 1

Department name: IRIF ☐ not applicable

☒ Same as organisation address

Street: RUE THOMAS MANN 5

Town: PARIS

Postcode: 75205

Country: France

If the location of the Department carrying out the proposed work is not the same as the location of the Host Institute, please note that although the proposal submission system calculates the budget of the project based on the location of the Host Institute, the budget of the project for the grant agreement will be calculated by using the country coefficient of the location of the Department carrying out the proposed work.

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Proposal ID **799557** *Acronym* **PolyBar** *Short name* **UNIVERSITE PARIS DIDEROT-PARIS7**

Researcher

The name and e-mail of the Researcher and Supervisor are read-only in the administrative form, only additional details can be edited here. To give access rights and contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Last Name*	BLOT	Last Name at Birth	
First Name(s)*	Valentin	Gender*	(•) Male ( ) Female
Title	Dr.	Country of residence*	France
Nationality*	France	Nationality 2	
Date of Birth (DD/MM/YYYY)	29/11/1986	Country of Birth*	France
		Place of Birth	Paris

Contact address

Current organisation name	Université Paris-Sud
Current Department/Faculty/Institute/ Laboratory name	Laboratoire de Recherche en Informatique

☐ Same as organisation address

Street	Bat 650 Ada Lovelace		
Postcode/Cedex*	91405	Town*	Orsay Cedex
Phone	+33169156629	Country*	France
Phone2 / Mobile	+33674173621		
E-Mail*	research@valentinblot.org		

ORCID ID	*If you have a ORCID number please enter it here (e.g. 9999-9999-9999-999X. where 9 represents numbers and X represents numbe*	
Researcher ID		*The maximum length of the identifier is 11 characters (ZZZ-9999-2010) and the minimum length is 9 characters (A-1001-2010).*
Other ID	*Please enter the type of ID here*	*Please enter the identifier number here*

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Qualifications

University Degree giving access to PhD	Date of award (DD/MM/YYYY)	31/08/2011
Doctorate	Start date (DD/MM/YYYY)	01/09/2011
Doctorate	Date of (expected) award (DD/MM/YYYY)	14/11/2014
Full time research experience	Number of months	72

(Measured from the date when a researcher obtained the degree entitling him/her to embark on a doctorate, either in the country in which the degree was obtained or in the country in which the researcher is recruited, even if a doctorate was never started or envisaged.)

Place of activity/place of residence (previous 5 years - most recent one first)

Indicate the period(s) and the country/countries in which you have legally resided and/or had your main activity (work, studies, etc) during the last 5 years up until the deadline for the submission of the proposal. Please fill in this section without gaps, until the call deadline (14/09/2017).

Period from	Period to	Duration (days)	Country
01/07/2017	14/09/2017	76	France
01/09/2014	30/06/2017	1034	United Kingdom
01/09/2011	31/08/2014	1096	France
	Total	2206	

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Proposal ID **799557** *Acronym* **PolyBar** *Short name* **UNIVERSITE PARIS DIDEROT-PARIS7**

Supervisor

The name and e-mail of the Researcher and Supervisor are read-only in the administrative form, only additional details can be edited here. To give access rights and contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title	Dr.	Sex	◉ Male ○ Female
First name*	**Hugo**	Last name*	**Herbelin**
E-Mail*	**hugo.herbelin@inria.fr**		
Position in org.	Directeur de Recherche INRIA		
Department	IRIF		

☒ Same as organisation address

Street	RUE THOMAS MANN 5				
Town	PARIS	Post code	75205		
Country	France				
Website	http://pauillac.inria.fr/~herbelin/				
Phone	+33157279087	Phone 2	*+xxx xxxxxxxxx*	Fax	*+xxx xxxxxxxxx*

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3 - Budget

Is the Researcher eligible for family allowance? (•) Yes ( ) No

Participant Number	Organisation Short Name	Country	Country Coefficient	Number of Months	Researcher Unit Cost			Institutional Unit Cost		Total
					Living Allowance	Mobility Allowance	Family Allowance	Research, training and networking costs	Management and Overheads	
1	UNIVERSITE PARIS DIDEROT-PARIS7	FR	1,11	24	123876,00	14400,00	12000,00	19200,00	15600,00	185076,00
Total				24	123876,00	14400,00	12000,00	19200,00	15600,00	185076,00

Partner Organisation from Third Country does not sign the Grant Agreement, does not recruit the researcher and does not directly claim costs from the action. The entire EC contribution is transmitted to the Host organisation located in Members States or Associated Countries.

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4 - Ethics issues table

1. HUMAN EMBRYOS/FOETUSES		Page
Does your research involve Human Embryonic Stem Cells (hESCs)?	○ Yes ◉ No	
Does your research involve the use of human embryos?	○ Yes ◉ No	
Does your research involve the use of human foetal tissues / cells?	○ Yes ◉ No	
2. HUMANS		**Page**
Does your research involve human participants?	○ Yes ◉ No	
Does your research involve physical interventions on the study participants?	○ Yes ◉ No	
3. HUMAN CELLS / TISSUES		**Page**
Does your research involve human cells or tissues (other than from Human Embryos/ Foetuses, i.e. section 1)?	○ Yes ◉ No	
4. PERSONAL DATA		**Page**
Does your research involve personal data collection and/or processing?	○ Yes ◉ No	
Does your research involve further processing of previously collected personal data (secondary use)?	○ Yes ◉ No	
5. ANIMALS		**Page**
Does your research involve animals?	○ Yes ◉ No	
6. THIRD COUNTRIES		**Page**
In case non-EU countries are involved, do the research related activities undertaken in these countries raise potential ethics issues?	○ Yes ◉ No	
Do you plan to use local resources (e.g. animal and/or human tissue samples, genetic material, live animals, human remains, materials of historical value, endangered fauna or flora samples, etc.)?	○ Yes ◉ No	
Do you plan to import any material - including personal data - from non-EU countries into the EU?	○ Yes ◉ No	
Do you plan to export any material - including personal data - from the EU to non-EU countries?	○ Yes ◉ No	
In case your research involves low and/or lower middle income countries, are any benefits-sharing actions planned?	○ Yes ◉ No	
Could the situation in the country put the individuals taking part in the research at risk?	○ Yes ◉ No	

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7. ENVIRONMENT & HEALTH and SAFETY		Page
Does your research involve the use of elements that may cause harm to the environment, to animals or plants?	◯ Yes ◉ No	
Does your research deal with endangered fauna and/or flora and/or protected areas?	◯ Yes ◉ No	
Does your research involve the use of elements that may cause harm to humans, including research staff?	◯ Yes ◉ No	
8. DUAL USE		**Page**
Does your research involve dual-use items in the sense of Regulation 428/2009, or other items for which an authorisation is required?	◯ Yes ◉ No	
9. EXCLUSIVE FOCUS ON CIVIL APPLICATIONS		**Page**
Could your research raise concerns regarding the exclusive focus on civil applications?	◯ Yes ◉ No	
10. MISUSE		**Page**
Does your research have the potential for misuse of research results?	◯ Yes ◉ No	
11. OTHER ETHICS ISSUES		**Page**
Are there any other ethics issues that should be taken into consideration? Please specify	◯ Yes ◉ No	

I confirm that I have taken into account all ethics issues described above and that, if any ethics issues apply, I will complete the ethics self-assessment and attach the required documents. ☒

How to Complete your Ethics Self-Assessment

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5 - Call specific questions

Eligibility Researcher (future fellow)

1. Were you in the last 5 years in military service? ○ Yes ◉ No

Other Questions

1. For communication purposes only, the European Commission REA asks for permission to publish the name of the researcher (future fellow) should the proposal be retained for funding. Does the researcher (future fellow) give this permission? ◉ Yes ○ No

2. Some national and regional public research funding authorities run schemes to fund MSCA applicants that score highly in the MSCA evaluation but which cannot be funded by the MSCA due to their limited budget. In case this proposal could not be selected for funding by the MSCA, do the researcher and supervisor consent to the European Commission disclosing to such authorities the results of its evaluation (score and ranking range) together with their names and contact details, non-confidential proposal title and abstract, proposal acronym, and host organisation? ◉ Yes ○ No

3. Is there a secondment in Member States or Associated Countries envisaged in Part B of this proposal? ○ Yes ◉ No

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Extended Open Research Data Pilot in Horizon 2020

If selected, applicants will by default participate in the Pilot on Open Research Data in Horizon 2020[1] , which aims to improve and maximise access to and re-use of research data generated by actions.

However, participation in the Pilot is flexible in the sense that it does not mean that all research data needs to be open. After the action has started, participants will formulate a Data Management Plan (DMP), which should address the relevant aspects of making data FAIR – findable, accessible, interoperable and re-usable, including what data the project will generate, whether and how it will be made accessible for verification and re-use, and how it will be curated and preserved. Through this DMP projects can define certain datasets to remain closed according to the principle "as open as possible, as closed as necessary". A Data Management Plan does not have to be submitted at the proposal stage.

Furthermore, applicants also have the possibility to opt out of this Pilot completely at any stage (before or after the grant signature). In this case, applicants must indicate a reason for this choice (see options below).

Please note that participation in this Pilot does not constitute part of the evaluation process. Proposals will not be penalised for opting out.

