seL4

Formal Verification of an OS Kernel

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NICTA Members
NICTA Partners

4.Verified

L4.Verified

1 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

The Problem

Small Kernels

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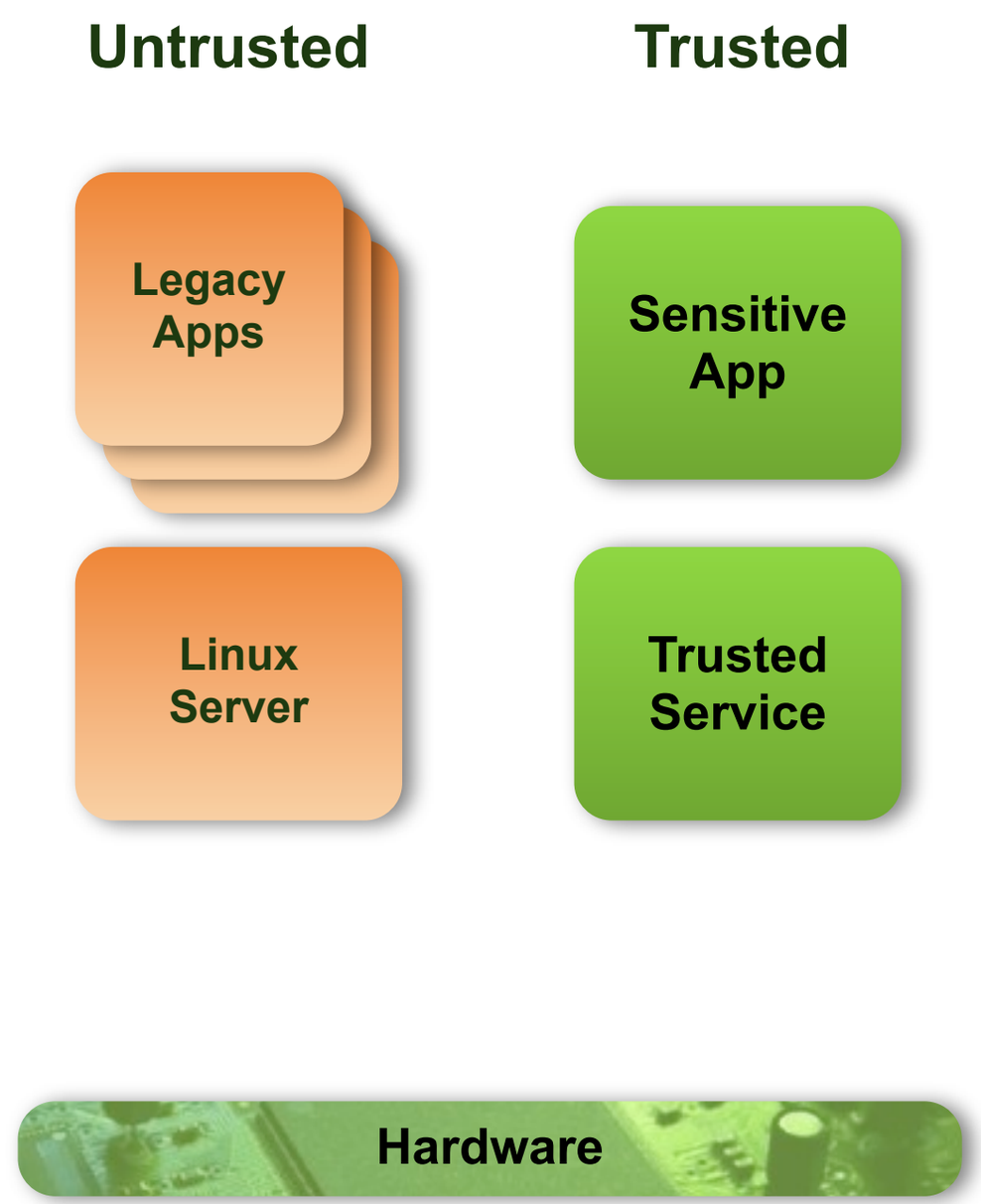
Small trustworthy foundation

- 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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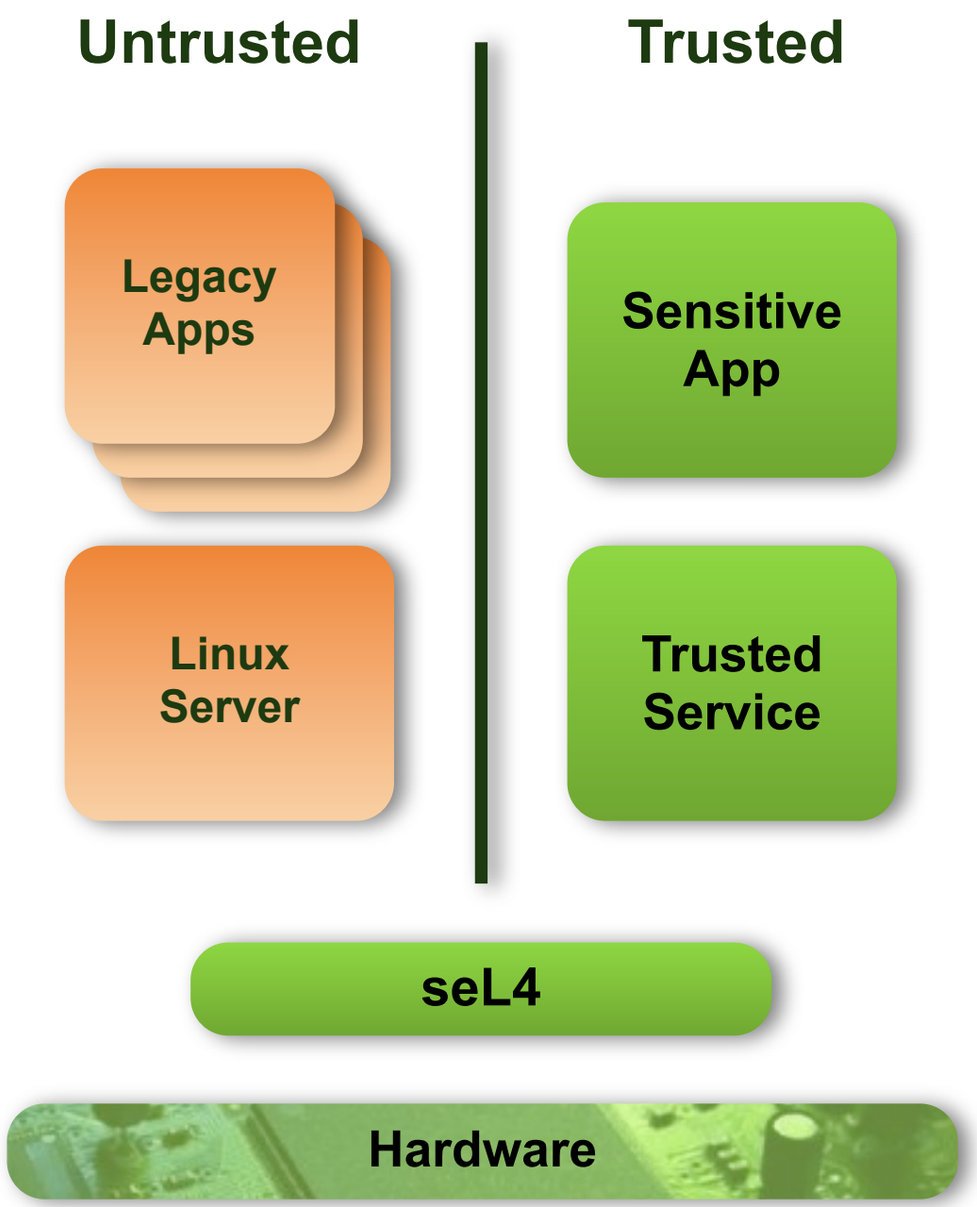

