Gabriel Scherer
Jan 2016 - Jul 2017: Northeastern University – with Amal Ahmed
Sep 2012 - Dec 2015: Gallium (INRIA Rocq.) – with Didier Rémy

Search for Program Structure

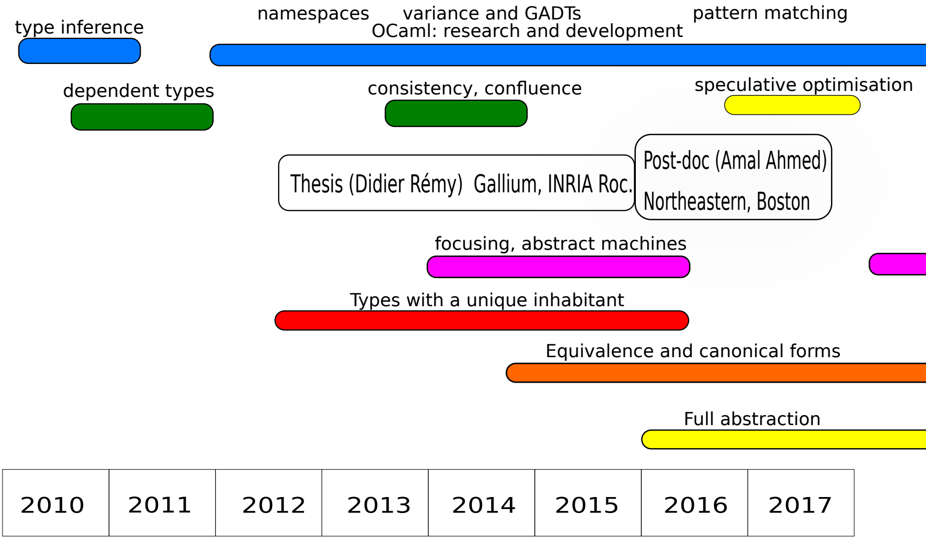
Theory, design and implementation of programming languages.

I am fond of programming.

I want to make it even better.

Designing good programming languages and tools is difficult.
We rely a lot on subjective opinions, gut feelings.

I try to capture usability aspects through formalism.
And implement the resulting designs.