We wish to opt out of the Pilot on Open Research Data in Horizon 2020.	○ Yes	◉ No

Further guidance on open access and research data management is available on the participant portal: http://ec.europa.eu/research/participants/docs/h2020-funding-guide/cross-cutting-issues/open-access-dissemination_en.htm and in general annex L of the Work Programme.

[1] *According to article 43.2 of Regulation (EU) No 1290/2013 of the European Parliament and of the Council, of 11 December 2013, laying down the rules for participation and dissemination in "Horizon 2020 - the Framework Programme for Research and Innovation (2014-2020)" and repealing Regulation (EC) No 1906/2006.*

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START PAGE

MARIE SKŁODOWSKA–CURIE ACTIONS

Individual Fellowships (IF)
Call: H2020-MSCA-IF-2017

PART B

"PolyBar"

This proposal is to be evaluated as:

[EF-ST]

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List of Participating Organisations

Participating organisations	Legal Entity Short Name	Academic (tick)	Non-academic (tick)	Country	Dept. / Division / Laboratory	Supervisor	Role of Partner Organisation
Beneficiary							
– Université Paris Diderot Paris 7	UPDiderot	✓		FRANCE	IRIF	Hugo Herbelin 	
Entity with a capital or legal link							
–	–	–	–	–	–	–	
Partner Organisation							
–	–	–	–	–	–	–	–

Additional data for non-academic beneficiaries

Name	Location of research premises (city / country)	Type of R&D activities	No. of full-time employees	No. of employees in R&D	Web site	Annual turnover (approx. in Euro)	Enterprise status (yes/no)	SME status (yes/no)
–	–	–	–	–	–	–	–	–

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1 Excellence

1.1 Quality and credibility of the research/innovation action (level of novelty, appropriate consideration of inter/multidisciplinary and gender aspects)

Introduction, state-of-the-art, specific objectives and overview of the action

Some computer programs are blind to the kind of input they are given. The program taking an object "a" and returning the pair "(a,a)" is such an example: its code is the same regardless of whether "a" is an integer, a real number, a vector or even another program. A programming language is polymorphic if it allows the writting of such programs. The aim of the PolyBar project is to define and study a computational translation from a polymorphic programming language into a non-polymorphic language extended with the bar recursion operator: an operator implementing recursion over well-founded trees. The concepts underlying polymorphism and bar recursion being very different, this translation will allow the study of polymorphism with new tools coming from recursion theory.

Polymorphism is the possibility of having a single function taking inputs of several types. Strachey identified two kinds of polymorphism[1]: parametric and ad-hoc polymorphism. The latter consists of either overloading (using the same function name for distinct pieces of code) or coercion (converting values from one type to another on the fly). As such, it is merely apparent polymorphism, and while it can be useful in some situations, it does not reflect the very essence of polymorphism. With parametric polymorphism (PP), the same piece of code is executed, regardless of the type of the input (as opposed to overloading) and no conversion is performed (as opposed to coercion). PP is often considered to be true polymorphism, and it is the kind we are interested in. Polymorphic λ-calculus, also called System F, is a very simple polymorphic functional programming language. As such, it is the main object of study for research on PP. System F has been discovered independently in the early 70's by Girard[2] and Reynolds[3] and has been a major source of inspiration for the widely used programming languages Haskell[4] and ML[5]. Girard additionally proved a representation theorem linking second-order arithmetic and System F, and Reynolds proved an abstraction theorem that identified System F's polymorphism with Strachey's notion of PP.

Second-order arithmetic (Z2)[6] is a mathematical theory for reasoning about natural numbers and sets of natural numbers. Since real numbers can be encoded as sets of natural numbers satisfying specific properties, most of mathematical analysis can be formalized within Z2. Under the Curry-Howard correspondence between mathematical theories and computer programming languages, Z2 corresponds to System F^2. In particular, strong normalization of System F (the fact that every computation terminates eventually) is equivalent to the consistency of Z2 (one cannot prove both a formula and its negation) and the functions from natural numbers to natural numbers that can be computed by an algorithm of System F can be proved total in Z2 (meaning that we can prove in Z2 the existence of an algorithm computing the function). Z2 and its subsystems are objects of intense research in the area of reverse mathematics[7].

Peano arithmetic (PA)[8], is a subtheory of Z2 that forbids reasoning on sets of natural numbers. PA is a very simple mathematical theory, though it is sufficient for Gödel's famous incompleteness theorem[9]: consistency of PA cannot be proved within PA. The difference between PA and Z2 is the comprehension axiom, that is valid in Z2 but not in PA. The comprehension axiom states that for any property P on natural numbers, the set $\{n \in \mathbb{N} | P(n)\}$ of natural numbers that satisfies P exists. Despite its apparent simplicity, this axiom turns PA into the much more expressive system Z2. Another way of extending expressiveness of PA is by adjoining to it the axiom of countable choice:

$$\forall m\, \exists n\, A(m,n) \Longrightarrow \exists f\, \forall m\, A(m, f(m))$$

[1] Christopher Strachey. "Fundamental Concepts in Programming Languages". In: *Higher-Order and Symbolic Computation* 13.1/2 (2000), pp. 11–49.

[2] Jean-Yves Girard. "Une extension de l'interprétation de Gödel à l'analyse, et son application à l'élimination des coupures dans l'analyse et la théorie des types". In: *2nd Scandinavian Logic Symposium*. North-Holland, 1971, pp. 63–69.

[3] John Reynolds. "Towards a theory of type structure". In: *Programming Symposium, Paris, April 9-11, 1974*. Lecture Notes in Computer Science. Springer, 1974, pp. 408–423.

[4] Paul Hudak et al. *Report on the functional programming language Haskell, version 1.0*. Tech. rep. Glasgow University, 1990.

[5] Michael Gordon et al. "A Metalanguage for Interactive Proof in LCF". in: *5th Symposium on Principles of Programming Languages*. ACM Press, 1978, pp. 119–130.

[6] David Hilbert and Paul Bernays. *Grundlagen der Mathematik, I, II*. vol. 40, 50. Die Grundlehren der mathematischen Wissenschaften. Springer, 1934, 1939.

[7] Stephen George Simpson. *Subsystems of second order arithmetic*. Perspectives in logic. Cambridge University Press, 2009.

[8] Giuseppe Peano. *Arithmetices principia: nova methodo exposita*. Fratres Bocca, 1889.

[9] Kurt Gödel. "Über formal unentscheidbare Sätze der Principia Mathematica und verwandter Systeme I". in: *Monatshefte für mathematik und physik* 38.1 (1931), pp. 173–198.

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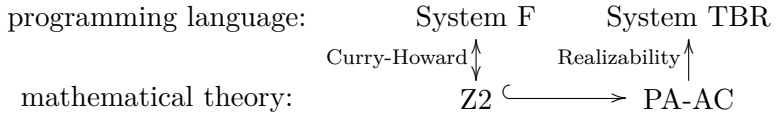
where $A(m,n)$ is a statement depending on the two natural numbers m and n. The resulting system will be denoted PA-AC. This gain of expressivity is witnessed by the well-known possibility of embedding Z2 into PA-AC: the comprehension axiom can be derived from the axiom of countable choice.

Realizability is a technique introduced by Kleene[10] as a formal account of the Brouwer-Heyting-Kolmogorov interpretation of proofs. Each formula has a set of realizers: programs that represent the computational content of the formula. In Kleene's realizability, the realizers are untyped programs. In particular, they may perform non-terminating computations. Later on, Kreisel[11] adapted Kleene realizability to a setting where realizers are typed. In particular, Kreisel's realizers always terminate. More recently, realizability came back in the spotlight with the work of Krivine[12], who devised a realizability model that is compatible with classical logic, using Griffin's discovery[13] that classical logic could be given computational content.

Bar recursion is an operator first defined by Spector[14] to give computational content to the comprehension axiom in the framework of Gödel's Dialectica interpretation[15]. The bar recursion operator is a powerful recursion scheme that allows a strong form of recursion while still avoiding non-terminating computations. The termination of this operator relies on the continuity of algorithms: an algorithm can only explore a finite part of a potentially infinite input before returning its output. Bar recursion and some variants of it have then been used to interpret the axiom of countable choice in Kreisel's realizability[16,17,18,19]. These works provide a computational interpretation of PA-AC in System TBR: an extension of Gödel's System T (a simply-typed λ-calculus with natural numbers and primitive recursion) with the bar recursion operator. This realizability interpretation of PA-AC in System TBR can be seen as the combination of an interpretation of PA into System T with an interpretation of the axiom of countable choice using bar recursion.

Combining the connections explained above, we obtain the following picture:



The experienced researcher (ER) recently gave the first translation from System F to System TBR by composing the above arrows within a single framework[20]. The PolyBar project aims at defining a direct computational translation from System F to System TBR, and exploiting it to give a new recursion-theoretic proof of termination of System F and unveil a connection between impredicativity and Zorn's lemma.

Objective 1. The ER will provide a direct computational translation from System F to System TBR, whose existence was proved in his recent work[20]. A program of System F is mapped to a proof of its termination in Z2. This proof is then translated into a proof in PA-AC by replacing instances of the comprehension axiom with instances of the axiom of countable choice. Finally, this proof is interpreted in System TBR through a bar recursive interpretation of the axiom of countable choice. The ER will obtain this direct translation through the removal of the artifacts still present in his proof-of-concept translation[20].