The Proof

The Proof

Functional Correctness

NICTA

Specification

Proof

Code

Functional Correctness

NICTA

What

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

Specification

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Specification

Proof

How

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

        case (word_t)SchedulerAction_ChooseNewThread:
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        default: /* SwitchToThread */
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    }
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void
chooseThread(void) {
    prio_t prio;
    tcb_t *thread, *next;
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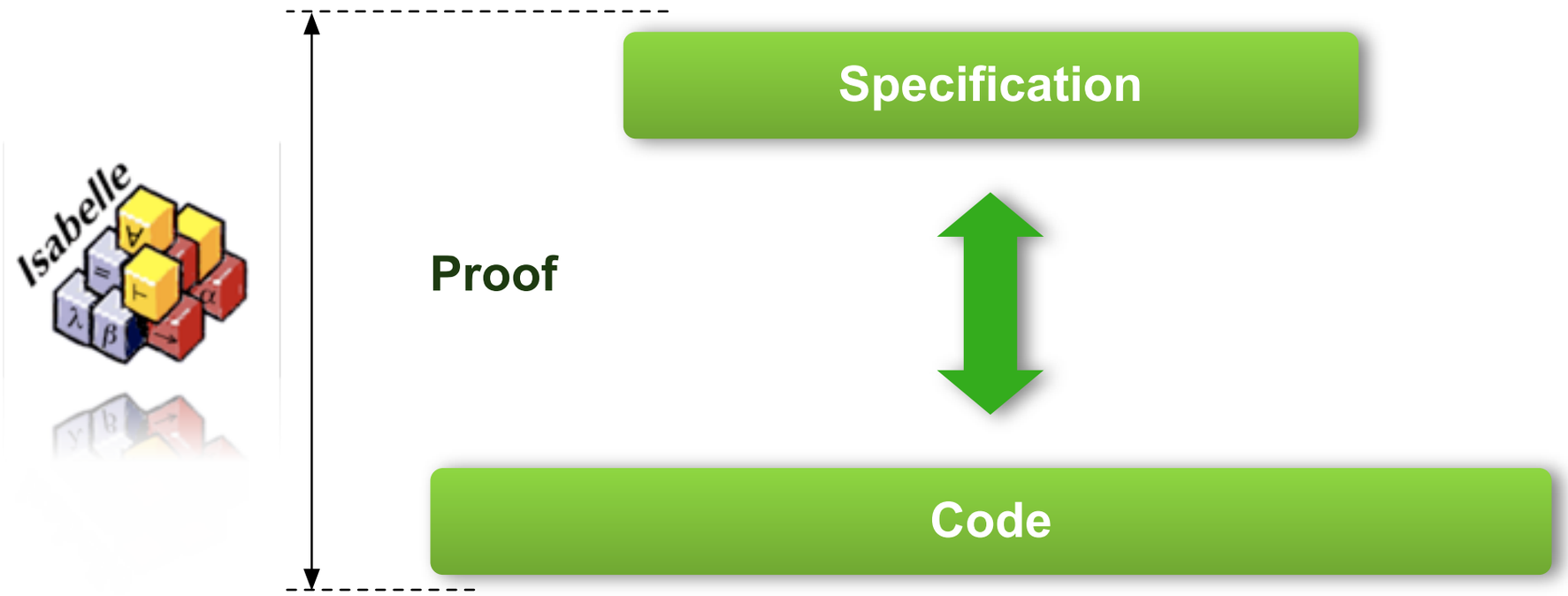
*conditions apply



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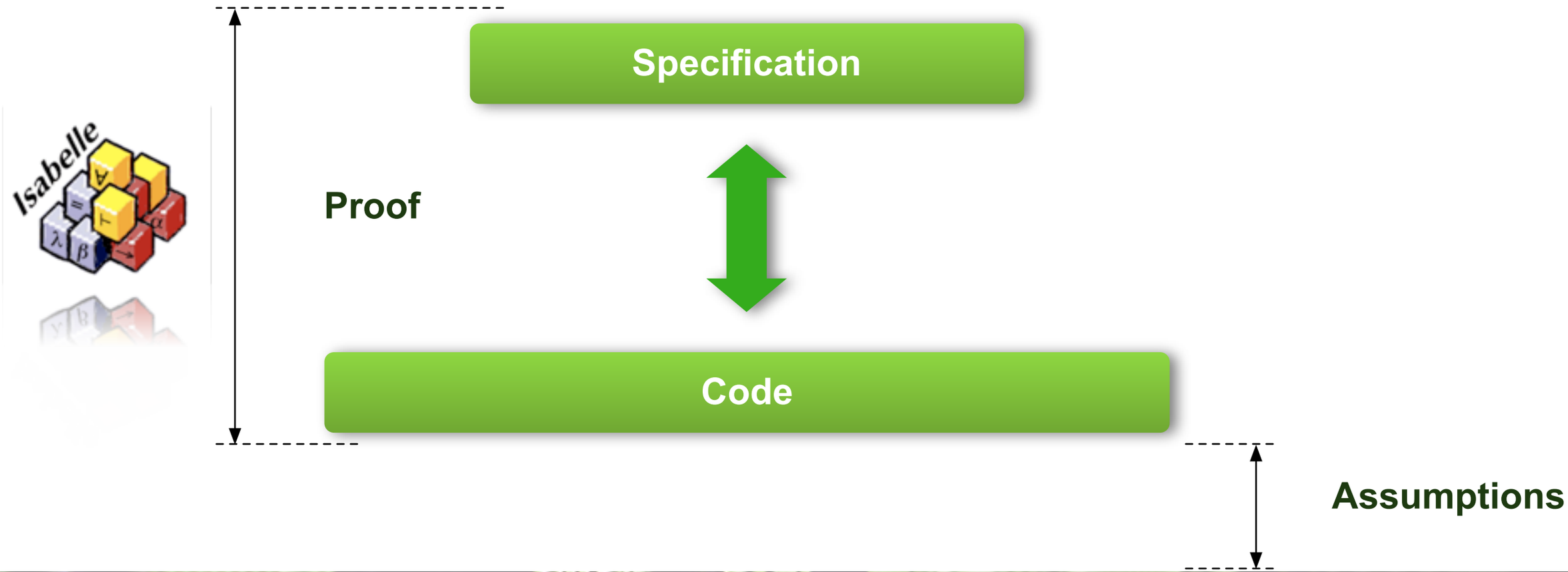


