NICTA

Large-scale proof and libraries in Isabelle/HOL

Gerwin Klein

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Department of Communications, Information Technology and the Arts
Australian Research Council

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L4Verified

L4.Verified

l microkernel

8,700 lines of C

0 bugs*

qed

*conditions apply

Windows

An exception 06 has occured at 0028:C11B3ADC in VxD DiskTSD(03) +
00001660. This was called from 0028:C11B40C8 in VxD voltrack(04) +
00000000. It may be possible to continue normally.

* Press any key to attempt to continue.
* Press CTRL+ALT+RESET to restart your computer. You will
  lose any unsaved information in all applications.

Press any key to continue

Windows Vista™

Stunning. Breakthrough. Entertaining.

HP TouchSmart PC and Microsoft Windows Vista deliver you a PC experience designed to fit wherever life happens.

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the Bay
the Bay

The Problem

Small Kernels

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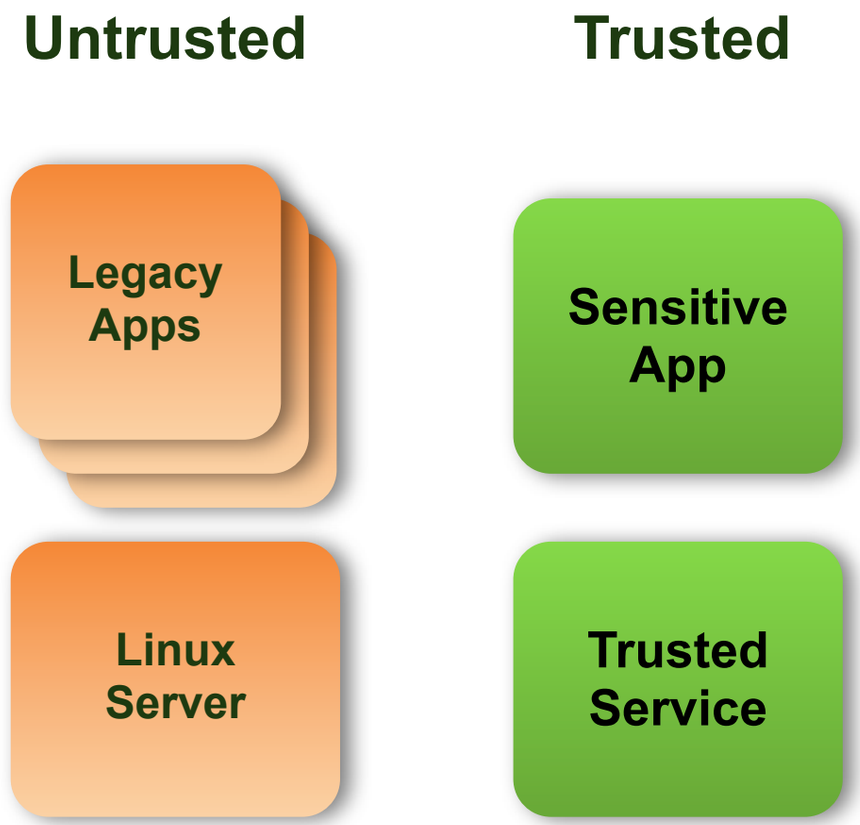
Small trustworthy foundation

- hypervisor, microkernel, nano-kernel, virtual machine, separation kernel, exokernel ...
- High assurance components in presence of other components



seL4 API:

- IPC
- Threads
- VM
- IRQ
- Capabilities

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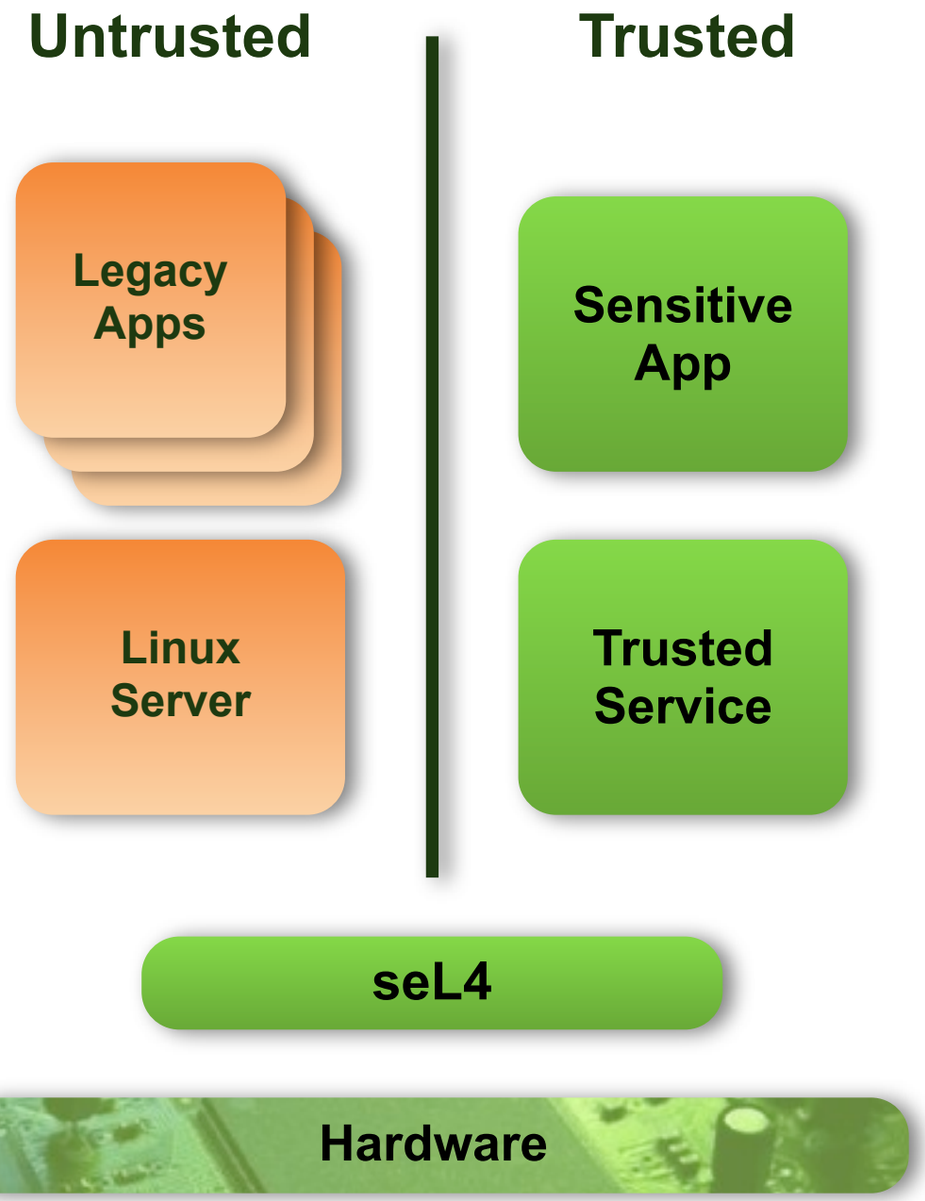


seL4 API:

- IPC
- Threads
- VM
- IRQ
- Capabilities

The Proof

The Proof

Functional Correctness

Specification

Proof

Code

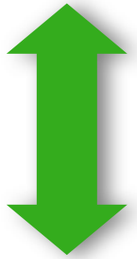
Functional Correctness

What

Proof

Specification

```
definition
  schedule :: unit s_monad where
  schedule ≡ do
    threads ← allActiveTCBs;
    thread ← select threads;
    switch_to_thread thread
  od
  OR switch_to_idle_thread
```



