# Deadlock-Free Separation Logic

## Linearity Yields Progress for Dependent Higher-Order Message Passing

Jules Jacobs Jonas Kastberg Hinrichsen Robbert Krebbers

**Deadlock-Free Separation Logic: Linearity Yields Progress for Dependent Higher-Order Message Passing**

JULES JACOBS, Radboud University Nijmegen, The Netherlands
JONAS KASTBERG HINRICHSEN, Aarhus University, Denmark
ROBBERT KREBBERS, Radboud University Nijmegen, The Netherlands

We introduce a linear concurrent separation logic, called **LinearActris**, designed to guarantee deadlock and leak freedom for message-passing concurrency. LinearActris combines the strengths of session types and concurrent separation logic, allowing for the verification of challenging higher-order programs with mutable state through dependent protocols. The key challenge is to prove the adequacy theorem of LinearActris, which says that the logic indeed gives deadlock and leak freedom "for free" from linearity. We prove this theorem by defining a step-indexed model of separation logic, based on *connectivity graphs*. To demonstrate the expressive power of LinearActris, we prove soundness of a higher-order (GV-style) session type system using the technique of logical relations. All our results and examples have been mechanized in Coq.

CCS Concepts: • **Theory of computation → Separation logic**; *Program verification*; Programming logic.

Additional Key Words and Phrases: Message passing, deadlocks, session types, separation logic, Iris, Coq

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POPL'24

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**POPL'24**

# The Iris Masterplan

Jules Jacobs, 2023-12-11

# History

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$\{P\}\ e\ \{Q\}$

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If P holds, and we run e, then Q holds

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| **Verification of programs with** | **Using** |
| --- | --- |
| *mutable local variables* | *Hoare logic (Hoare)* |
| + *pointers & data structures* | *Separation logic (Reynolds)* |
| + *shared-memory concurrency* | *Concurrent separation logic (O'Hearn)* |

# What is Iris?

## *Iris from the ground up*

### *A modular foundation for higher-order concurrent separation logic*


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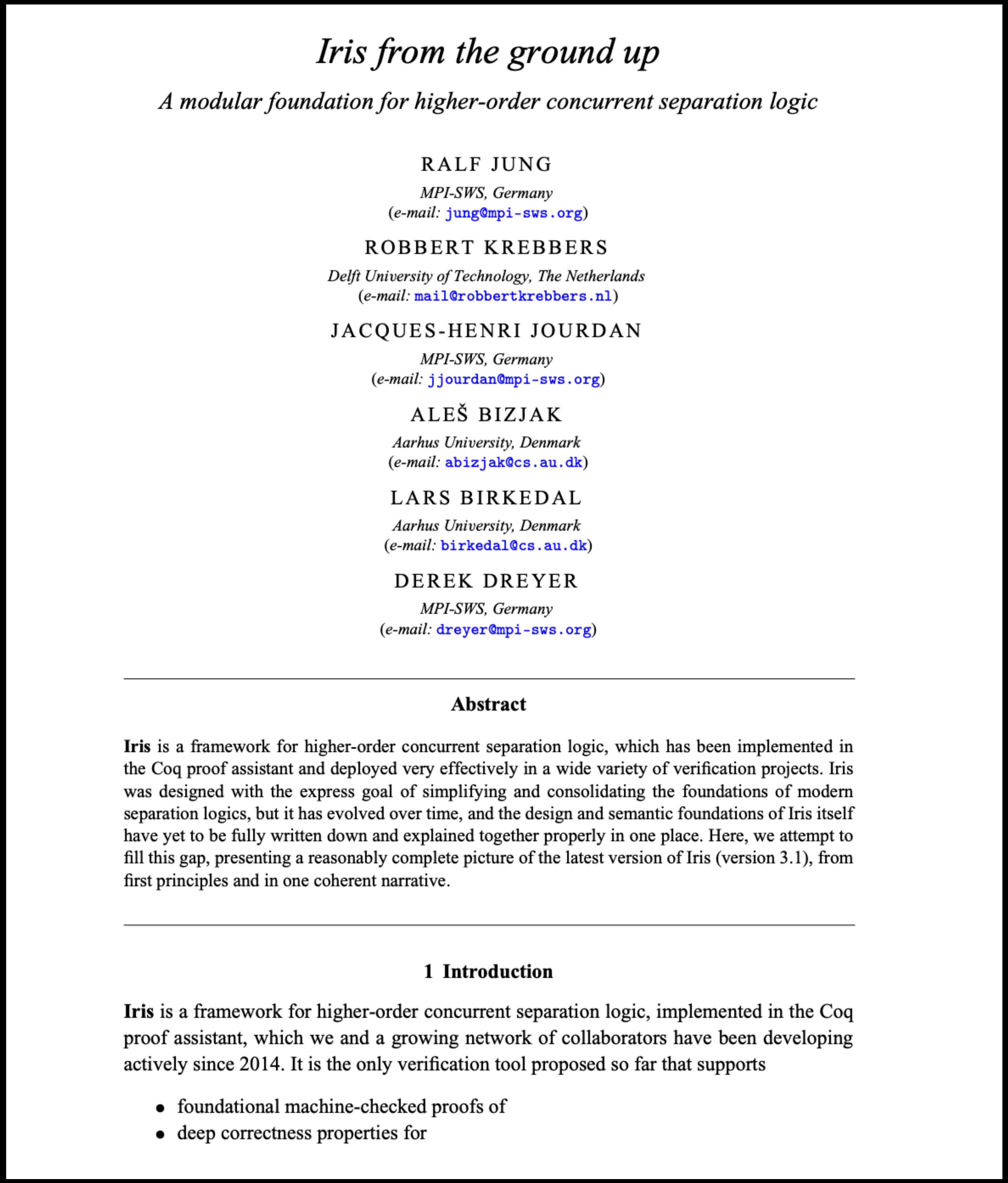
### 1 Introduction