*conditions apply

Expectation

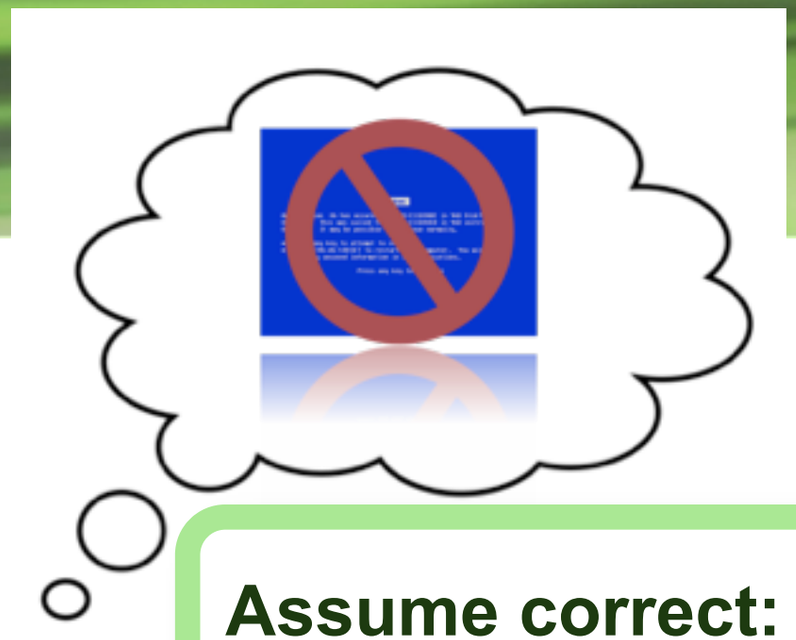
Specification

Proof

Code

Assumptions

*conditions apply



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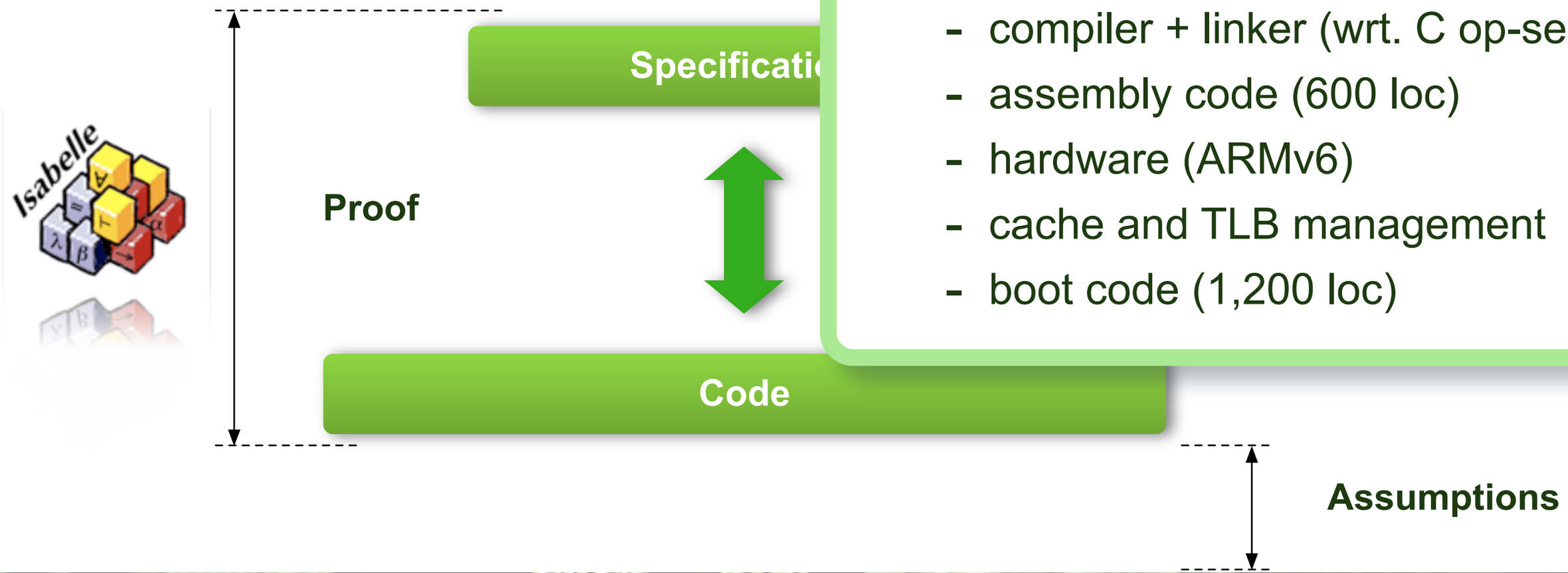

Assume correct:

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

Implications

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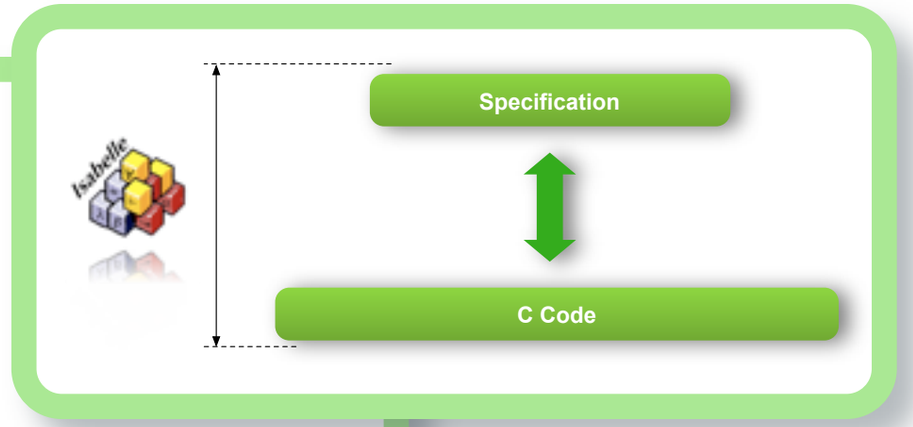


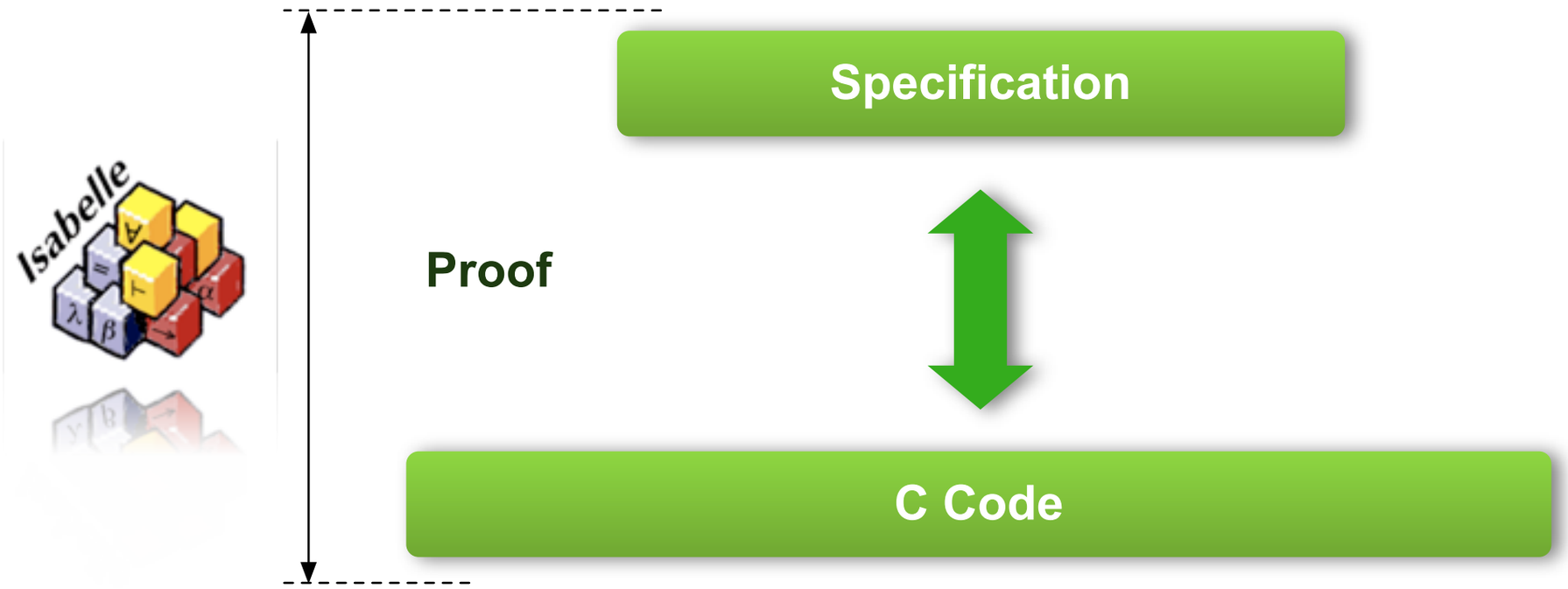
Execution always defined:

- no null pointer de-reference
- no buffer overflows
- no code injection
- no memory leaks/out of kernel memory
- no div by zero, no undefined shift
- no undefined execution
- no infinite loops/recursion

Not implied:

- “secure” (define secure)
- zero bugs from expectation to physical world
- covert channel analysis

Proof Architecture



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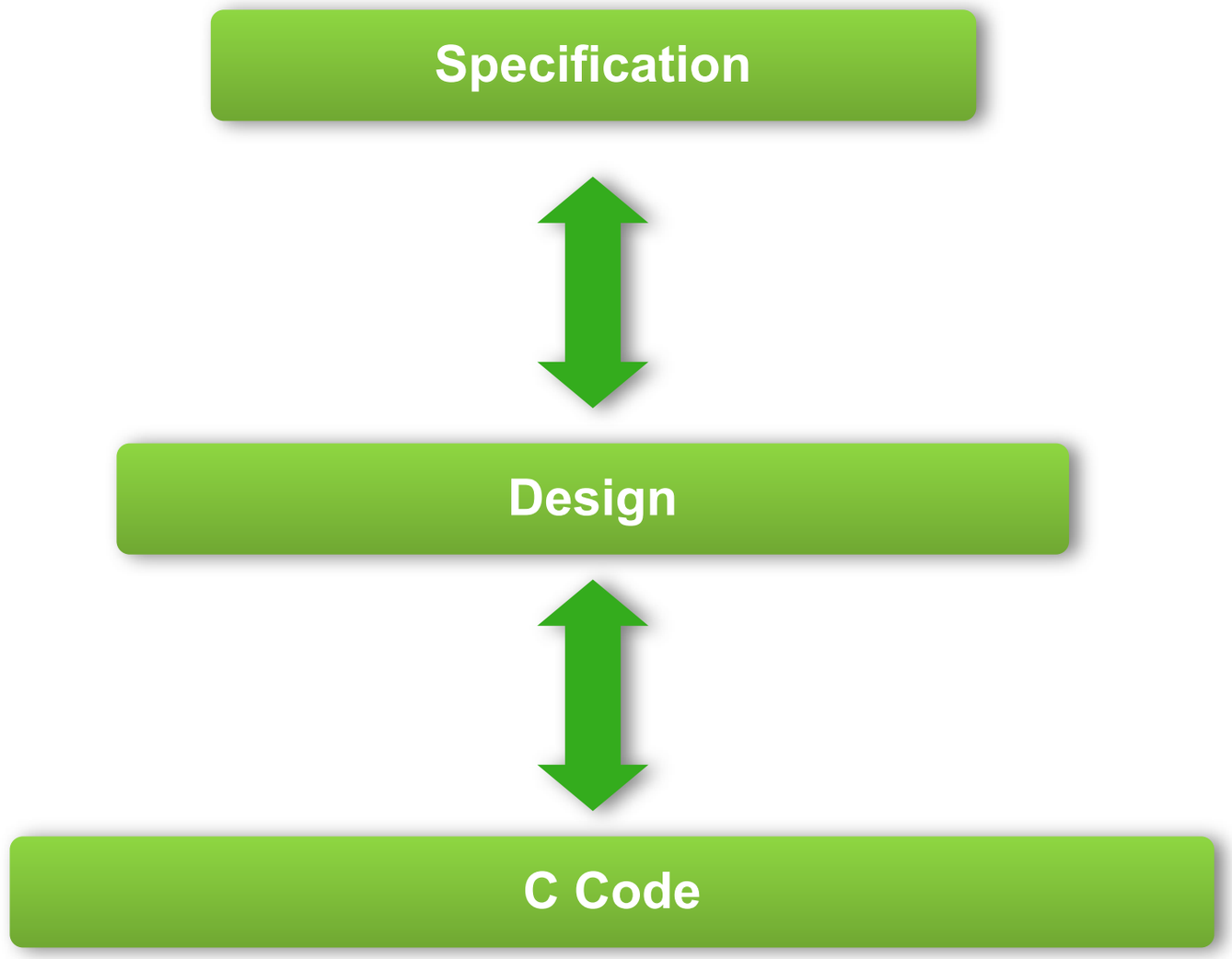