Code

Functional Correctness

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What

Proof

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Implementation

```
void
schedule(void) {
    switch ((word_t)ksSchedulerAction) {
        case (word_t)SchedulerAction_ResumeCurrentThread:
            break;

        case (word_t)SchedulerAction_ChooseNewThread:
            chooseThread();
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        default: /* SwitchToThread */
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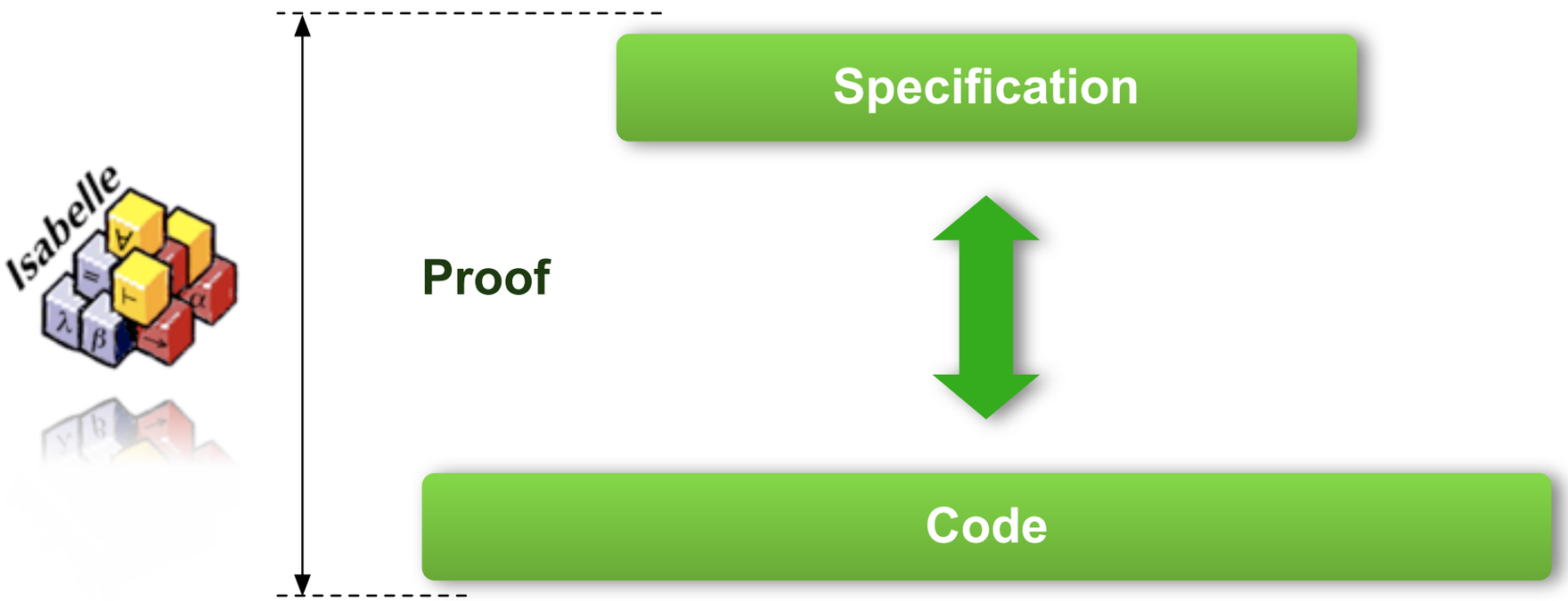
            break;
    }
}

void
chooseThread(void) {
    prio_t prio;
    tcb_t *thread, *next;
```

*conditions apply



*conditions apply

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Expectation

Specification

Proof

Code

Assumptions

*conditions apply

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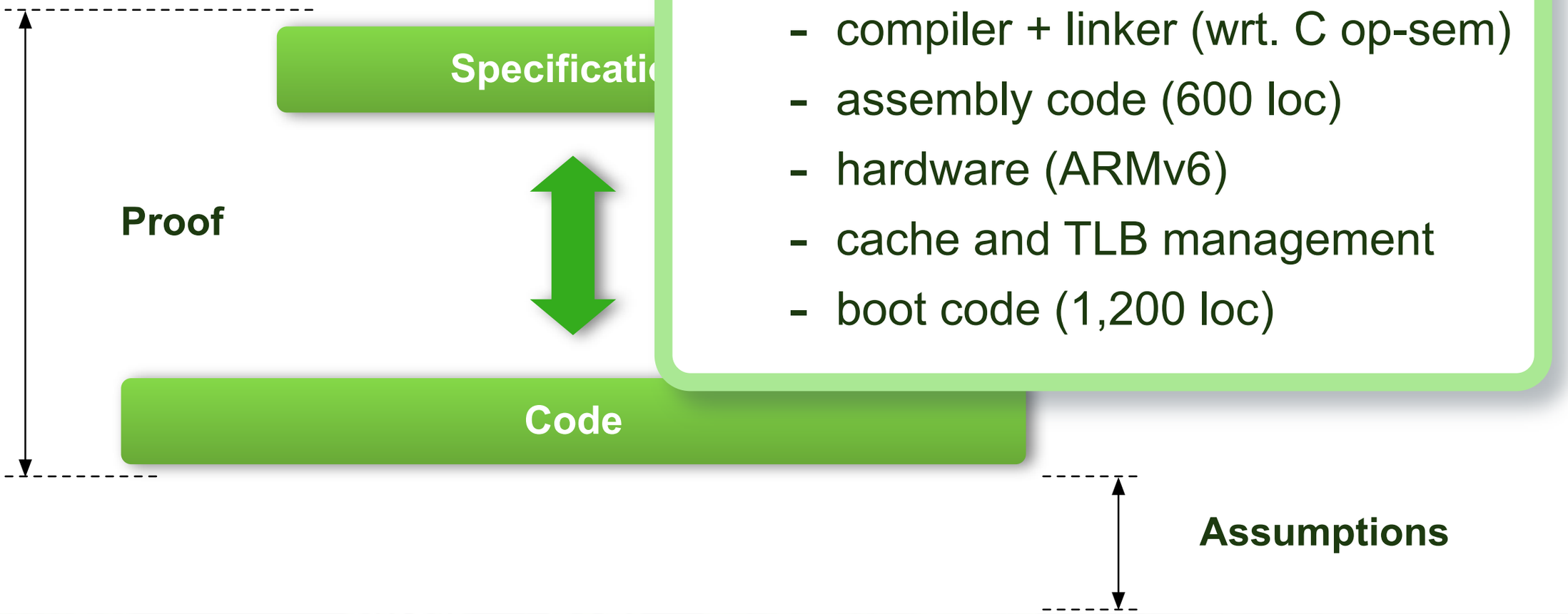
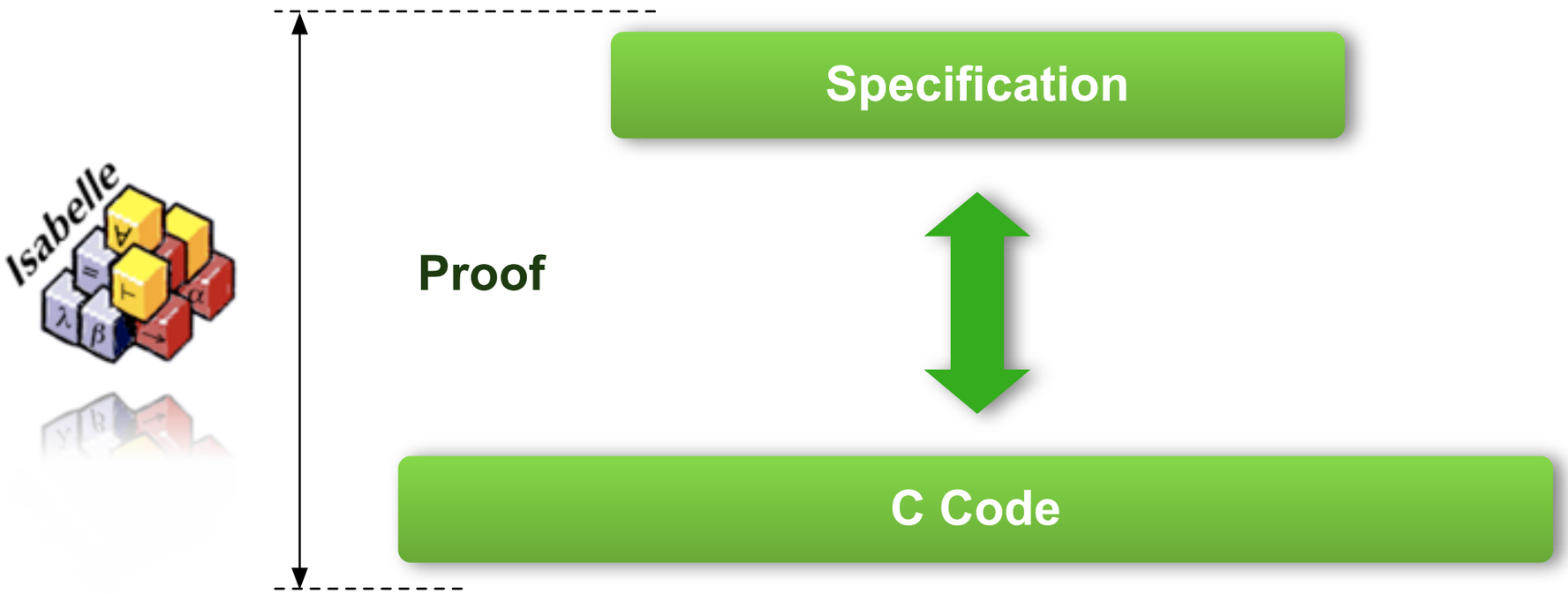
Assume correct:

- compiler + linker (wrt. C op-sem)
- assembly code (600 loc)
- hardware (ARMv6)
- cache and TLB management
- boot code (1,200 loc)



Proof Architecture



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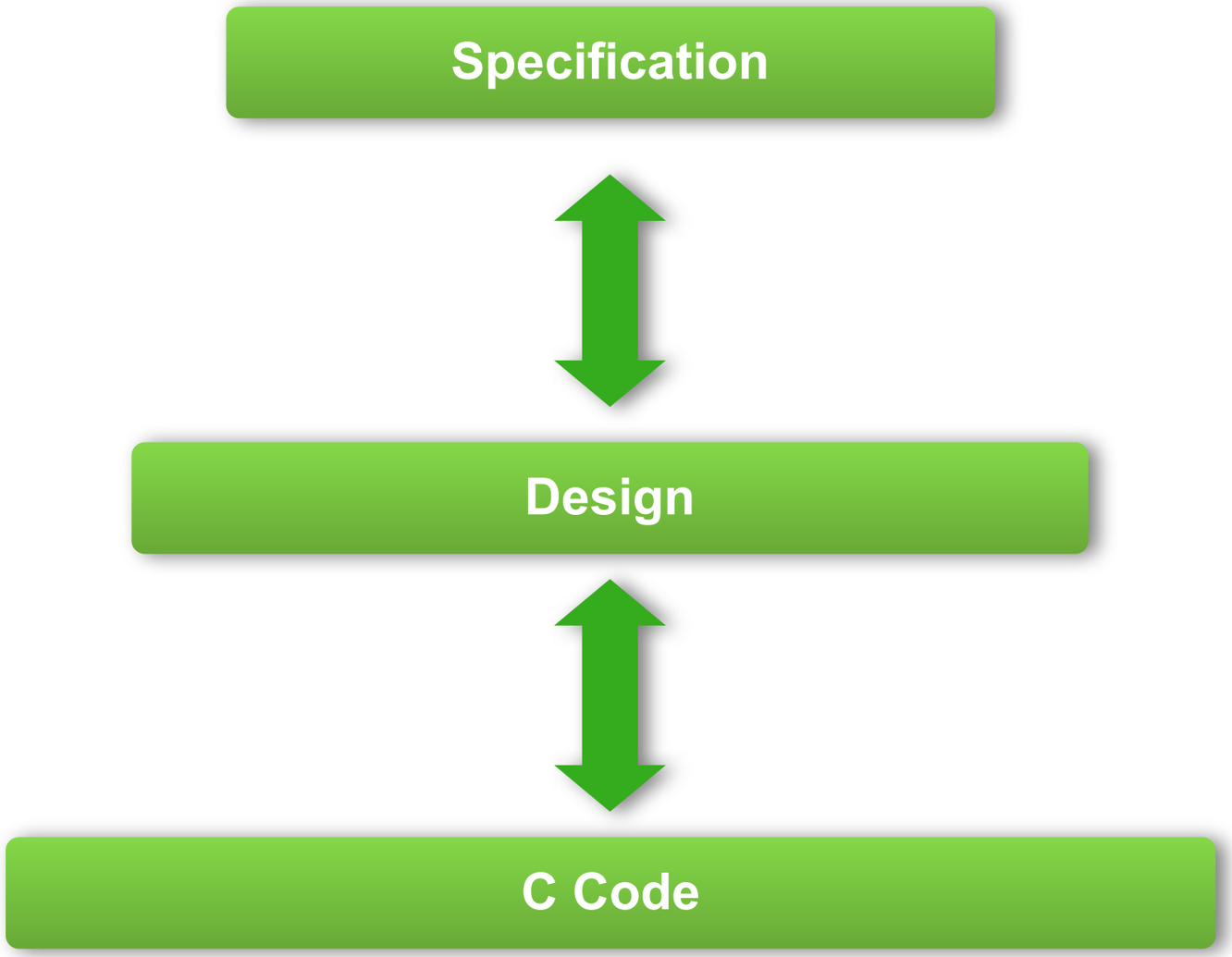