type inference
namespaces
variance and GADTs
pattern matching
OCaml: research and development
dependent types
consistency, confluence
speculative optimisation
Thesis (Didier Rémy) Gallium, INRIA Roc.
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Northeastern, Boston
focusing, abstract machines
Types with a unique inhabitant
Equivalence and canonical forms
Full abstraction
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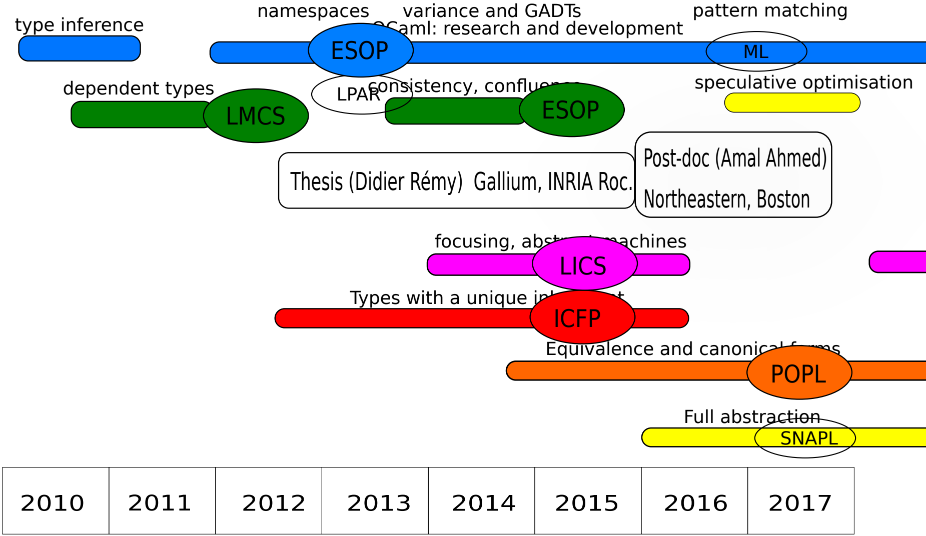
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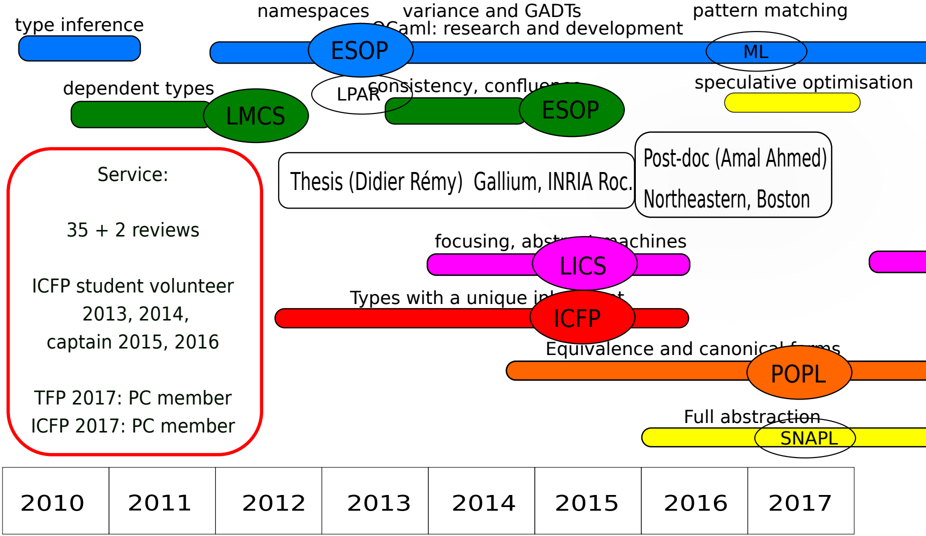
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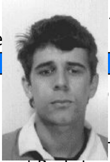

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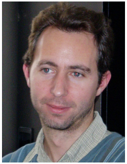

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2010	2011	2012	2013	2014	2015	2016	2017

2012-2017: Research and development on OCaml

- technical contributions to the implementation (committer #2)
- community building: opening the development process
  (github, code reviews, social events)
  20 contributors in 2012, 93 in 2017
- research problems identified and studied

Example: ambiguous pattern variables, with Luc Maranget

- bug report from the Why3 team
- research and publication – ML workshop post-proceedings
- patch to the compiler, merged in 4.04.0
- cross-language discussions with Haskell, Rust designers

Community recognition:
PC member for the OCaml Workshop 2016, PC chair for 2017.

Project: Search for Program Structure

Program equivalence

We have tools to check that a program verifies a specification.

Few tools to check program equivalence.
(richer programming languages $\Rightarrow$ more complex equivalences.)

Untapped potential for applications; tools for:

- verified refactoring
- consistency checking for implicit programming
- program synthesis (see further)

Challenge: undecidability.

Past result: Full simply-typed equivalence is decidable

"Deciding equivalence with sums and the empty type"
Gabriel Scherer (at Northeastern)
POPL 2017
https://arxiv.org/abs/1610.01213

History

Simple types: formal model of datatypes in programming.

Decidability of equivalence:

- $\Lambda C(\alpha, \to)$: Tait, 1967 or earlier; easy
- $\Lambda C(\alpha, \to, \times)$: essentially the same proof.
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- $\Lambda C(\alpha, \to, \times, 1, +, 0)$:
  Open problem that needed a different approach. hard

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  my work (POPL 2017)

```
module type PARAM = sig
  type error
  val process : input → (output + error)
  ...
end

module Action (P : PARAM) = struct
  let process_or_stdout input =
    match P.process input with
    | σ1 out → out
    | σ2 err → report_error_stdout (); exit 1
  let process_or_email input =
    match P.process input with
    | σ1 out → out
    | σ2 err → report_error_email (); exit 2
  ...
end
```