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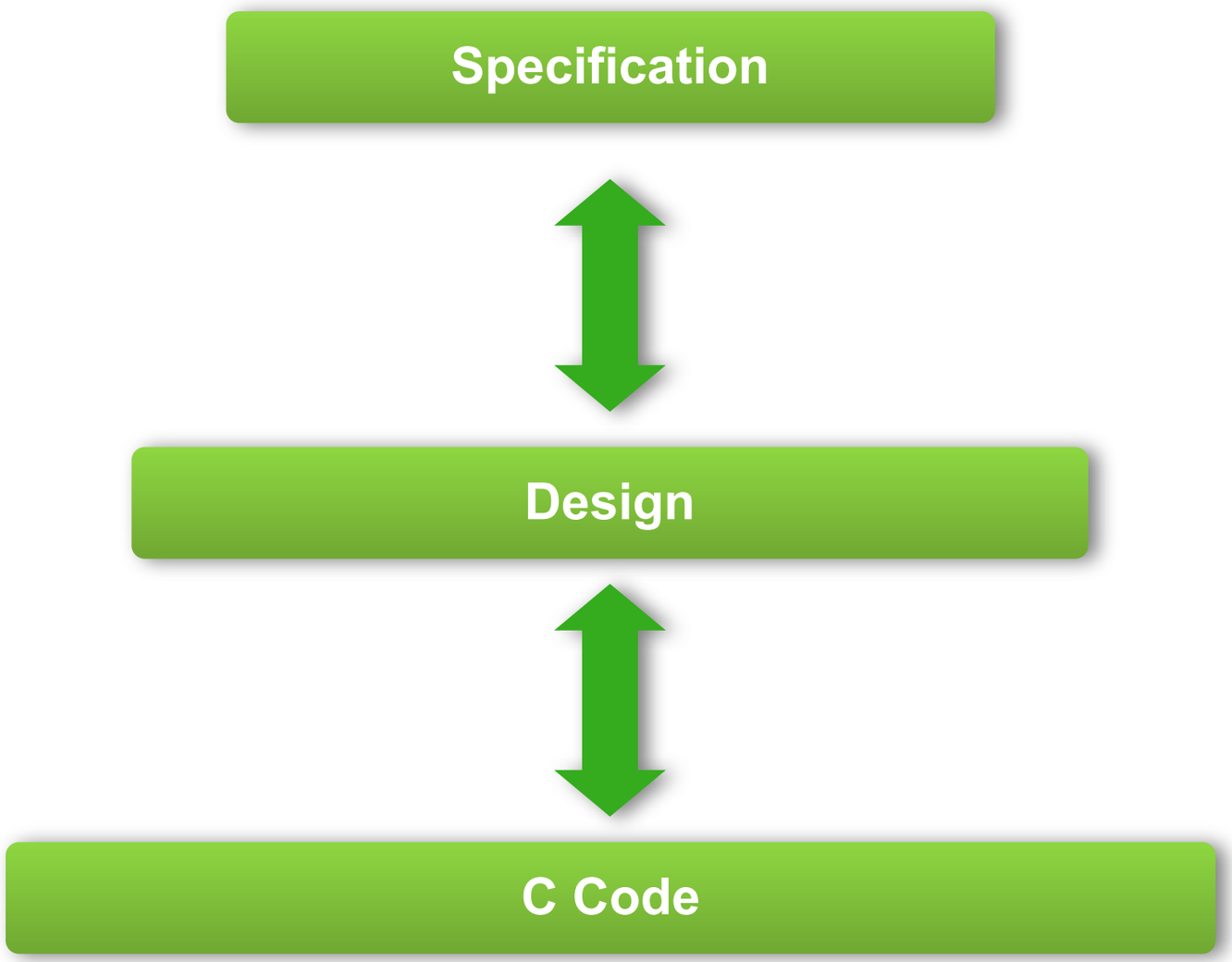