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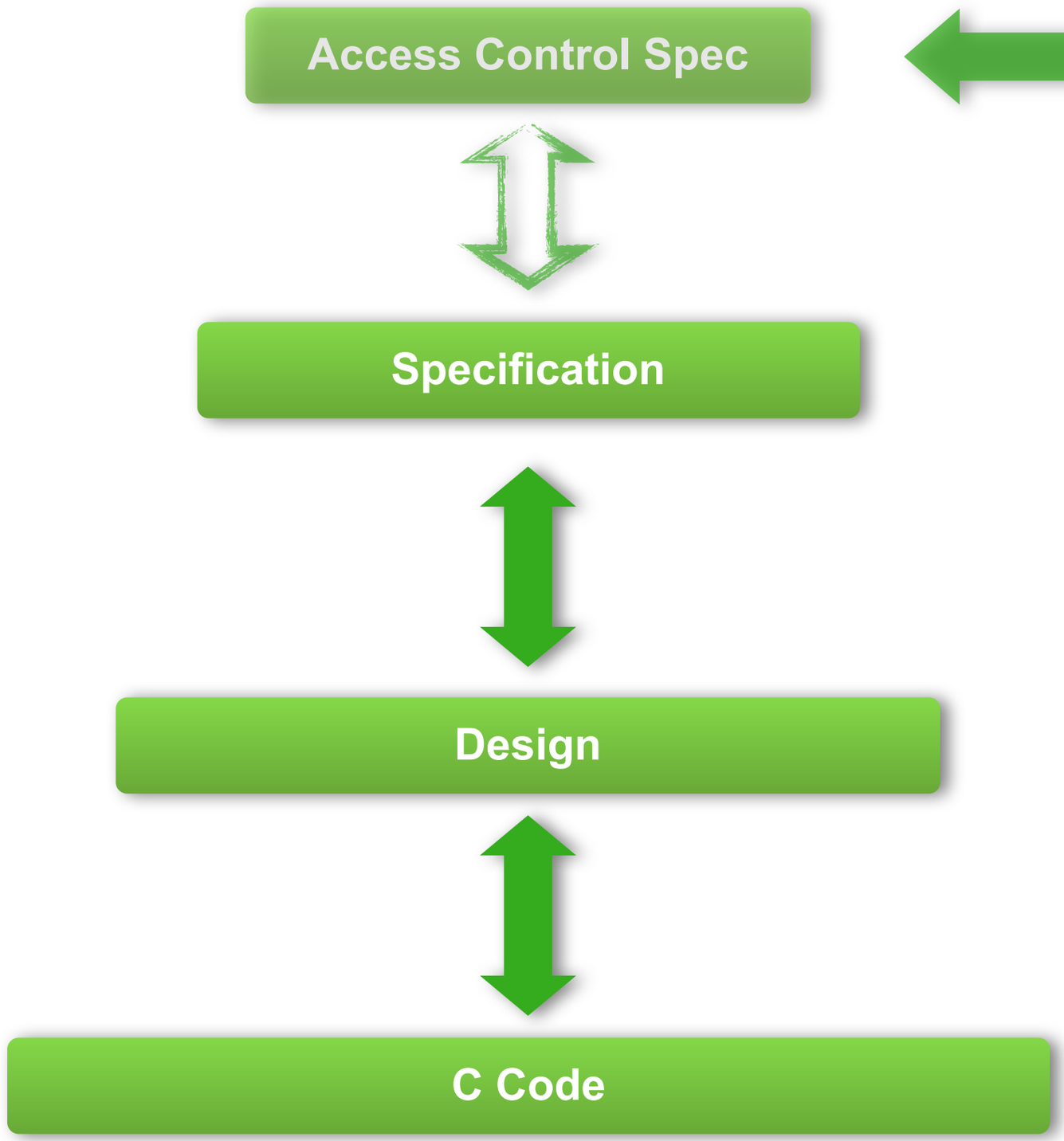
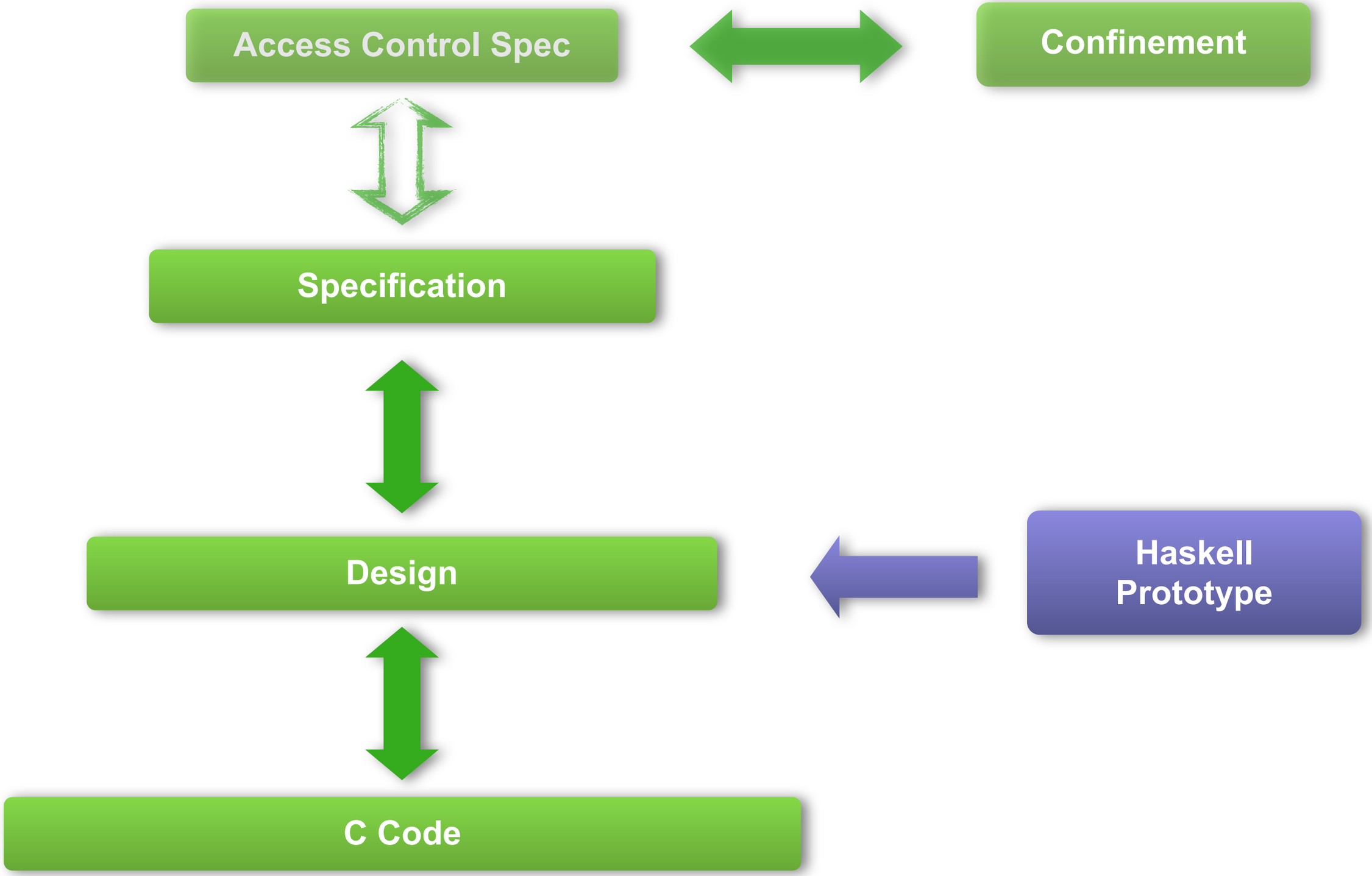