**Iris** is a framework for higher-order concurrent separation logic, implemented in the Coq proof assistant, which we and a growing network of collaborators have been developing actively since 2014. It is the only verification tool proposed so far that supports

- foundational machine-checked proofs of
- deep correctness properties for

# What is Iris?



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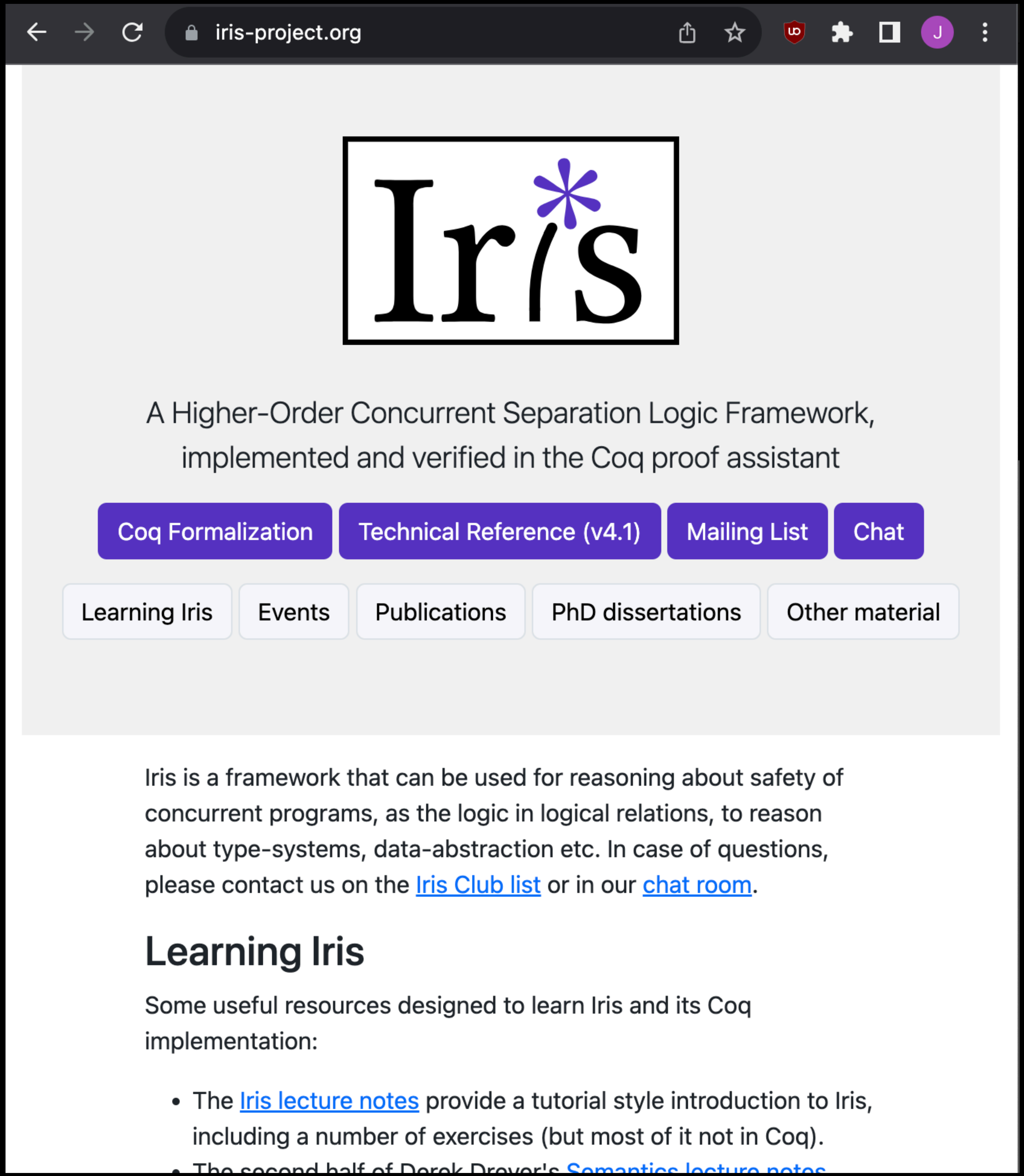

# What is Iris, really?

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HeapLang {P} e {Q}

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Definition newlock : val := λ: <>, ref #false.

Definition acquire : val := rec: "acquire" "l" :=
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Coq

Iris

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## iProp {P} e {Q}

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Definition lock_inv (γ : gname) (l : loc) (R : iProp Σ) : iProp Σ :=
    ∃ b : bool, l ↦ #b ∗ if b then True else own γ (Excl ()) ∗ R.

Definition is_lock (γ : gname) (lk : val) (R : iProp Σ) : iProp Σ :=
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Lemma acquire_spec γ lk R :
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Proof.
  iIntros (Φ) "#Hl HΦ". iLöb as "IH". wp_rec.
  wp_apply (try_acquire_spec with "Hl"). iIntros ([]).
  - iIntros "[Hlked HR]". wp_if. iApply "HΦ"; auto with iFrame.
  - iIntros "_". wp_if. iApply ("IH" with "[HΦ]"). auto.
Qed.
```

## Proof Mode

# What is Iris, really?

Coq

Iris

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Qed.
```

## Proof Mode

Iris has many innovations over CSL!

I will not talk about these

Ask me, and I'll tell you what I know

# Iris’ adequacy theorem

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(based on operational semantics for HeapLang in Coq, with heap + thread pool)

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Partial correctness: e may loop!

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(based on operational semantics for HeapLang in Coq, with heap + thread pool)

Partial correctness: e may loop!

Very partial: e may deadlock!

# Why are there 91 Iris papers?

## Publications

Below, we give an overview of the research that uses Iris one way or another.