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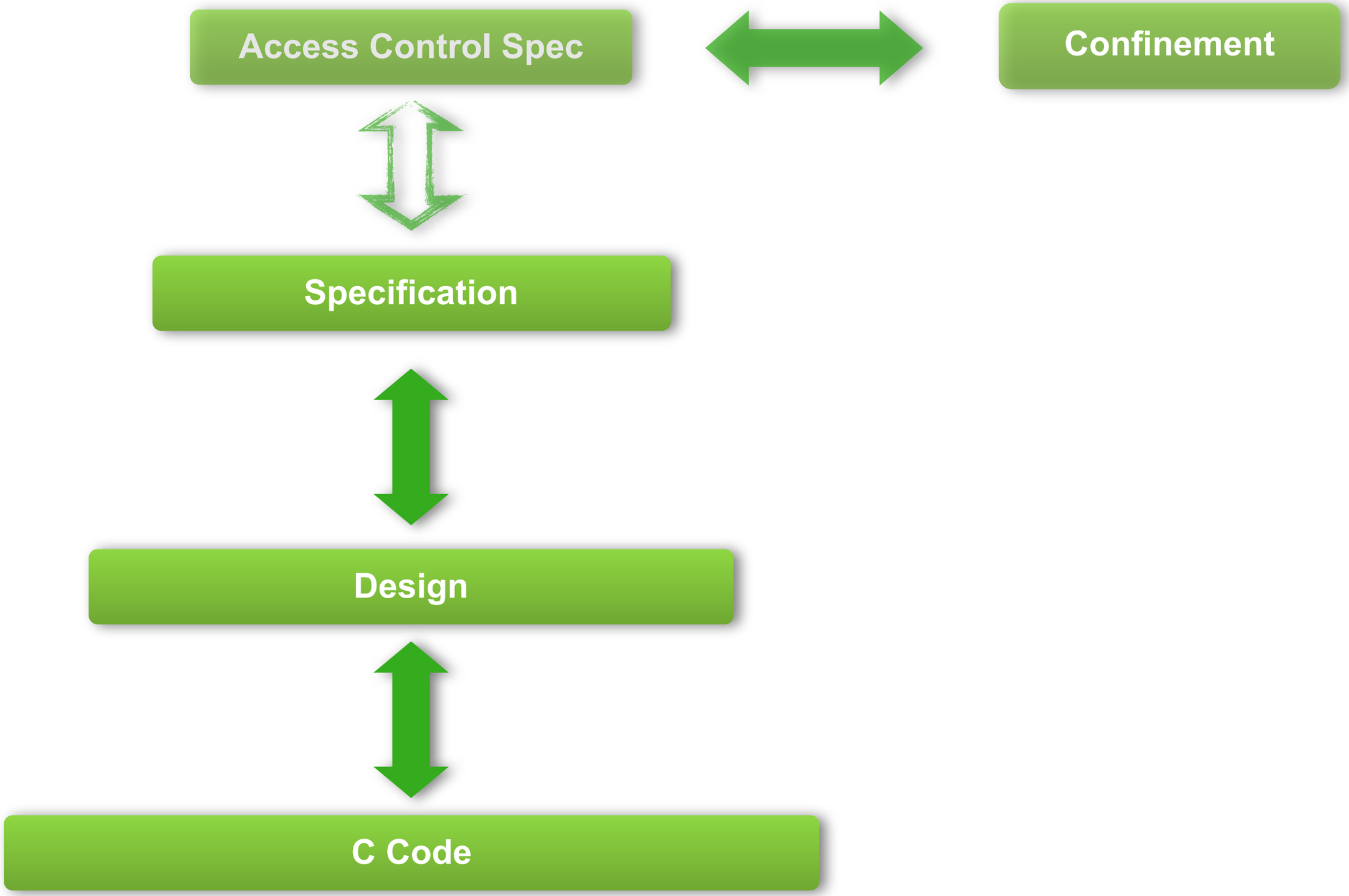

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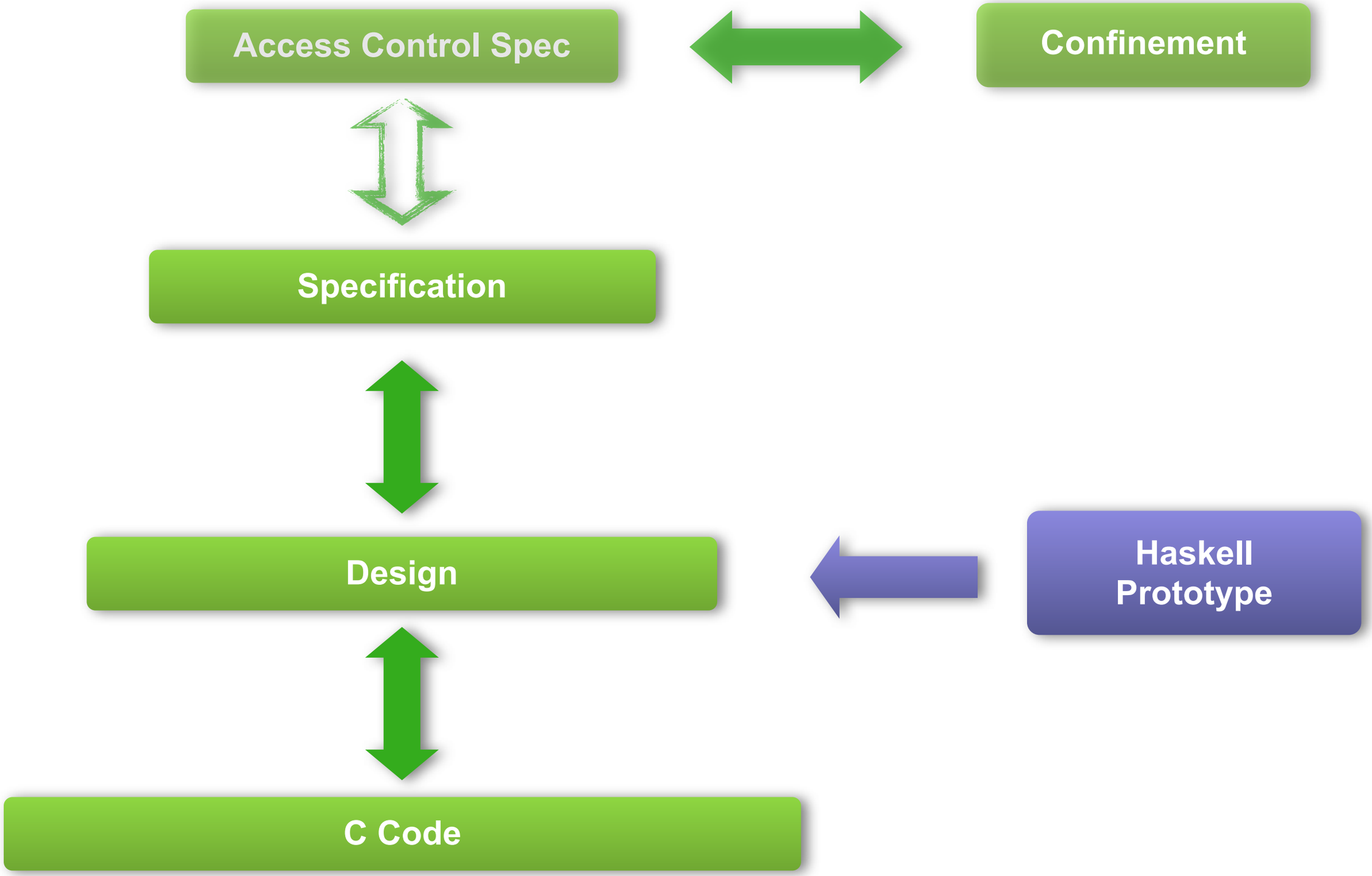