Proof Architecture



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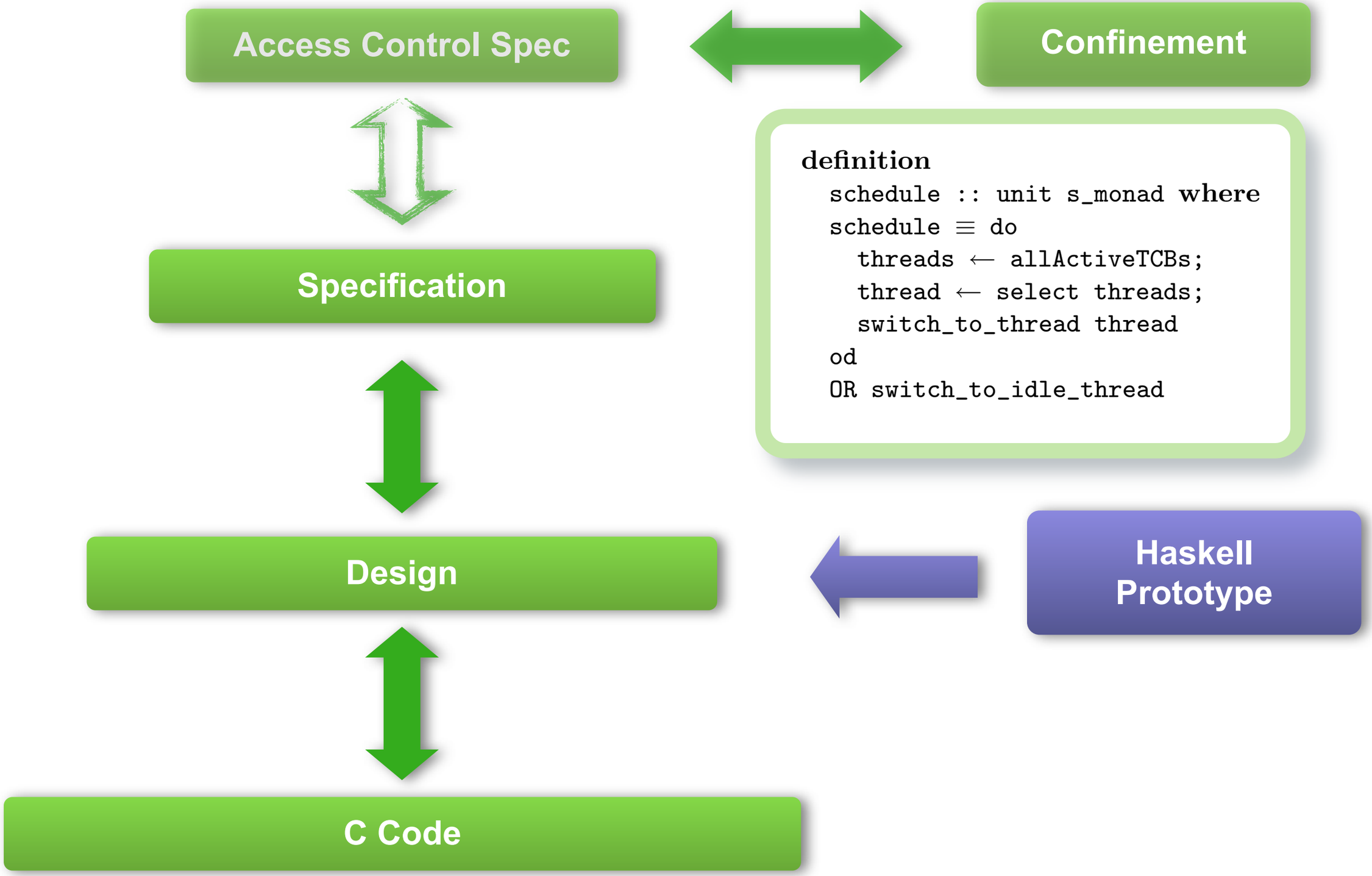

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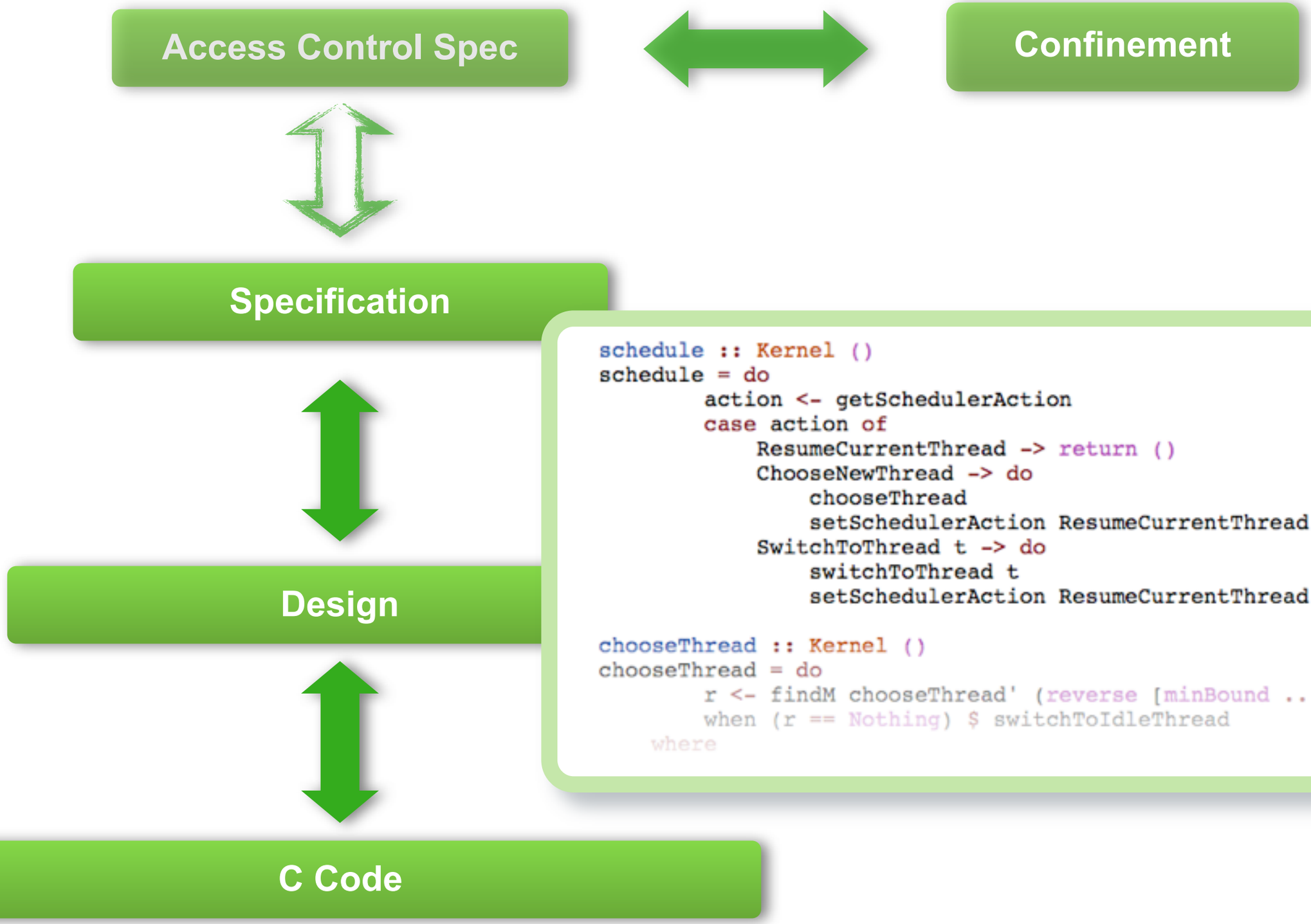