Objective 2. Once this translation has been defined, the ER will analyze further the mechanics involved in it. A study of the translations of system F programs exhibiting different but typical behaviors will guide

[10] Stephen Cole Kleene. "On the Interpretation of Intuitionistic Number Theory". In: *Journal of Symbolic Logic* 10.4 (1945), pp. 109–124.

[11] Georg Kreisel. "Interpretation of analysis by means of constructive functionals of finite types". In: *Constructivity in mathematics: Proceedings of the colloquium held at Amsterdam, 1957*. Studies in Logic and the Foundations of Mathematics. North-Holland Publishing Company, 1959, pp. 101–128.

[12] Jean-Louis Krivine. "Realizability in classical logic". In: *Panoramas et synthèses* 27 (2009), pp. 197–229.

[13] Timothy Griffin. "A Formulae-as-Types Notion of Control". In: *17th Symposium on Principles of Programming Languages*. ACM Press, 1990, pp. 47–58.

[14] Clifford Spector. "Provably recursive functionals of analysis: a consistency proof of analysis by an extension of principles in current intuitionistic mathematics". In: *Recursive Function Theory: Proceedings of Symposia in Pure Mathematics*. Vol. 5. American Mathematical Society, 1962, pp. 1–27.

[15] Kurt Gödel. "Über eine bisher noch nicht benützte Erweiterung des finiten Standpunktes". In: *Dialectica* 12.3-4 (1958), pp. 280–287.

[16] Stefano Berardi, Marc Bezem, and Thierry Coquand. "On the Computational Content of the Axiom of Choice". In: *Journal of Symbolic Logic* 63.2 (1998), pp. 600–622.

[17] Ulrich Berger and Paulo Oliva. "Modified bar recursion and classical dependent choice". In: *Logic Colloquium '01*. Vol. 20. Lecture Notes in Logic. Springer-Verlag, 2005, pp. 89–107.

[18] Valentin Blot and Colin Riba. "On Bar Recursion and Choice in a Classical Setting". In: *11th Asian Symposium on Programming Languages and Systems*. Vol. 8301. Lecture Notes in Computer Science. Springer, 2013, pp. 349–364.

[19] Valentin Blot. "Typed realizability for first-order classical analysis". In: *Logical Methods in Computer Science* 11.4 (2015).

[20] Valentin Blot. "An interpretation of system F through bar recursion". In: *32nd ACM/IEEE Symposium on Logic in Computer Science*. IEEE, 2017, pp. 1–12.

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the ER and provide valuable insights. Examples of such programs include arithmetical operations on natural numbers, operators on lists and abstract algorithms like the doubling operator $\lambda\alpha.\lambda f : \alpha \to \alpha.\lambda x : \alpha.f\,(f\,x)$ or the self-application operator $\lambda x : \forall\alpha\,(\alpha \to \alpha)\,.x\,(\forall\alpha\,(\alpha \to \alpha))\,x$. The analysis of the translated programs will also provide a recursion-theoretic point of view on polymorphism-related concepts like impredicativity and parametricity.

Objective 3. With the help of the translation from System F to System TBR obtained from objective 1, the ER will provide a new proof of termination of System F. Indeed, because the translation is computational, the termination of System TBR implies that of System F. While the usual termination proof for System F relies on the impredicative notion of reducibility candidates, termination of System TBR uses a restricted version of Zorn's lemma (the full version of which being equivalent to the axiom of choice in Zermelo-Frænkel set theory). These two principles have very little in common at first sight, but a termination proof for System F that relies on Zorn's lemma will provide the first formal connection between these two concepts.

Research methodology and approach

Each of the three objectives will be subdivided in work packages that we describe here.

Objective 1:

- **WP1:** There exists several variants of the normalization proof of System F. In order to get an insightful translation, the ER will have to determine which variant he will use in the Curry-Howard map from System F to Z2. In particular, a strong normalization proof may give unnecessary complex proofs in Z2, and the ER will investigate head or weak head normalization proofs, which are more suited to a natural translation from System F to System TBR.
- **WP2:** The ER will combine the Curry-Howard map defined in WP1 with the logical translation from Z2 to PA-AC and the realizability interpretation to obtain the translation of System F to System TBR. This will require some adaptations of the ER's previous works on the realizability interpretation[21,22,23,24] to take care of the specific setting of the PolyBar project.

Objective 2:

- **WP3:** The ER will apply the translation obtained from objective 1 to canonical programs. First, he will consider the case of arithmetical operations, which are mostly a sanity check. Then, he will study the translations of polymorphic list operators, which use the restricted form of polymorphism implemented in the ML family of programming language. Finally, he will study the translation of programs using the full power of impredicative polymorphism, like doubling or self-application. These will be the starting points for a systematic study of polymorphism through bar recursion.
- **WP4:** Study of the translations of canonical programs obtained in WP3 will trigger the first step towards a study of polymorphism and parametricity through bar recursion. The ER will attack these problems while tuning the translation obtained from objective 1 to tighten the connection between type instantiation in System F and calls to the bar recursion operator. At the end of this work package, the translation of System F to System TBR will provide a new, direct interpretation of polymorphism in terms of bar recursion.

Objective 3:

- **WP5:** With the help of the translation obtained from objective 1, the ER will reduce the impredicative proof of termination of System F to the proof of termination of System TBR that relies on a restricted form of Zorn's lemma. Therefore, the combination of the translation from System F to System TBR with the termination proof of System TBR will provide a new proof of termination of System F that relies on Zorn's lemma.
- **WP6:** The ER will investigate the correspondence between the mathematical concept of impredicativity and Zorn's lemma by comparing the usual impredicative proof of termination of System F with the proof obtained in WP5 that relies on Zorn's lemma.

Originality and innovative aspects of the research programme

The PolyBar project will give new insights on polymorphic programming, providing new tools for producing safer software. Proving properties about polymorphic programs is a particularly difficult task. For example, the proof of termination of System F requires an invariant that was found by means of trial and error:

[21] Valentin Blot. "Game semantics and realizability for classical logic". PhD thesis. École Normale Supérieure de Lyon, 2014.

[22] Blot, "Typed realizability for first-order classical analysis", see n. 19.

[23] Valentin Blot. "Hybrid realizability for intuitionistic and classical choice". In: *31st ACM/IEEE Symposium on Logic in Computer Science*. ACM, 2016, pp. 575–584.

[24] Blot, "An interpretation of system F through bar recursion", see n. 20.

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Girard's reducibility candidates[25]. Conversely, simply-typed programming languages often enjoy properties that allows for more straightforward proofs of correctness. In particular, termination of System T can be proved combinatorially, associating a measure to each program in such a way that the measure decreases during the computation. This method is more flexible and direct than that of reducibility candidates and properties about simply-typed programs are often easier to obtain than in the polymorphic case.

The PolyBar project will extend the combinatorial techniques used in simply-typed languages to the polymorphic world. This will bring a new range of techniques for proving properties about polymorphic programs and promote the use of polymorphic languages in environments where safety is important. With the rapid development of machine learning and intense research on autonomous cars, more and more decisions will be taken by computer software for which software bugs can have dramatic consequences. In these situations, testing software is not an option and properties of the programs must be formally proved. But these formal proofs often require that the programmer works in a constrained programming language, ruling out polymorphism. The PolyBar project will improve the state-of-the-art by extending the use of well-known proof techniques to polymorphic programming languages: computer programmers will be able to use the sophisticated features of polymorphism and still prove correctness properties on their programs.

The lifting of a logical correspondence (between Z2 and PA-AC) at the computational level (between System F and System TBR) can also be adapted to other logical correspondences between subsystems of Z2 and variants of Martin-Löf's type theory (MLTT)[26], such as the correspondence between arithmetical transfinite recursion (ATR_0) and MLTT with a hierarchy of universes. Such a result will be an important step in reverse mathematics, a rapidly evolving field founded by Harvey Friedman and Stephen Simpson[27].

The PolyBar project will also give a new approach for studying parametricity. This concept, first identified by Reynolds[28], is a property enjoyed by polymorphic functions, stating that such a function behaves independently of the particular instance that is executing: it maps related inputs to related outputs. Parametricity has proved to be a very valuable tool in the study of polymorphism, a typical example being Wadler's method for deriving properties from types in such a way that all polymorphic functions of a given type satisfy the associated property[29]. This tool allows the derivation of properties of polymorphic programs automatically and therefore greatly simplifies the process of proving correctness of polymorphic programs.

Finally, the PolyBar project will give new insights on the notion of impredicativity, a central notion in computer science and mathematics that is at the core of Russel's paradox. This paradox triggered the crisis about the foundations of mathematics in the early 20th century, which in turn led to Gödel's incompleteness theorems and Church and Turing's negative answers to Hilbert's entscheidungsproblem. Today, impredicativity is actively studied in type theory, where nested impredicative levels make systems inconsistent[30]. The PolyBar project will make the first formal connection between impredicativity and the axiom of choice: an axiom which is of great interest to set theorists since it is equivalent to Zorn's lemma and the well-ordering theorem.