Intuition

0 represents impossible cases.

```
module P = struct
  type error = 0
  let process : input -> (output + 0) = ...
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$$\frac{\Gamma \vdash t : 0 \qquad \Gamma \vdash u_1, u_2 : A}{\Gamma \vdash u_1 \approx_\eta u_2 : A}$$

Question

What is a canonical form for simply-typed terms?

Redundancy: two (syntactically) distinct terms that are equivalent.

Canonical representation: a syntax of programs with no redundancy:

$$(\not\approx_{\mathtt{stx}}) \implies (\not\approx_{\mathtt{sem}})$$

(Decides equivalence.)

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(Decides equivalence.)

With only functions and pairs, easy.
It does not scale to sums (even booleans !).

Idea

Curry-Howard, again: programs as proofs.

The structure of

canonical forms

corresponds to the structure of

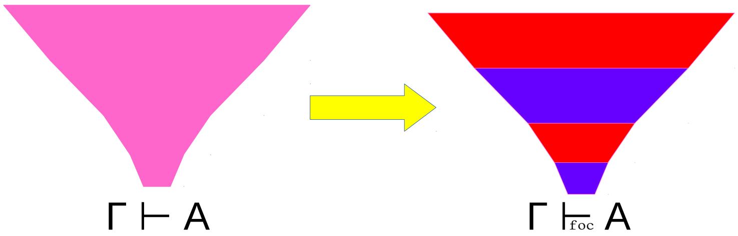
proof search

Restricting the search space restricts expression redundancy.

Research transfer from proof theory.

Proof search: Focusing

(existing work)



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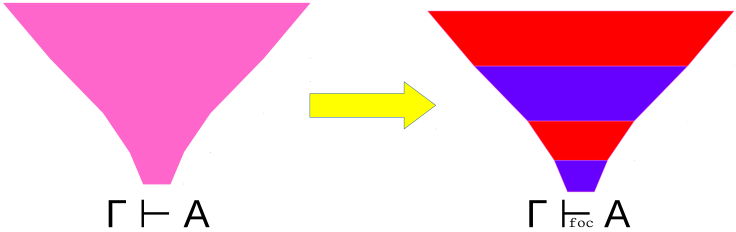

Gives a term representation ($\vdash_{\texttt{foc}}$).
Not yet canonical.

Proof search: Saturation

(my contribution).

Idea: make all possible deductions from the environment first.

Canonical representation.

Proof search: Saturation

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Idea: make all possible deductions from the environment first.

Canonical representation.

$$\frac{\Gamma \vdash t : 0 \qquad \Gamma \vdash u_1, u_2 : A}{\Gamma \vdash u_1 \approx_\eta u_2 : A}$$

Saturation discovers t.

Proof search: Saturation

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Canonical representation.

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Saturation discovers t.

(Booleans $\Rightarrow$ BDDs)

Application: program synthesis

Canonical representations tell us about program structure.

Program synthesis by searching among canonical representations.

Discussions with synthesis groups at MIT, UPenn, Princeton.
Heuristics subsumed by focusing.

Project: Search for Program Structure

Transfer proof representation techniques
to programming language applications.

Gives strong results in restricted setting (simple types),
also useful in richer languages – “more canonical” representations.

Applications: new programming language features and tools.

Continued exchange between logic and programming techniques
(inductives, second-order logic, dependent types) is necessary.

(Not detailed here)
Multi-language programming and interoperation.

Parsifal

Expertise in proof theory, focusing, automated theorem proving.

Applied mostly to proof systems so far.

Me: expertise and application goals in programming languages.

Foundational proof certificates for prover interoperability
$\leftrightarrow$ programming languages interoperation.

Ambitious programming projects (Abella, Psyche, Bedwyr, Mætning...).
$\leftrightarrow$ OCaml expertise.

Timeline

Short term

- Verified refactoring.
- Canonicity and polymorphism.
- OCaml plus expert languages.

Medium term

- Program synthesis for dependent types.
- Focusing, abstract machines and CBPV.
- Verified/unverified interoperability.

Long term

- Understanding pure program structure.
- Generic focusing and canonicity.
- Hybrid proof/program synthesis for effective verified programming.

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