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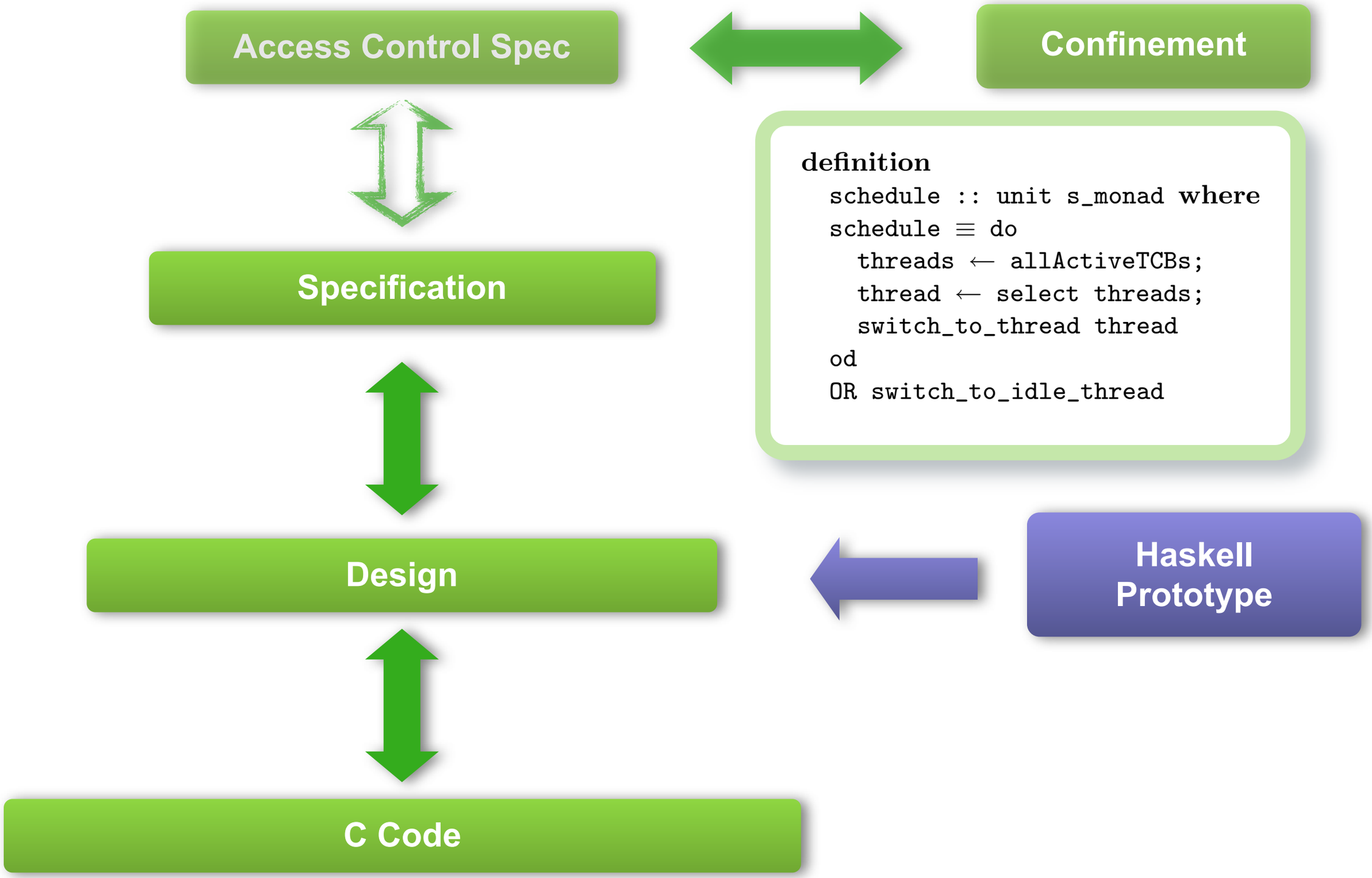


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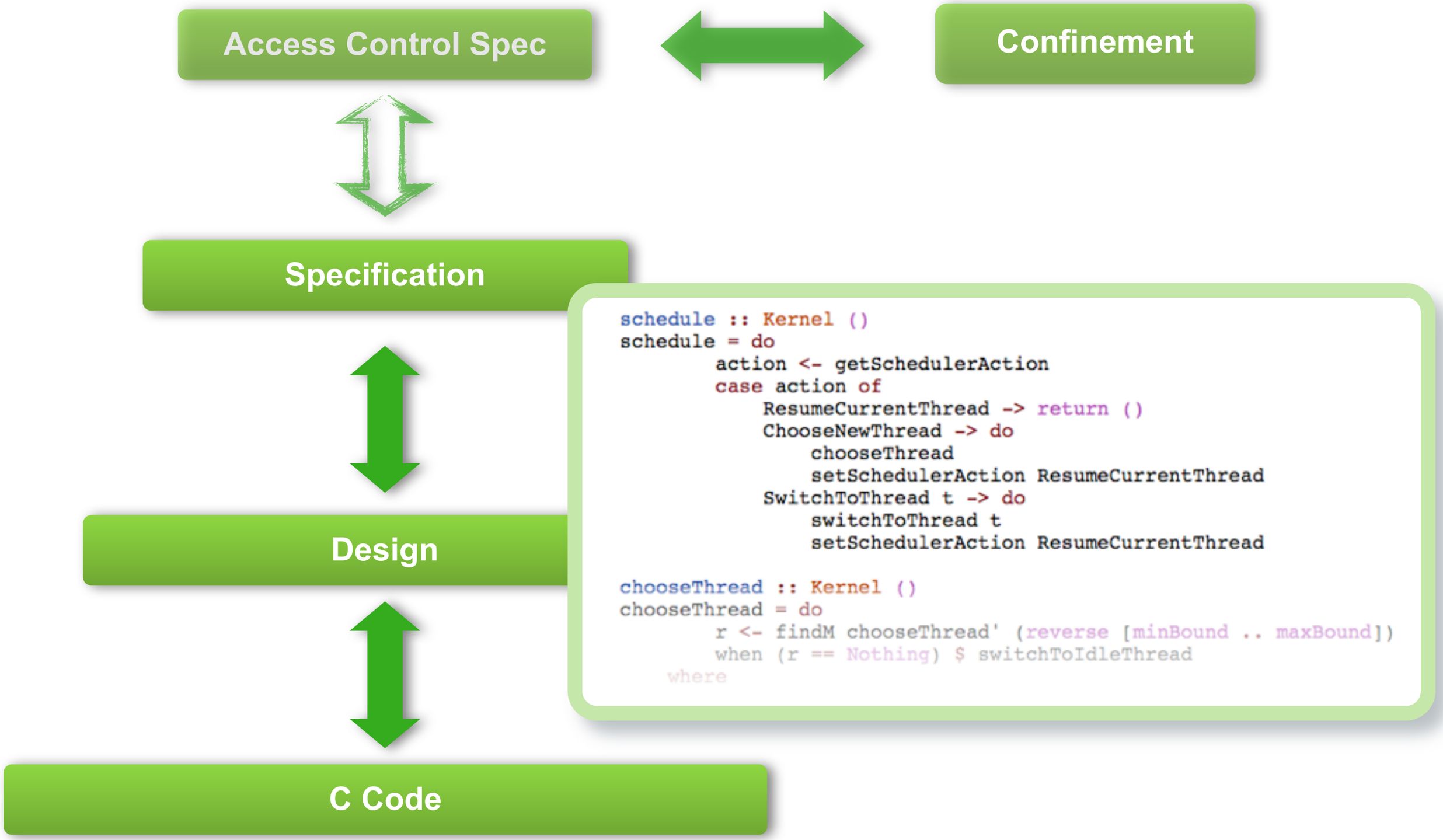