1.2 Quality and appropriateness of the training and of the two way transfer of knowledge between the researcher and the host

Training programme for the experienced researcher

The ER is an expert in realizability and bar recursion and will receive a specific training at the host institute, in particular on System F, polymorphism and impredicativity. Indeed, both the supervisor and several other researchers of the institute are international leaders in the field of type theory. The host institute is also leading the development of the Coq proof assistant[31]. This software project is based on the calculus of inductive constructions, a type theory that supports dependent and inductive types, an impredicative kind and a hierarchy of predicative kinds. Moreover the type theoretic foundations of Coq make it a programming language as well. During his three-year stay in the UK, the ER became familiar with

[25] Girard, "Une extension de l'interprétation de Gödel à l'analyse, et son application à l'élimination des coupures dans l'analyse et la théorie des types", see n. 2.

[26] Per Martin-Löf. "The Hilbert-Brouwer controversy resolved?" In: *One Hundred Years of Intuitionism (1907–2007): The Cerisy Conference*. Birkhäuser Basel, 2008, pp. 243–256.

[27] Simpson, see n. 7.

[28] Reynolds, see n. 3.

[29] Philip Wadler. "Theorems for Free!" In: *4th international conference on Functional Programming languages and Computer Architecture*. ACM, 1989, pp. 347–359.

[30] Jean-Yves Girard. "Interprétation fonctionnelle et élimination des coupures de l'arithmétique d'ordre supérieur". PhD thesis. Université Paris 7, 1972.

[31] https://coq.inria.fr/

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all the aspects of the British school in computer science, centered around denotational models of functional programming language. During his stay at the host institute, he will broaden his perspective by learning about the French school, mostly centered around the Curry-Howard correspondence. Moreover, the ER will perform hands-on training activities around the Coq proof assistant. He will learn how to develop efficiently formal proofs of his results under this proof assistant, thereby connecting his theoretical research with concrete implementation. Meetings with the supervisor will be organized twice a month to discuss progress of the project as well as scientific issues and ideas.

The ER will attend the institute-wide IRIF seminar where speakers from the best research institutions in the world are invited in one of the two series: distinguished talks or expository talks. The ER will have the opportunity to talk about his research and learn the state-of-the art in the many fields of the institute through interactions with internationally leading experts. The PPS team seminar and the several thematic working groups of the institute will also give him the opportunity to disseminate his research in the community. Finally, the ER will also participate to the national monthly "chocola" meetings in Lyon, bringing together researchers in logic and computation from the main four French research centers on these topics: Paris, Lyon, Marseille and Chambéry.

Beyond new scientific expertise, the ER will also have the opportunity to develop his teaching skills through some of the 20 training courses organized by the university's Support Service for Innovative Teaching Methods and Digital Education. Having his own fellowship, the ER will learn about grant management and improve his skills on grant writing with the help of the university's European Research Network that provides training for Horizon 2020 proposals. In particular, this will help the ER for writing an ERC grant proposal at the next stage of his career. The ER will take part in the training of the supervisor's PhD and master students through one-to-one discussions about the students' research projects and individual courses on realizability, bar recursion and other subjects of expertise of the ER. He will also write research internship proposals and supervise his own students on 2-3 months periods.

Transfer of knowledge to host

The ER has spent three years in the United Kingdom as a postdoctoral researcher, first at the University of Bath and then at Queen Mary University of London. The ER will bring to France the research network built in the UK. First, the ER will strengthen the existing links between researchers in Bath and in Paris area: Jim Laird and Guy McCusker (University of Bath) collaborate with Giulio Manzonetto (Université Paris 13) on quantitative models of programming languages, and Alessio Guglielmi and Willem Heijtjes (University of Bath) collaborate with Michel Parigot (Université Paris 7) and Lutz Straßburger (École Polytechnique). Beyond strengthening existing links, the ER will also create new collaborations, especially in recursion theory with Ulrich Berger (Swansea University), Paulo Oliva (Queen Mary University of London) and Martín Escardó (University of Birmingham), but also with researchers from the game semantics community: Andrzej Murawski (University of Warwick), Nikos Tzevelekos (Queen Mary University of London) and Dan Ghica (University of Birmingham). Finally, the ER has links with several other theoretical computer scientists: Marcelo Fiore (Cambridge University), Paul Blain Levy (University of Birmingham) and others.

More than a research network, the ER will disseminate in France the knowledge he acquired in the UK. First, the ER deepened his knowledge on game semantics for modelling polymorphism since Jim Laird (University of Bath) defined models of several polymorphic languages. The ER also discussed the issue of modeling dependent types with Matthijs Vákár (University of Oxford) who works with game semantics expert Samson Abramsky (University of Oxford). Moreover, the ER gained experience in deep inference systems and atomic calculi, through discussions with Allesio Guglielmi and Willem Heijltjes (University of Bath). The ER also had the opportunity of following short courses on categorical models of logic and programming languages by categorical expert John Power (University of Bath). This knowledge will be transfered to the host by several means: seminars, working groups, short courses and participation in the supervision of master and PhD students.

1.3 Quality of the supervision and of the integration in the team/institution

Qualifications and experience of the supervisor

The supervisor (Hugo Herbelin, M, 49 y.o.) is an internationally recognized expert in proof theory and programming language, with a substantial amount of papers published in top-tier journals on theoretical computer science (Journal of Functional Programming, Annals of Pure and Applied Logic, Journal of Logic and Computation) and most prestigious conferences in the field (Principles of Programming Languages, Logic In Computer Science, International Conference on Functional Programming, International Colloquium

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on Automata Languages and Programming). The supervisor's area of expertise is highly relevant to the PolyBar project, and completes that of the ER. The supervisor has a strong background in computational interpretations of proofs and reducibility candidates. More recently, he identified a correspondence between PA-AC and a call-by-need programming language with cofixpoints which is computationally close to the bar recursive interpretation of PA-AC. He obtained his Habilitation degree in 2005 and supervised many master students, 10 PhD students (including 4 co-supervisions) and 4 postdoctoral researchers. Among the supervisor's former PhD students, one is a professor in Montevideo, Uruguay, one is a lecturer in Strasbourg, France, and many of them work in the industry, in the domain of formal methods. The supervisor also has experience in project management since he has been the site leader in the two state-funded ANR projects Récré[32] and Paral-ITP[33].

Hosting arrangements

The ER will be an employee of the Université Paris-Diderot, getting general access to health service, vacation, benefits, etc. The University has obtained 52 FP7 projects (including 23 PEOPLE) and 9 ERDF in the past, and is currently involved in 23 FP7 and H2020 projects. It is the host institute of 6 ERC projects, 1 large COFUND doctoral project, 1 PEOPLE and 1 MSCA IF. It is also the beneficiary of 13 collaborative projects, among which 1 ITN MSCA, 1 PEOPLE-ITN, 1 RISE and 2 IMI. Moreover, it is a third party in 4 ERC.

The host institute IRIF is the result of a recent merge between the two former computer science labs of Université Paris-Diderot. The institute hosts 90 permanent researchers who are available to offer supervision and assistance, and 80 postdoctoral researchers and PhD students. French is the ER's native language, and he is proficient in English which is the common spoken language at the IRIF. The institute is affiliated with the prestigious national center for scientific research (CNRS) and hosts two project-teams of the national institute for computer science and mathematics (INRIA), the supervisor belonging to one of these (PI.R2). The ER will integrate the largest group of the institute, PPS, which has a strong record of more than 200 publications in the last five years in top international journals and conferences in the field. The ER will benefit from a rich scientific environment with multiple thematic seminars and working groups organized every two weeks that will serve to reinforce milestones, assess the progress of deliverables and manage risks while also preparing for conferences and outreach events. The ER will also have meetings with the supervisor every two weeks to dicuss progress and scientific ideas. The ER will have an office space within the PPS research group's premises with a desk, a whiteboard, an internet connection and access to scientific papers from all major publishers.

1.4 Capacity of the researcher to reach or re-enforce a position of professional maturity/independence

The ER is an internationally recognized expert in the field of typed realizability, bar recursion, and their use in a game semantics setting. Many of his works provided the first connections between fields that were thought to be unrelated: realizability and game semantics[34], bar recursion and control operators[35], game semantics and classical extraction[36], strong existentials and bar recursion[37], and finally bar recursion and polymorphism[38]. His work encompasses a particularly broad spectrum in theoretical computer science, covering subjects as diverse as proof theory, category theory, domain theory, game semantics, linear logic and realizability. His results have been published in the most prestigious conferences of the field, most of the time as a single author. This demonstrates the independence and maturity of the ER who is able to conduct research and set objectives on his own.

The ER presented his research at numerous occasions, including international peer-reviewed conferences (DGCI'09, TLCA'13, FSCD'16, LICS'16, LICS'17), international workshops (TYPES'13/'15/'16/'17, GaLoP'13/'15/'16/'17, Geocalisation in Chambéry'15, Realizability in Montevideo'16) and invited seminars (Paris in 2014, Marseille and Cambridge in 2015, Saclay in 2016 and 2017, Oxford, Cachan and Villetaneuse in 2017). Moreover, the ER had a prolific postdoctoral experience during which he published two papers

[32] http://recre.ens-lyon.fr/description

[33] https://www.lri.fr/~wolff/projects/ANR-Paral-ITP/index.html

[34] Valentin Blot. "Realizability for Peano Arithmetic with Winning Conditions in HON Games". In: *Annals of Pure and Applied Logic* 168.2 (2017), pp. 254–277.