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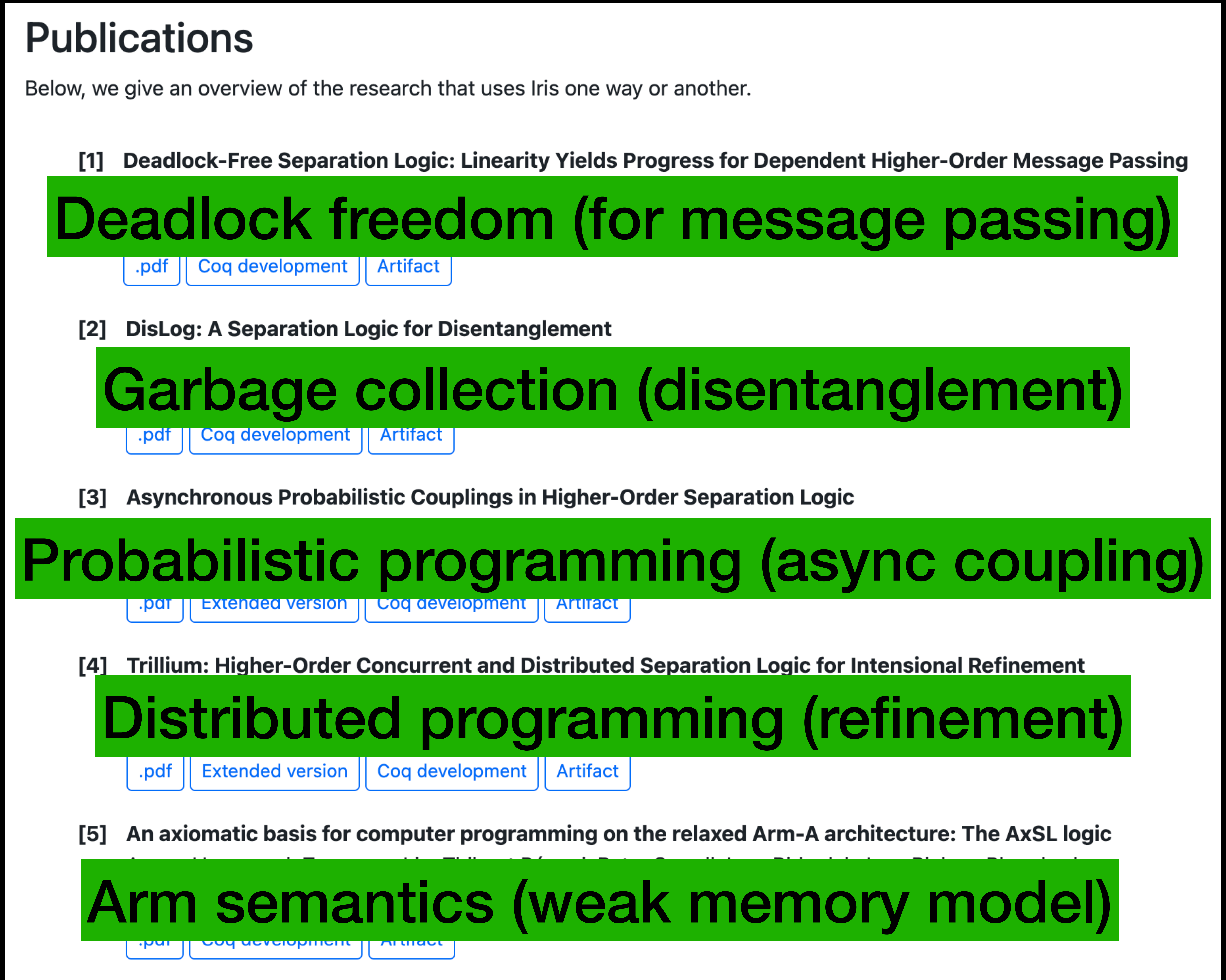