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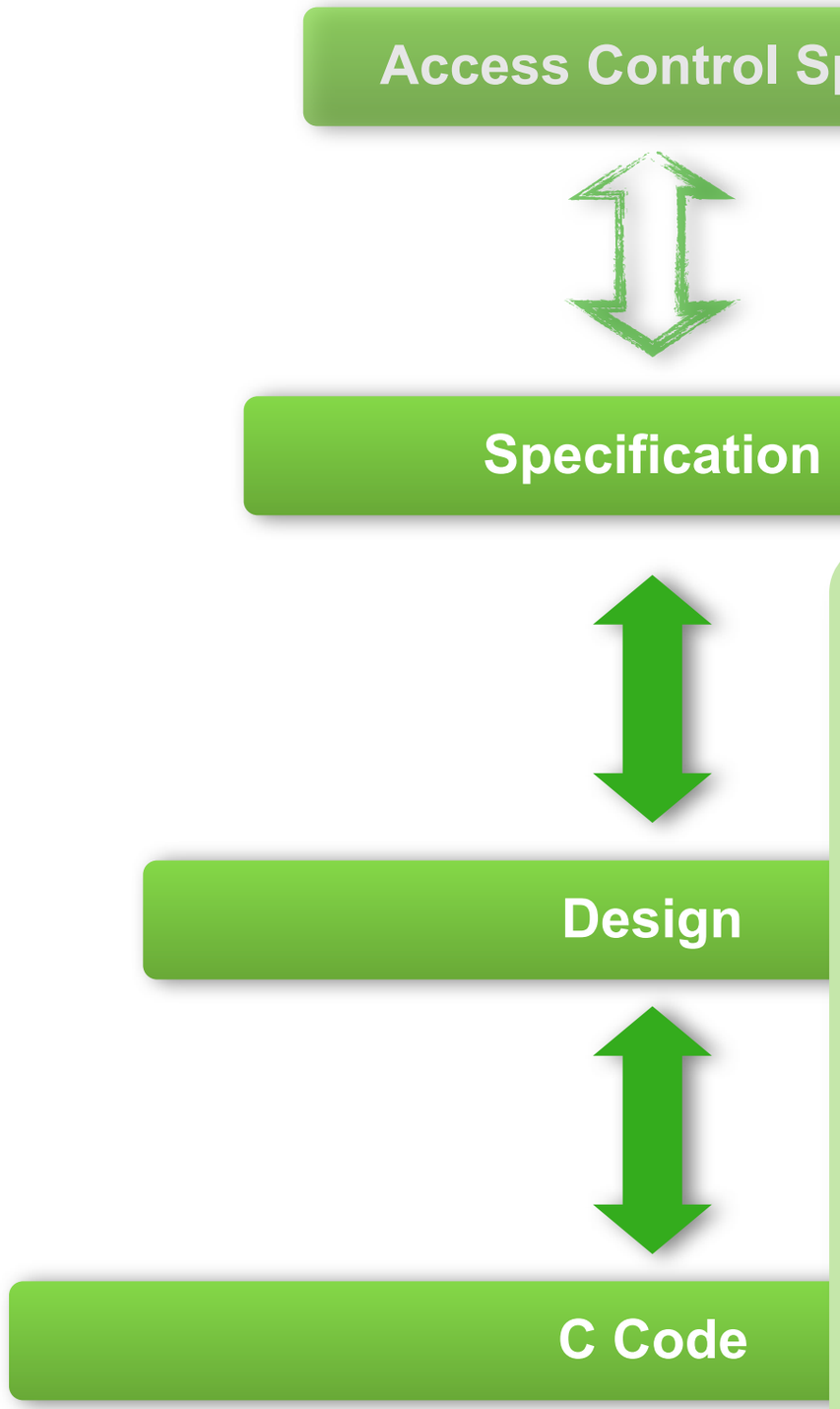


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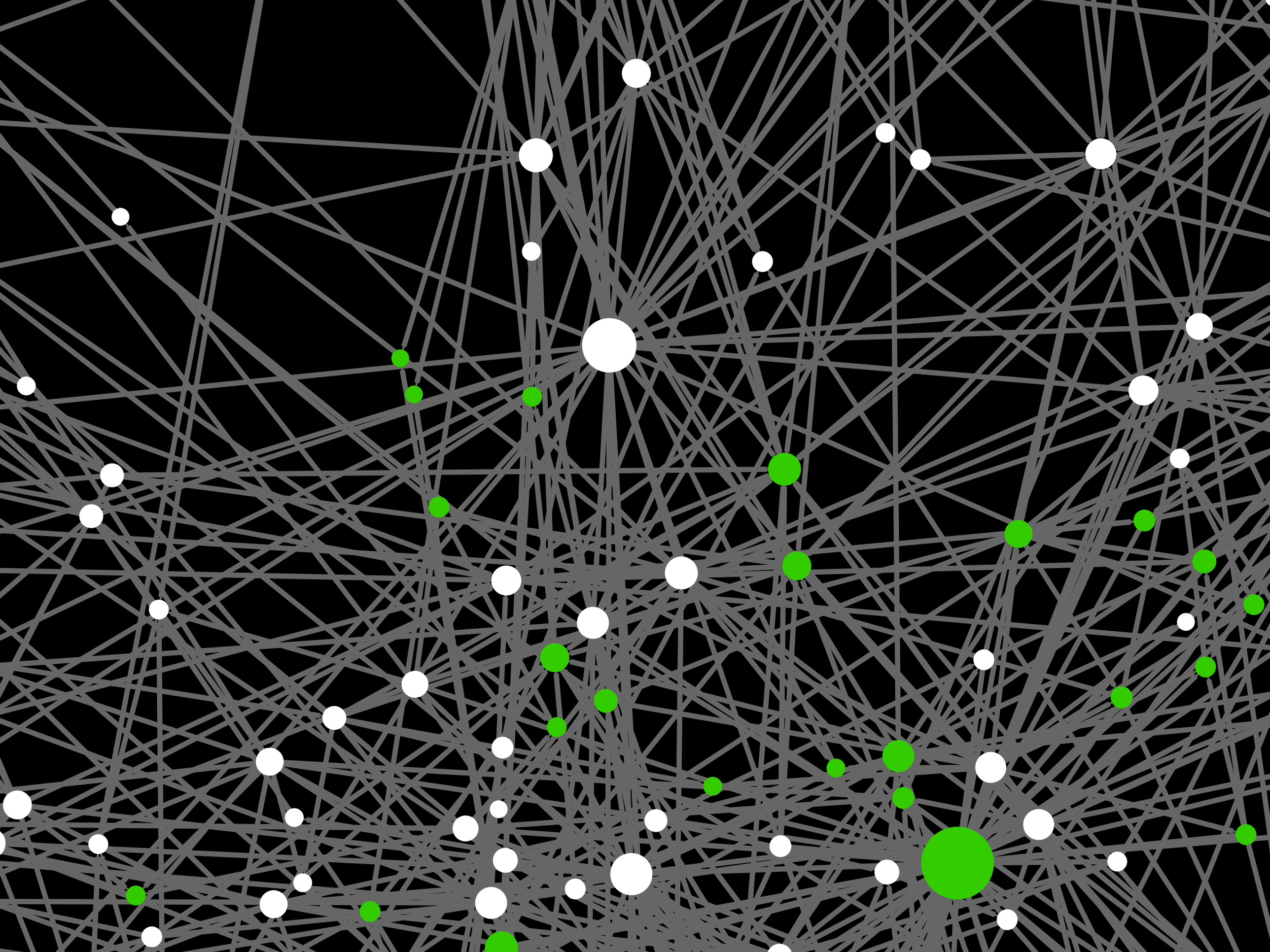


seL4

Did you find any Bugs?