[35] Blot and Riba, see n. 18.

[36] Valentin Blot. "Classical Extraction in Continuation Models". In: *1st International Conference on Formal Structures for Computation and Deduction*. Schloss Dagstuhl - Leibniz-Zentrum fuer Informatik, 2016, 13:1–13:17.

[37] Blot, "Hybrid realizability for intuitionistic and classical choice", see n. 23.

[38] Blot, "An interpretation of system F through bar recursion", see n. 20.

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in international journals (LMCS and APAL) and three papers in international peer-reviewed conferences with published proceedings (FSCD'16, LICS'16 and LICS'17), all of them as a single author. He has also experience with the administration of research since he took and will take part in the program comittee of international workshops GaLoP'16 and LOLA'18. Finally, the ER had a three-year teaching experience during his PhD, gave courses at the University of Bath and currently teaches at Université Paris-Sud. He was also involved in science outreach projects during his PhD (MathÀLyon and Hippocampe).

The PolyBar project will give the ER an exceptional opportunity to initiate new collaborations, both with his supervisor and the many researchers of the host institute interested in his work. The ER will publish the results of his collaborations at the host institute in the best international journals (Information and Computation, Logical Methods in Computer Science) and conferences (Principles Of Programming Languages, Logic In Computer Science). He will also disseminate his research outcomes within the host institute and beyond in order to obtain the best possible citation response.

2 Impact

2.1 Enhancing the potential and future career prospects of the researcher

The Marie Skłodowska-Curie fellowship will broaden the field of expertise of the ER, adding to his knowledge of realizability and semantics of programming languages a complementary experience in type theory and proof assistants. This will give the ER the possibility of interacting with most of the European research centers in his field, and therefore open up new carrer opportunities.

Working at the host institute, the ER will develop a research network with the leading researchers in his field, both French and from abroad. First, the ER will live in Paris and, while his permanent place of work will be at the Université Paris-Diderot, he will visit regularly other research centers in and around Paris: Université Paris-13, CNAM Paris, École Polytechnique, INRIA Paris research center, École Normale Supérieure de Paris-Saclay, Université Paris-Sud and Université Paris-Est. Moreover, participating to the monthly chocola meetings will not only enlarge the ER's network with researchers from École Normale Supérieure de Lyon, Université Aix-Marseille and Université de Savoie (Chambéry), but also with international speakers invited to the meeting. Participating in seminars from University Paris-Diderot and other parisian universities, the ER will also strengthen his international network by creating new links with their invited speakers.

The advances obtained through the PolyBar project will lead to publications in the best international journals and conferences, and greatly improve the publication record of the ER. This in turn will increase his employability in the best European research institutions, as a lecturer or full-time researcher.

After the project, the ER will have gained management experience both at the scientific level with the management of his objectives using work packages, and at the financial level with the management of the Marie Skłodowska-Curie funding for research-related expenses. Moreover, he will have gained experience in the supervision of master and PhD students, paving the way for supervision of his own doctoral students, and to the Habilitation degree.

The ER will also have strengthened his teaching profile with trainings from the university's Support Service for Innovative Teaching Methods and Digital Education, as well as his capacity to fund his research with the help of the European Research Network of the university. Finally, the ER will have obtained skills in the dissemination of research, both within the academic sector through his participation to workshops and conferences and to a wider audience by taking part in many outreach activities, such as the european forum ESOF 2018, the national science festival taking place every year in October, the yearly researcher's night at the end of september, and "the conversation": an online media outlet written by the academics and research community and delivered directly to the public.

2.2 Quality of the proposed measures to exploit and disseminate the action results

Dissemination of the research results

The ER will disseminate his research outputs both in written form in journals and conference proceedings and as oral presentations in seminars, workshops and conferences. The ER will present his project as ongoing work in workshops like TYPES, and submit his most significative achievements to the top conferences Logic In Computer Science (LICS), Principles of Programming Languages (POPL) and International Conference on Functional Programming (ICFP), but also results obtained throughout the project to conferences such as Foundations of Software Science and Computation Structure (FOSSACS), Computer Science Logic (CSL),

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Foundations of Software Technology and Theoretical Computer Science (FSTTCS), European Symposium on Programming (ESOP) or Formal Structures of Computation and Deduction (FSCD). Moreover, detailed versions of the most significant results will be submitted to journals such as Mathematical Structures in Computer Science (MSCS), Annals of Pure and Applied Logic (APAL) and Logical Methods in Computer Science (LMCS). For all the publications made during the project, the ER will adhere to the open access policies of the European Union: Université Paris-Diderot encourages green open access publishing and offers an institutional repository, HAL-Diderot, which will be used whenever possible.

Exploitation of results and intellectual property

Results and Intellectual Property right will be owned by Université Paris-Diderot and, if needed, shared with other institutions (e.g. CNRS) according to existing partnership agreements. The university will adequately protect the results if they can reasonably be expected to be commercially or industrially exploited. For the evaluation, protection and exploitation of such results, the university will entrust the SATT Idfinnov[39] (a Parisian technology transfer acceleration company).

2.3 Quality of the proposed measures to communicate the action activities to different target audiences

The ER will engage in scientific activities directed to a non-academic audience. He will run a booth at the european researcher's night in Paris in September[40], during which he will communicate his research to the general public through hands-on experiments with computer programming. He will organize activities during the national science festival in October[41] such as a 3-minute presentation of his research (in line with the 3-minute thesis competition) and one of the famous "rallye mathématique" during which secondary-school and high-school students discover mathematical principles through hands-on activities. The 2018 edition of the international popular science conference ESOF, organized by EuroScience, will take place in Toulouse in July[42]. The ER will participate in this famous meeting and use this wonderful opportunity to have the general public engaged in the results of his research. Moreover, the ER will organize hands-on activities directed to the general public as part of the Science in the City Festival that runs in parallel of ESOF. The ER will also publish articles about his research in the online media "The Conversation"[43] of which Université Paris Diderot is a partner, and submit a short movie about his research to the national competition "Sciences en Lumière"[44] organized every two years by Université de Lorraine. All these activities are a natural continuation of the activities the ER did during his PhD with the organization of a Hippocampe activity (for high school students) and a MathÀLyon workshop (for secondary school students). For the latter, the ER built an experiment to illustrate the non-commutativity of certain homotopy groups[45].

3 Quality and Efficiency of the Implementation

3.1 Coherence and effectiveness of the work plan

The Gantt chart below describes the planned timeline for the implementation of the work packages over the two years of the PolyBar project. It describes the three objectives and their decomposition as six work packages together with their dependencies, the three milestones and the four deliverables. The objectives and work packages were defined in the first section and we describe here the milestones and deliverables.

Milestone 1 and deliverable **D1** form the cornerstone of the project's main contributions (objectives 1 and 2). The ER will describe the translation from System F to System TBR and submit a short version to an international peer-reviewed conference and a more detailed version to a high impact international journal. **Milestone 2** and deliverable **D2** are the first exploitation of the translation, applying it to a set of canonical programs of system F. The deliverable will take the form of a report containing the translated programs together with an analysis of their structure and behavior. **Milestone 3** and deliverable **D3** consist of a new proof of termination for System F relying on Zorn's lemma. This will be submitted to a leading international conference and a journal if the new proof requires more details than what can appear in conference proceedings in order to be fully explained. Finally, deliverable **D4** consists of a journal paper

[39] http://www.idfinnov.com/en
[40] https://nuitdeschercheurs-france.eu
[41] https://fetedelascience.fr
[42] http://www.esof.eu
[43] https://theconversation.com/fr/anglais
[44] http://www.sciencesenlumiere.fr
[45] https://valentinblot.org/pro/Movie1.mp4,https://valentinblot.org/pro/Movie2.mp4

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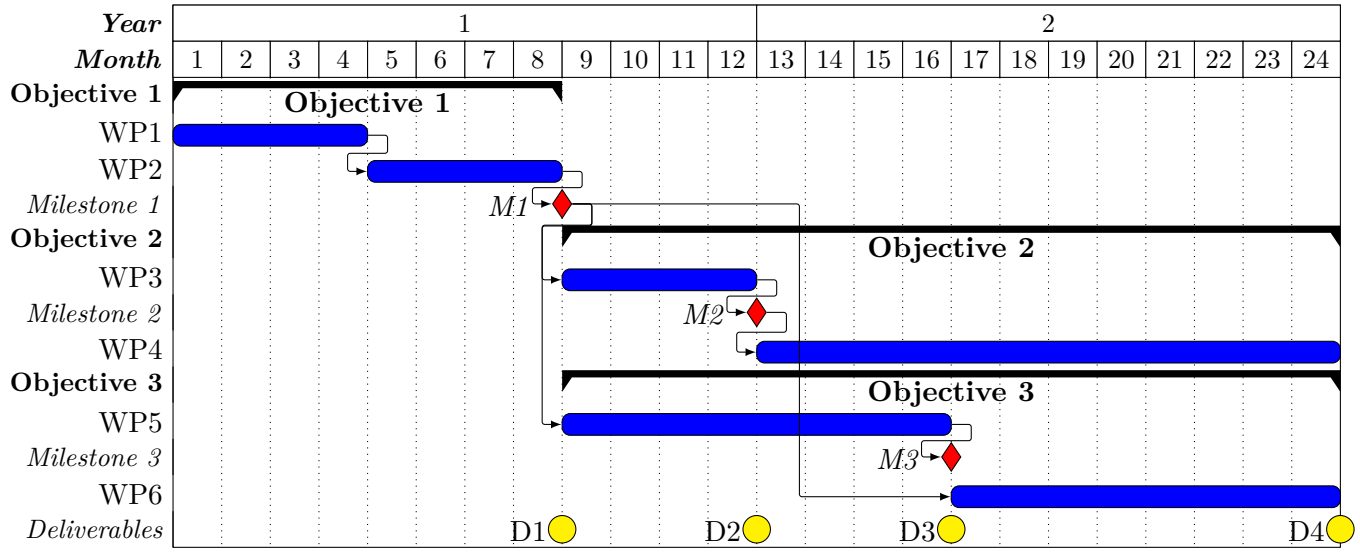

summarizing the outcomes of the ER's study of polymorphism through bar recursion, as well as his works towards connecting impredicativity with Zorn's lemma.