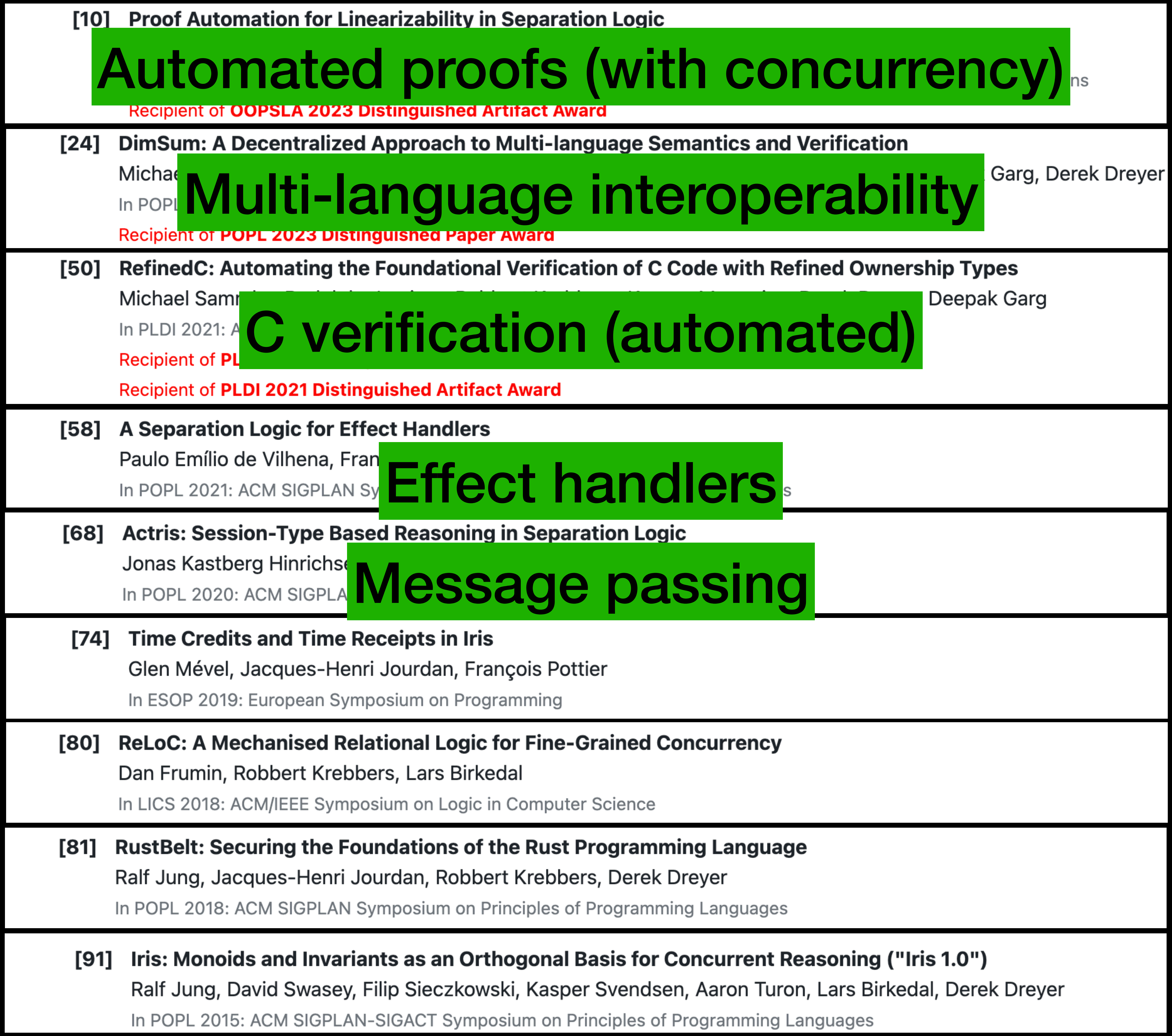

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**Deadlock freedom (for message passing)**

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☆ An Iris Instance for Verifying CompCert C Programs

William Mansk

**Iris + CompCert**

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**Automated proofs (with concurrency)**

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Michae … Garg, Derek Dreyer

In POPL

**Multi-language interoperability**

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Michael Samm … Deepak Garg

In PLDI 2021: A

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[58] **A Separation Logic for Effect Handlers**

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**Comparison: 200+ papers on effect handlers & way more on probabilistic programming**

# The Masterplan

Iris

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Iris

Build a fully verified software stack

Hypervisor, OS, compiler, type system, database,

web server, …, and your code!

# The Masterplan

All programming paradigms

Strong adequacy theorems

Fully mechanised proofs

End-to-end theorems

Free theorems from types

Strong reasoning principles

Proof automation

Modular proofs

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