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Bugs found

- in C: 160
- in design: ~150
- in spec: ~150

460 bugs

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        d

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                    next = thread->tcbSchedNext;
                    tcbSchedDequeue(thread);
                }
                else {
                    switchToThread(thread);
                    return;
                }
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```

ead;

Effort

Haskell design	2	py
First C impl.	2	weeks
Debugging/Testing	2	months
Kernel verification	12	py
Formal frameworks	10	py
Total	25	py

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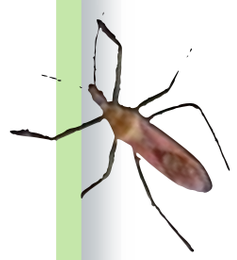

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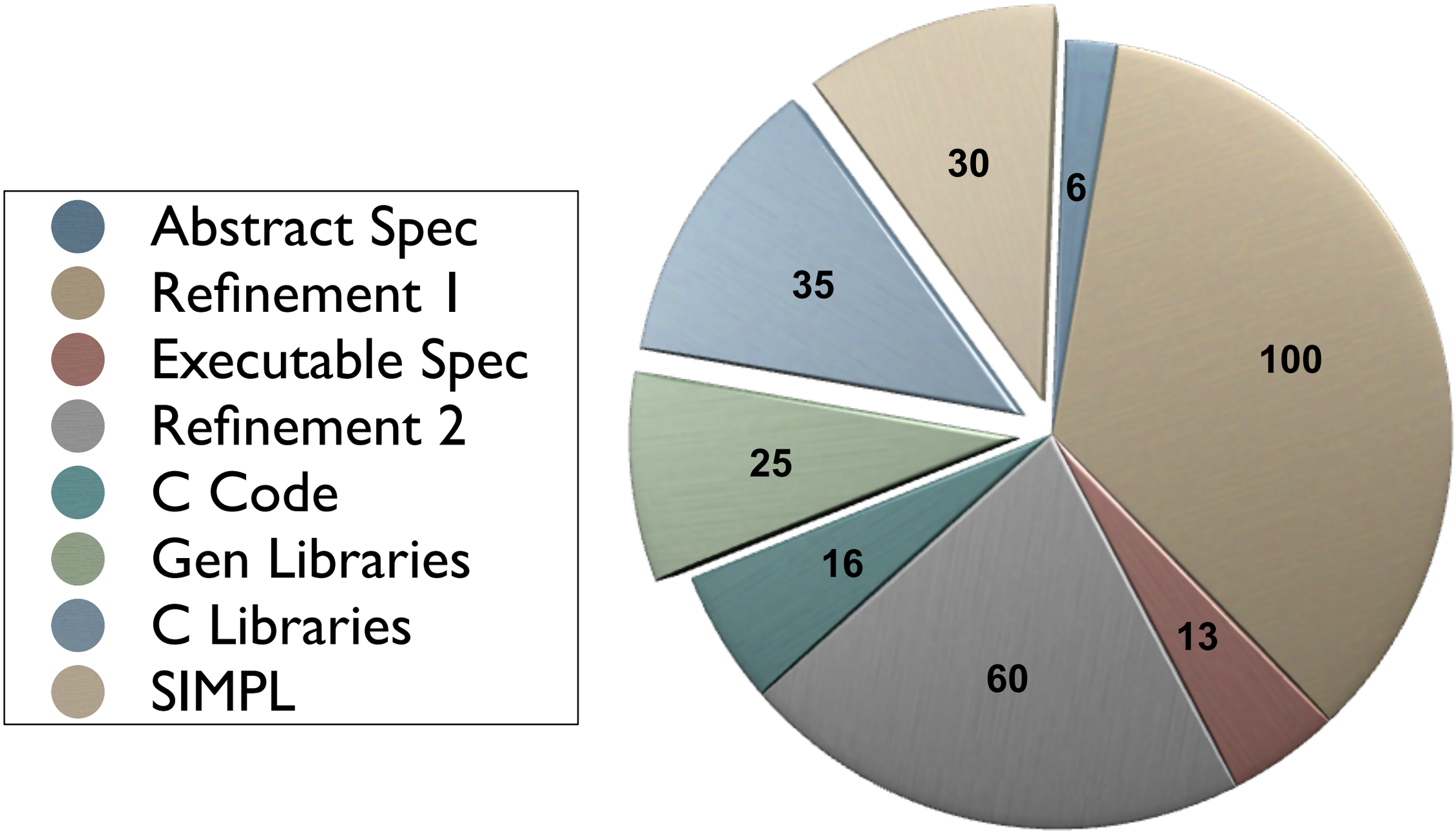
Proofs and Libraries

Proofs and Libraries

Main Proof Components



Theory Inclusion Graph

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Main Libraries

- Libraries
  - Word library
  - Enums
  - Haskell library support
  - Monads
  - Monad VCG + case splitter + strengthening
  - Refinement on Monads
  - Submonads and rewriting under refinement
  - Refinement between Monads and C + tools
  - SIMPL + imperative VCG
  - Crunch
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Tools

- Productivity tools
  - theorem search (find_thms)
  - theorem moving (Levity)
  - finding definitions (locate)
  - theorem web search (www_find)
  - numeral syntax (hex, oct, binary)

- Isabelle
  - Record package
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What we thought would work

- Automation
  - First order provers (vampire)
  - SAT for word problems
  - Termination proofs

- What we thought might be a problem
  - Performance
  - Memory
  - Lemmas/goals/proofs too big to parse

Problems

Problems

- What turned out to be a problem

Problems

- What turned out to be a problem
  - Isabelle updates

Problems

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  - Annoying word proofs
  - Developing/maintaining libraries + frameworks
    - Hard to get over good enough

Wish List

- Better name space management
- Better performance (time + memory)
- Better parallelisation
  - run nitpick, quickcheck, sledgehammer etc in background
  - run proofs faster interactively
- Better dependency handling
  - faster turnaround for deep definition changes
  - faster image rebuilding

Archive of Formal Proofs

Archive of Formal Proofs

AFP

- Repository of Isabelle proofs
  - Open Source (BSD + LGPL)
  - Maintained
  - Archived, version controlled
  - Quality controlled

- Hosted on SourceForge
  - [http://afp.sf.net]

Screen Shot

NICTA

The Archive of Formal Proofs

http://afp.sourceforge.net/

Google

Google SMH Spiegel Slashdot L4v Wiki Bugzilla ERTOS 2 Wiki

The Archive of Formal Proofs

The Archive of Formal Proofs is a collection of proof libraries, examples, and larger scientific developments, mechanically checked in the theorem prover Isabelle. It is organized in the way of a scientific journal and has an ISSN: 2150-914x. Submissions are refereed. The preferred citation style is available [here]. A development version of the archive is available as well.