3.2 Appropriateness of the allocation of tasks and resources

For **WP1**, the ER will collect and analyze the several proofs of normalization for System F of the litterature. He will then choose and optionally adapt the proof that suits best to the project. This mostly bibliographical task is of low risk and the ER will benefit from discussions with the supervisor who knows the relevant litterature. For reaching the first objective, the completion of **WP2** relies on an adaptation of the ER's previous work to the new setting. The ER masters bar recursive interpretations of the axiom of countable choice and this task is of low risk. With his translation at hand, the ER will then embark concurrently in the second and third objectives. **WP3** is a technical task that consists in applying the translation to canonical programs. This is again of low risk since the translation will be fixed from the first objective. The second part of the second objective, **WP4**, is more exploratory and involves technical manipulations as well as a high-level reasoning on the results obtained from the beginning of the project. Because the amount of work needed will depend to some extent on the translation obtained from the first objective, this task presents a medium risk concerning the time needed to complete it. **WP5** will be performed by combining the translation with the termination proof of bar recursion and eliminating the intermediary steps. This is again of medium risk since the steps to eliminate will be identified after completion of the first objective and the amount of work needed for this can vary in range from a few months to more than a year. Nevertheless, this work package is achievable within the time allocated to the project. Finally, **WP6** is very exploratory and will require the ER to become very familiar with the concept of impredicativity. The research environment will be highly beneficial for this, but this task is still of high risk given the complexity of the concepts involved.

3.3 Appropriateness of the management structure and procedures, including risk management

Organisation and management structure, progress monitoring mechanisms

The meetings between the ER and his supervisor, every two weeks, will be an opportunity for discussing progress of the project. The planned timeline will be discussed and adjusted if needed, to ensure that the project's progress is satisfactory. The deliverables will be elaborated in advance, with the supervisor controlling that they are adequate. Moreover, the ER will get carrer advices from the supervisor, as well as from other senior members of the group. Whenever the ER is not confident with a scientific decision to be made, he will discusss the issue with the supervisor and other members of the group to ensure that the best option is always chosen.

The ER recently moved back to France so he will not need any visa, health insurance registration or bank account opening. He also has experience with the procedure for finding accomodation in France, which will be an important asset. This means that he will start working full-time on the PolyBar project from day 1, an important condition for its success.

The pre-award research support team within the Research and Innovation Support Office (DARI) will

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support the ER during the implementation of the project acting as a "helpdesk" and interface with both the European commission and other administrative offices at the university. The grants office will assist the ER in financial issues. The ER will also benefit from the presence of an administrative assistant in the laboratory, who will help him in any administrative matter related to travel and other expenses. Given the theoretical nature of the project, the research, training and networking costs will be used mostly for travelling, both to European research institutions for disseminating the results, and to workshops and conferences to present the outcomes of the project to an international audience. The financial plan will be discussed with the supervisor, and revised after one year. The ER will have regular contacts with the grants office to keep track of the financial well-being of the project, and the grants office will provide the necessary financial reports. The human resources department will be in charge of the preparation of the work contract, in liaison with the DARI. The ER will sign a 24 months employment contract (it is commonly referred as "CDD" in France) allowing him to receive salary and mobility/family allowances, according to Marie Skłodowska Curie rules. The agreement signed between the university and the ER will be in conformity with the provisions set forth in the grant agreement. The university also counts with a health and prevention service taking care of life and work conditions of its staff.

Risk analysis and contingency plan

Given the theoretical nature of the project, the only risks are scientific. The first objective is low risk since it consists of a review of the existing litterature followed by an adjustment of the ER's previous work. This will secure the success of the first 8 months of the project. After milestone 1 has been reached, the ER will work towards Objectives 2 and 3 concurrently. WP3 being a low risk task, the ER will start working on WP4 after a year. While it is expected that WP4 will be achieved within 6-8 months, there is a risk that the translation is not as direct as expected, in which case the study of polymorphism through bar recursion will need more time to achieve. This is the reason why the ER reserved the possibility of extending WP4 to a whole year if necessary.

WP5 is a technical task and there is a risk that the translation defined by objective 1 cannot be simplified enough so as to get the direct proof of termination of System F. In case this risk would arise, the ER would study his supervisor's calculus[46], a call-by-need calculus with co-fixpoint operators that gives yet another computational interpretation of the axiom of countable choice. Though this is still to be investigated, the proof of normalization of Herbelin's calculus is reminiscent of that of the bar recursion operator and it will give a new approach for finding an alternative proof of normalization for System F.

Finally, WP6 is a high risk task since impredicativity is a concept that is still poorly understood, despite being a century old. Therefore, there is a risk that the connections between impredicativity and Zorn's lemma obtained from the alternative proof of normalization of System F are not tight enough to obtain a clear explanation of impredicativity in terms of Zorn's lemma. In case this risk arises, the ER will rather concentrate on subsystem ATR_0 of Z2 and explore the restrictions of the bar recursion operator that still allow for a cut-elimination proof of ATR_0. Therefore, he will make a connection between the predicative reductionism of ATR_0 and the restriction of Zorn's lemma that is suitable for the proof of termination of the restricted bar recursion associated to ATR_0.

3.4 Appropriateness of the institutional environment (infrastructure)

The ER, having recently moved to France, will embark on the PolyBar project right on his arrival, avoiding the administrative overhead of moving to a foreign country. Université Paris-Diderot has experience in management of European grants, including Marie Skłodowska-Curie fellowships, and will provide the necessary administrative support so the ER can concentrate on the project. The university signed the "European Charter and Code for Researchers" in 2007 and has set up a working group since December 2015 to prepare the application for the "HR Excellence in Research Award". The ER will be given an office in the PPS group's premises, computing facilities and access to scientific papers from all major publishers.

Many researchers in the PPS group have expertise in System F and more generally in type theory. Discussions with these experts will guarantee a clear success for the project. Moreover, the environment of the institute, where a wide range of topics are represented, will extend the ER's area of expertise and open up new carrer opportunities for him. The PPS group at Université Paris-Diderot is therefore the ideal environment for reaching the research and training objectives of the fellowship.

[46] Hugo Herbelin. "A Constructive Proof of Dependent Choice, Compatible with Classical Logic". In: *27th IEEE Symposium on Logic in Computer Science*. IEEE Computer Society, 2012, pp. 365–374.

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4 CV of the Experienced Researcher

Personal informations

Name	Valentin Blot
Date of birth	November 29th, 1986
Website	https://valentinblot.org/pro/

Positions

Sep. 2017-	**Post-doctoral researcher**, *Université Paris-Sud*, France
Jan. 2017-June 2017	**Post-doctoral researcher**, *Queen Mary University of London*, United Kingdom
Sep. 2014-Dec. 2016	**Post-doctoral researcher**, *University of Bath*, United Kingdom
Sep. 2011-Aug. 2014	**PhD candidate**, *École Normale Supérieure de Lyon*, France
Sep. 2011-Aug. 2014	**Teaching assistant**, *École Normale Supérieure de Lyon*, France

Education

Sep. 2011-Aug. 2014	**Doctorate**, *École Normale Supérieure de Lyon*, France
Sep. 2008-Aug. 2011	**Master's degree**, *École Normale Supérieure de Lyon*, France
Sep. 2009-Aug. 2010	**Agrégation of mathematics**, *École Normale Supérieure de Lyon*, France French competitive exam for teaching in secondary education
Sep. 2004-Aug. 2008	**Bachelor's degree**, *École Normale Supérieure de Lyon*, France

PhD thesis

Title	Game semantics and realizability for classical logic
Supervisor	Colin Riba
Director	Olivier Laurent
Defense	November 7th, 2014 at *École Normale Supérieure de Lyon*, France
Jury	Pierre-Louis Curien (president, CNRS), Pierre Hyvernat (Université de Savoie), Olivier Laurent (director, CNRS), Andrzej Murawski (reviewer, University of Warwick), Colin Riba (Supervisor, ENS Lyon), Thomas Streicher (reviewer, Technische Universität Darmstadt)

Communications (Workshops and conferences)

Jun. 29th, 2017	**An interpretation of system F through bar recursion**, *Chocola workshop*, Lyon, France
Jun. 22th, 2017	**An interpretation of system F through bar recursion**, *LICS conference*, Reykjavik, Iceland
May 30th, 2017	**An interpretation of system F through bar recursion**, *TYPES conference*, Budapest, Hungary
Apr. 23rd, 2017	**Dependent Types as Concrete Data Structures**, *GaLoP workshop*, Uppsala, Sweden
Oct. 13rd, 2016	**Hybrid realizability for intuitionistic and classical choice**, *Chocola workshop*, Lyon, France
Jul. 22nd, 2016	**A computational interpretation of system F through bar recursion**, *Realizability in Montevideo workshop*, Montevideo, Uruguay

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Jul. 7th, 2016 **Hybrid realizability for intuitionistic and classical choice**, *LICS conference*, New York, United States

Jun. 23rd, 2016 **Classical extraction in continuation models**, *FSCD conference*, Porto, Portugal

May 24th, 2016 **Hybrid realizability for intuitionistic and classical choice**, *TYPES conference*, Novi Sad, Serbia

Apr. 2nd, 2016 **Extraction from classical proofs using game models**, *GaLoP workshop*, Eindhoven, Netherlands

Jun. 9th, 2015 **Typed realizability for first-order classical analysis**, *Géocalisation in Chambéry*, Chambéry, France

May 19th, 2015 **Typed realizability for first-order classical analysis**, *TYPES conference*, Talinn, Estonia

Apr. 12nd, 2015 **Positional interpretation of Peano arithmetic with winning strategies**, *GaLoP workshop*, London, United Kingdom

Jul. 18th, 2013 **Realizability for Peano arithmetic with winning conditions in HO games**, *GaLoP workshop*, London, United Kingdom

Jun. 27th, 2013 **Realizability for Peano arithmetic with winning conditions in HO games**, *TLCA conference*, Eindhoven, Netherlands

Apr. 26th, 2013 **Realizability for Peano arithmetic with winning conditions in HON games**, *TYPES conference*, Toulouse, France

Oct. 2nd, 2009 **Quasi-Affine Transformation in Higher Dimension**, *DGCI conference*, Montréal, Canada

Communications (seminar invitations)

Jun. 9th, 2017 **Logic, Computation and Reasoning seminar**, *Université Paris 13*, Villetaneuse, France

Jun. 7th, 2017 **Foundations, Logic and Structures seminar**, *University of Oxford*, Oxford, United Kingdom

May 11th, 2017 **Preuves Automatiques et Raisonnement sur des SpécIFicAtions Logiques seminar**, *École Polytechnique*, Palaiseau, France

Apr. 18th, 2017 **Laboratoire Spécification et Vérification seminar**, *ENS Cachan*, Cachan, France

Mar, 30th, 2017 **Deducteam seminar**, *ENS Cachan*, Cachan, France

Jan. 19th, 2017 **Theory seminar**, *Queen Mary University of London*, London, United Kingdom

Dec. 16th, 2016 **Verification of Algorithms, Languages and Systems seminar**, *LRI*, Saclay

Dec. 10th, 2015 **Logic of Programming seminar**, *Aix-Marseille Université*, Marseille, France

Nov. 27th, 2015 **Programming, Logic, and Semantics seminar**, *University of Cambridge*, Cambridge, United Kingdom

Oct. 22nd, 2014 **Mathematical Foundations seminar**, *University of Bath*, Bath, United Kingdom

Jul. 4th, 2014 **Proofs, Programs, Systems seminar**, *Université Paris-Diderot*, Paris, France

2011-2014 **Plume seminar**, *École Normale Supérieure de Lyon*, Lyon, France
Several times

Other research activities

Jul. 2018 **Program Committee**, *LOLA workshop*, Oxford, United Kingdom

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Apr. 2016 **Program Committee**, *GaLoP workshop*, Eindhoven, Netherlands

Sep. 2016 **Reviewer**, *CSL conference*, Marseille, France

Apr. 2015 **Reviewer**, *FoSSaCS conference*, London, United Kingdom

Jun. 2013 **Reviewer**, *TLCA conference*, Eindhoven, Netherlands

Teaching experience

Sep. 2017-Jan. 2018 **Algorithmics and programming languages**, 1st year BSc, *Institut Universitaire de Technologie d'Orsay*, France

Jan. 2016-May 2016 **Security and integrity**, MSc, *University of Bath*, United Kingdom

Jan. 2014-Jun. 2014 **Software project**, 3rd year BSc, *École Normale Supérieure de Lyon*, France

Sep. 2013-Jan. 2014 **Introduction to algorithmics and imperative programming**, 1st year BSc, *Université Lyon 1*, France

Jan. 2013-Jun. 2013 **Logic**, 3rd year BSc, *École Normale Supérieure de Lyon*, France

Sep. 2012-Jan. 2013 **Computer architecture, systems, networks**, 3rd year BSc, *École Normale Supérieure de Lyon*, France

Jan. 2012-Jun. 2012 **Logic**, 3rd year BSc, *École Normale Supérieure de Lyon*, France

Sep. 2011-Jan. 2012 **Classical logic**, 3rd year BSc, *University Lyon 1*, France

Sep. 2011-Jan. 2012 **Introduction to algorithmics and imperative programming**, 1st year BSc, *Université Lyon 1*, France

Science outreach

Jun. 5th-7th, 2013 **Hippocampe activity: infinity**, *École Normale Supérieure de Lyon*, France

A class of high school students come to a research lab and spend 3 days working on a given scientific topic, under the supervision of a researcher

Feb. 5th, 2014 **MathsÀLyon activity**, *Collège Marcel Aymé de Dagneux*, France

Researchers in mathematics come for one day into a secondary school and support the students in doing experiences highlighting various mathematical concepts

Fellowships

2011 **Three-year PhD fellowship** awarded by the ministry of higher education and research, *École Normale Supérieure de Lyon*, France

2007 **Four-year fellowship** awarded by the ministry of higher education and research, *École Normale Supérieure de Lyon*, France

Publications in journals

Feb. 2017 Blot, **Realizability for Peano Arithmetic with Winning Conditions in HON Games**, *Annals of Pure and Applied Logic, special issue on the 7th workshop on Games for Logic and Programming Languages (GaLoP)*

We build a realizability model for Peano arithmetic based on winning conditions for HON games. Our winning conditions are sets of desequentialized interactions which we call positions. We define a notion of winning strategies on arenas equipped with winning conditions. We prove that the interpretation of a classical proof of a formula is a winning strategy on the arena with winning condition corresponding to the formula. Finally we apply this to Peano arithmetic with relativized quantifications and give the example of witness extraction for Π^0_2-formulas.

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Dec. 2015 Blot, **Typed realizability for first-order classical analysis**, *Logical Methods in Computer Science (LMCS)*

We describe a realizability framework for classical first-order logic in which realizers live in (a model of) typed $\lambda\mu$-calculus. This allows a direct interpretation of classical proofs, avoiding the usual negative translation to intuitionistic logic. We prove that the usual terms of Gödel's system T realize the axioms of Peano arithmetic, and that under some assumptions on the computational model, the bar recursion operator realizes the axiom of dependent choice. We also perform a proper analysis of relativization, which allows for less technical proofs of adequacy. Extraction of algorithms from proofs of Π^0_2 formulas relies on a novel implementation of Friedman's trick exploiting the control possibilities of the language. This allows to have extracted programs with simpler types than in the case of negative translation followed by intuitionistic realizability.

Publications in conference proceedings

Jun. 2017 Blot, **An interpretation of system F through bar recursion**, *32nd ACM/IEEE Symposium on Logic in Computer Science*

There are two possible computational interpretations of second-order arithmetic: Girard's system F and Spector's bar recursion. While the logic is the same, the programs obtained from these two interpretations have a fundamentally different computational behavior and their relationship is not well understood. We make a step towards a comparison by defining the first translation of system F into a simply-typed total language with bar recursion. This translation relies on a realizability interpretation of second-order arithmetic. Due to Gödel's incompleteness theorem there is no proof of termination of system F within second-order arithmetic. However, for each individual term of system F there is a proof in second-order arithmetic that it terminates, with its realizability interpretation providing a bound on the number of reduction steps to reach a normal form. Using this bound, we compute the normal form through primitive recursion. Moreover, since the normalization proof of system F proceeds by induction on typing derivations, the translation is compositional. The flexibility of our method opens the possibility of getting a more direct translation that will provide an alternative approach to the study of polymorphism, namely through bar recursion.

Jul. 2016 Blot, **Hybrid realizability for intuitionistic and classical choice**, *31st ACM/IEEE Symposium on Logic in Computer Science*

In intuitionistic realizability like Kleene's or Kreisel's, the full axiom of choice is trivially realized. It is even provable in Martin-Löf's intuitionistic type theory. In classical logic, however, even the weaker axiom of countable choice proves the existence of non-computable functions. This logical strength comes at the price of a complicated computational interpretation which involves strong recursion schemes like bar recursion. We take the best from both worlds and define a realizability model for arithmetic and the axiom of choice which encompasses both intuitionistic and classical reasoning. In this model two versions of the axiom of choice can co-exist in a single proof: intuitionistic choice and classical countable choice. We interpret intuitionistic choice efficiently, however its premise cannot come from classical reasoning. Conversely, our version of classical choice is valid in full classical logic, but it is restricted to the countable case and its realizer involves bar recursion. Having both versions allows us to obtain efficient extracted programs while keeping the provability strength of classical logic.