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2010

2010-06-24: Free Groups
Author: Joachim Breitner

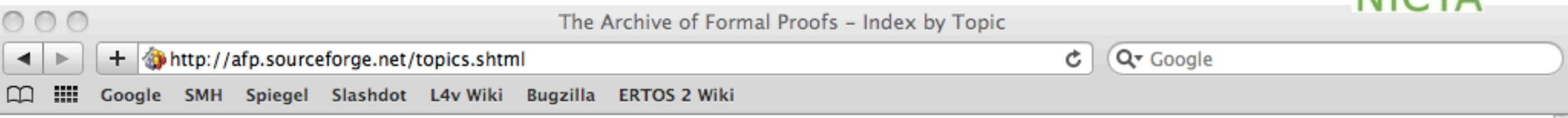
2010-06-20: Category Theory
Author: Alexander Katovsky

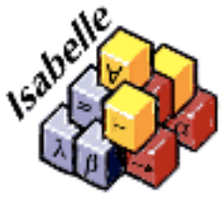
2010-06-17: Executable Matrix Operations on Matrices of Arbitrary Dimensions
Author: Christian Sternagel and René Thiemann

2010-06-14: Abstract Rewriting
Author: Christian Sternagel and René Thiemann

2010-05-28: Verification of the Deutsch-Schorr-Waite Graph Marking Algorithm using Data Refinement
Author: Viorel Preoteasa and Ralph-Johan Back

Index by Topic





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Computer Science

Automata and Formal Languages
Regular-Sets Presburger-Automata Functional-Automata Tree-Automata

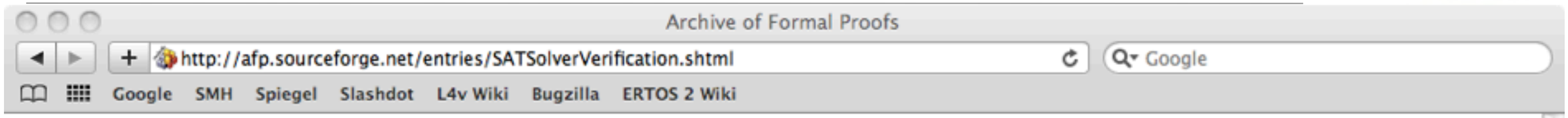
Algorithms
DPT-SAT-Solver Depth-First-Search FFT GraphMarkingIBP
SATSolverVerification MuchAdoAboutTwo **Distributed:** DiskPaxos
GenClock ClockSynchInst

Data Structures
AVL-Trees BDD BinarySearchTree FinFun Collections FileRefinement
List-Index Matrix Huffman Lazy-Lists-II

Functional Programming
Coinductive Stream-Fusion

Programming Languages
Language Definitions: CoreC++ FeatherweightJava Jinja JinjaThreads
Locally-Nameless-Sigma POPLmark-deBruijn Simpl **Type**
Systems: MiniML VolpanoSmith **Logics:** Simpl Abstract-Hoare-Logics
BytecodeLogicJmlTypes DataRefinementIBP SIFPL **Compiling:** Compiling-

An Entry



Formal Verification of Modern SAT Solvers

Title:	Formal Verification of Modern SAT Solvers
Author:	Filip Maric
Submission date:	2008-07-23
Abstract:	This document contains formal correctness proofs of modern SAT solvers. Following (Krstic et al, 2007) and (Nieuwenhuis et al., 2006), solvers are described using state-transition systems. Several different SAT solver descriptions are given and their partial correctness and termination is proved. These include: • a solver based on classical DPLL procedure (using only a backtrack-search with unit propagation), • a very general solver with backjumping and learning (similar to the description given in (Nieuwenhuis et al., 2006)), and • a solver with a specific conflict analysis algorithm (similar to the description given in (Krstic et al., 2007)). Within the SAT solver correctness proofs, a large number of lemmas about propositional logic and CNF formulae are proved. This theory is self-contained and could be used for further exploring of properties of CNF based SAT algorithms.

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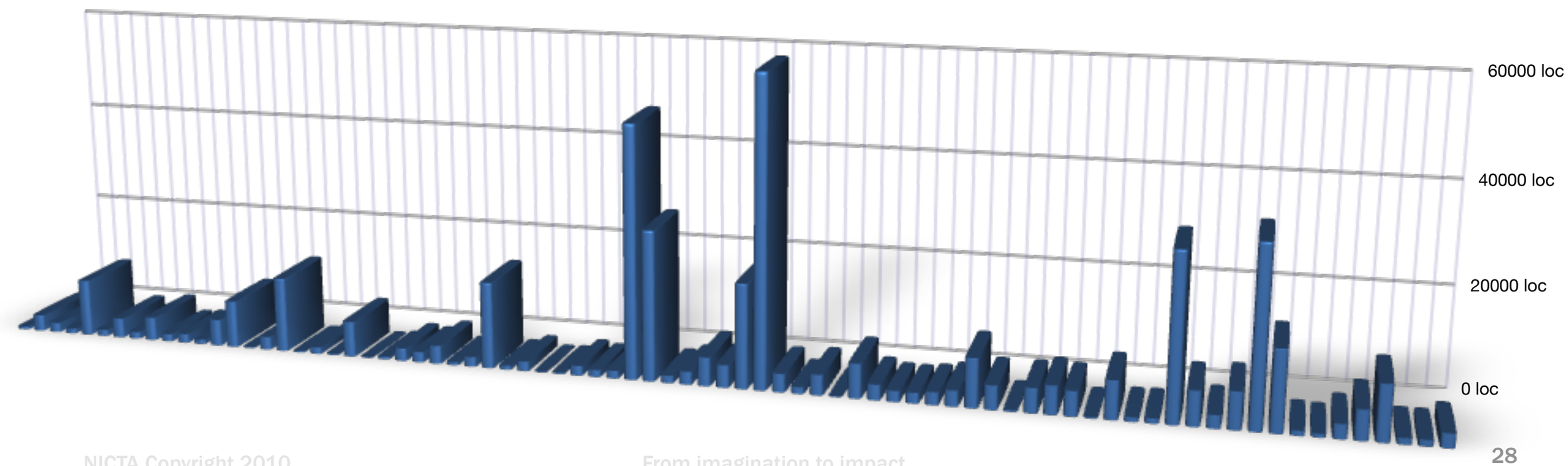
SOURCEFORGE.NET
project summary

Proof outline
Proof document
Browse theories
Download this entry

Statistics

- Numbers
  - started 2003
  - now 77 entries
  - 473 kloc of proof scripts
  - 22,000 lemmas
  - runs 4-6h daily
- Typical entry
  - belongs to a paper
  - nice proof document
  - small, 1-4 kloc
  - some big developments



What works well

- Archival and Maintenance
  - everything kept up to date by Isabelle team
  - new release with every Isabelle release
  - good number of submissions
  - mostly good quality submissions
  - some authors keep improving their entries
    - (but need better high-level change tracking, versioning)

  - good test bed for Isabelle team
  - good place to publish proofs for paper authors
  - authors can get repository access

Reuse?

- Not much reuse:
  - Few entries designed as libraries
  - Few entries used in others (3)

- Reasons
  - Cultural (mostly papers)
  - Good libraries go directly into Isabelle distribution
  - Technical hurdles
    - not enough instruction on how to include
    - could give more built-in support, name spaces again
    - can’t import from more than one image
    - dependencies? hackage site?

Summary

Summary

Summary

Proof Libraries are like Program Libraries

- **L4.verified:**
  - 200kloc proof
  - lots of libraries
  - some are reusable, costs more work, usually worth it

- **Archive of Formal Proofs**
  - 77 entries, 470kloc proof in total
  - works well for papers
  - not so well for libraries yet, hope to get more in the future

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Thank You