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Jun. 2016 Blot, **Classical extraction in continuation models**, *1st International Conference on Formal Structures for Computation and Deduction (FSCD)*

We use the control features of continuation models to interpret proofs in first-order classical theories. This interpretation is suitable for extracting algorithms from proofs of Π^0_2 formulas. It is fundamentally different from the usual direct interpretation, which is shown to be equivalent to Friedman's trick. The main difference is that atomic formulas and natural numbers are interpreted as distinct objects. Nevertheless, the control features inherent to the continuation models permit extraction using a special "channel" on which the extracted value is transmitted at toplevel without unfolding the recursive calls. We prove that the technique fails in Scott domains, but succeeds in the refined setting of Laird's bistable bicpos, as well as in game semantics.

Dec. 2013 Blot and Riba, **On Bar Recursion and Choice in a Classical Setting**, *11th Asian Symposium on Programming Languages and Systems (APLAS)*

We show how Modified Bar-Recursion, a variant of Spector's Bar-Recursion due to Berger and Oliva can be used to realize the Axiom of Countable Choice in Parigot's Lambda-Mu-calculus, a direct-style language for the representation and evaluation of classical proofs. We rely on Hyland-Ong innocent games. They provide a model for the instances of the axiom of choice usually used in the realization of classical choice with Bar-Recursion, and where, moreover, the standard datatype of natural numbers is in the image of a CPS-translation.

Jun. 2013 Blot, **Realizability for Peano Arithmetic with Winning Conditions in HON Games**, *11th International Conference on Typed Lambda Calculi and Applications (TLCA)*

We build a realizability model for Peano arithmetic based on winning conditions for HON games. First we define a notion of winning strategies on arenas equipped with winning conditions. We prove that the interpretation of a classical proof of a formula is a winning strategy on the arena with winning condition corresponding to the formula. Finally we apply this to Peano arithmetic with relativized quantifications and give the example of witness extraction for Π^0_2-formulas.

Nov. 2009 Coeurjolly, Blot and Jacob-Da Col, **Quasi-Affine Transformation in 3-D: Theory and Algorithms**, *13th International Workshop on Combinatorial Image Analysis (IWCIA)*

In many applications and in many fields, algorithms can considerably be speed up if the underlying arithmetical computations are considered carefully. In this article, we present a theoretical analysis of affine transformations in dimension 3. More precisely, we investigate the arithmetical paving induced by the transformation to design fast algorithms.

Sep. 2009 Blot and Coeurjolly, **Quasi-Affine Transformation in Higher Dimension**, *15th IAPR International Conference on Discrete Geometry for Computer Imagery (DGCI)*

In many applications and in many fields, algorithms can considerably be speed up if the underlying arithmetical computations are considered carefully. In this article, we present a theoretical analysis of discrete affine transformations in higher dimension. More precisely, we investigate the arithmetical paving structure induced by the transformation to design fast algorithms.

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5 Capacity of the Participating Organisations

Université Paris Diderot (Paris VII)	
General Description	University Paris Diderot, previously known as Paris 7, is a leading public research multidisciplinary university in France and a major actor in the European higher education and research area. With its 29,000 students, 19% of whom are international, its 2,500 scientists and its 90 research laboratories, the university has acquired an international reputation for the excellence of its standards of research in science, medicine, dentistry, humanities and social sciences. Created in 1970, according to humanist principles set out by eighteenth-century encyclopaedist Denis Diderot, the university's ambition is to enlighten the 21st-century society by opening up new fields of study, renewing traditional disciplines, and connecting with the community at large. Paris Diderot is ranked 199 in THE (Times Higher Education) ranking, 261 in QS (Quacquarelli Symonds) ranking, 151 in SciMago and 101-150 in the ARWU (Shanghai) ranking (5th-6th HEI in France). The university has recently been relocated in a new campus on the west bank of the seine, a new developing area of Paris, a few streets down from the French National Library (BNF). Since 2009, the university has been part of "Sorbonne Paris Cité", a cluster of 8 higher education and research organisations aiming to reinforce their effectiveness and international attractiveness, especially in research. The IRIF hosts 90 permanent academic staff members and 80 postdoctoral researchers and PhD students. The institute is affiliated with the prestigious national center for scientific research (CNRS) and hosts a project-team of the national institute for computer science and mathematics (INRIA), to which the supervisor belongs.
Role and Profile of key persons (supervisor)	The supervisor, Hugo Herbelin, is an internationally recognized senior researcher in computational interpretations of proofs and type theories who published a substantial number of papers in the best international journals and conferences in theoretical computer science. He is part of the Proofs, Programs, Systems group (PPS) of the Foundations of Computer Science Research Institute (IRIF). The PPS group had more than 200 publications during the last five years in the best international journals and conferences. The supervisor will work closely with the ER, meeting him at least twice a month to discuss both the progress of the project and the scientific challenges the ER will have to face. The ER will also work with other members of the group, including PhD students and postdoctoral researchers.
Key Research Facilities, Infrastructure and Equipment	The ER will be given an office with a desk, a whiteboard, an internet connection and access to scientific papers from all major publishers.
Independent research premises?	The ER will work in a Joint Research Unit (UMR), a laboratory recognized and backed by both the University Paris Diderot and the National Center for Scientific Research (CNRS).
Previous Involvement in Research and Training Programmes	As one of the France's leading research-intensive universities, the University Paris Diderot has a long experience in the field of European research projects. It obtained 52 FP7 projects of which 23 PEOPLE projects, and 9 ERDF projects. The supervisor obtained his Habilitation degree in 2005 and supervised many master students, 10 PhD students (including 4 co-supervisions) and 4 postdoctoral researchers. The PPS group of the IRIF has been involved in 2 FP7 projects and 15 projects funded by the French national agency for research (ANR) in the last 10 years.
Current Involvement in Research and Training Programmes	Paris Diderot is currently involved in 23 projects from the 7th FP and the Horizon 2020 programs. It is the host institution in 6 ERC projects, 1 large COFUND doctoral project, 1 PEOPLE and 1 MSCA IF. It is also the beneficiary of 13 collaborative projects of which 1 ITN MSCA project, 1 PEOPLE-ITN, 1 RISE and 2 IMI. Paris Diderot is also a third party in 4 ERC. The PPS team of IRIF is currently involved in 4 projects funded by the French national agency for research (ANR).
Relevant Publications and/or research/innovation products	Hugo Herbelin. "A Constructive Proof of Dependent Choice, Compatible with Classical Logic". In: *27th IEEE Symposium on Logic in Computer Science*. IEEE Computer Society, 2012, pp. 365–374 Hugo Herbelin. "An Intuitionistic Logic that Proves Markov's Principle". In: *25th IEEE Symposium on Logic in Computer Science*. IEEE Computer Society, 2010, pp. 50–56 Hugo Herbelin and Silvia Ghilezan. "An approach to call-by-name delimited continuations". In: *35th Symposium on Principles of Programming Languages*. ACM, 2008, pp. 383–394 Pierre-Louis Curien and Hugo Herbelin. "The duality of computation". In: *5th International Conference on Functional Programming*. ACM Press, 2000, pp. 233–243

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6 Ethical Aspects

There are no ethical issues associated with the PolyBar project

7 Letters of Commitment (GF only)

No letters of commitment are required for this European Fellowship proposal.

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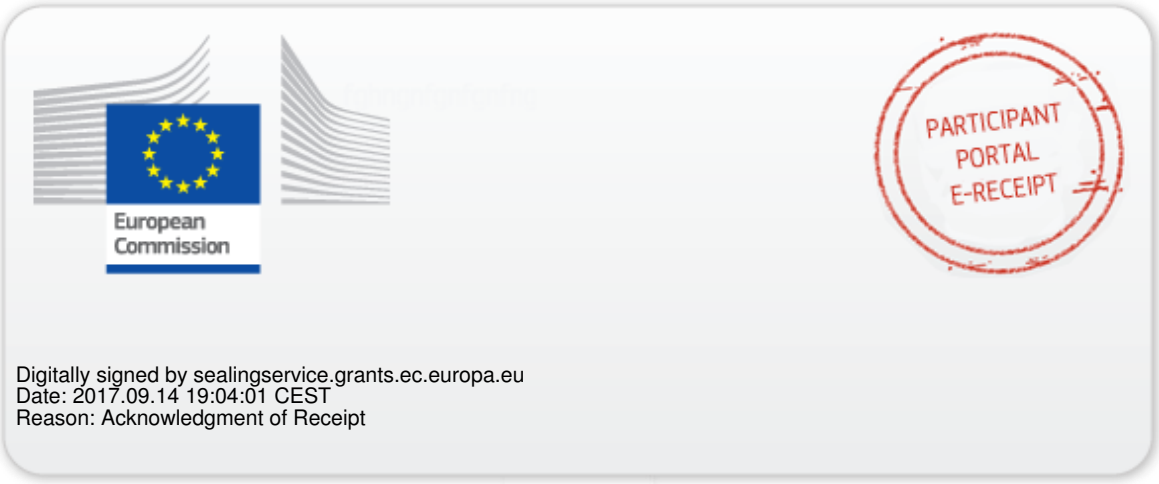

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