Proof Architecture

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Access Control Spec

Confinement

Specification

Design

C Code

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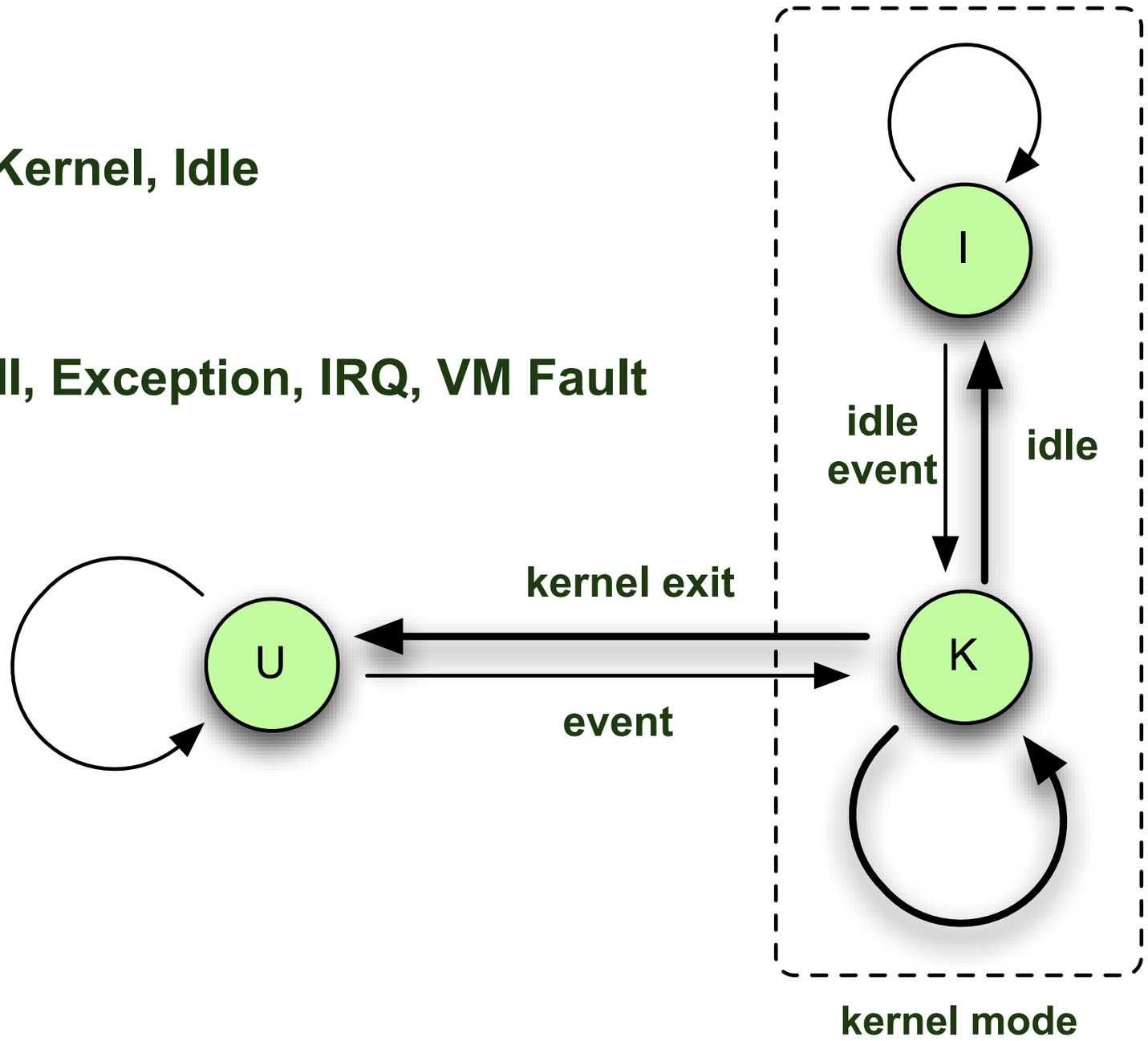
System Model

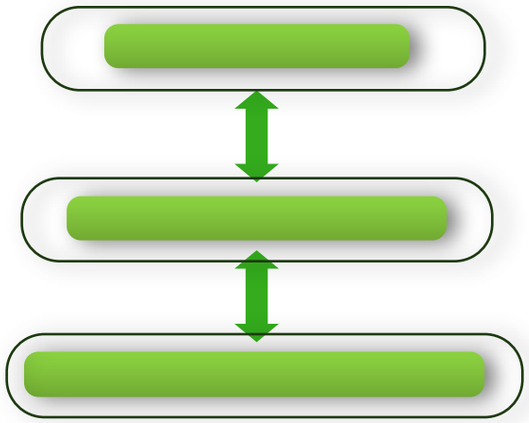
States:

User, Kernel, Idle

Events:

Syscall, Exception, IRQ, VM Fault





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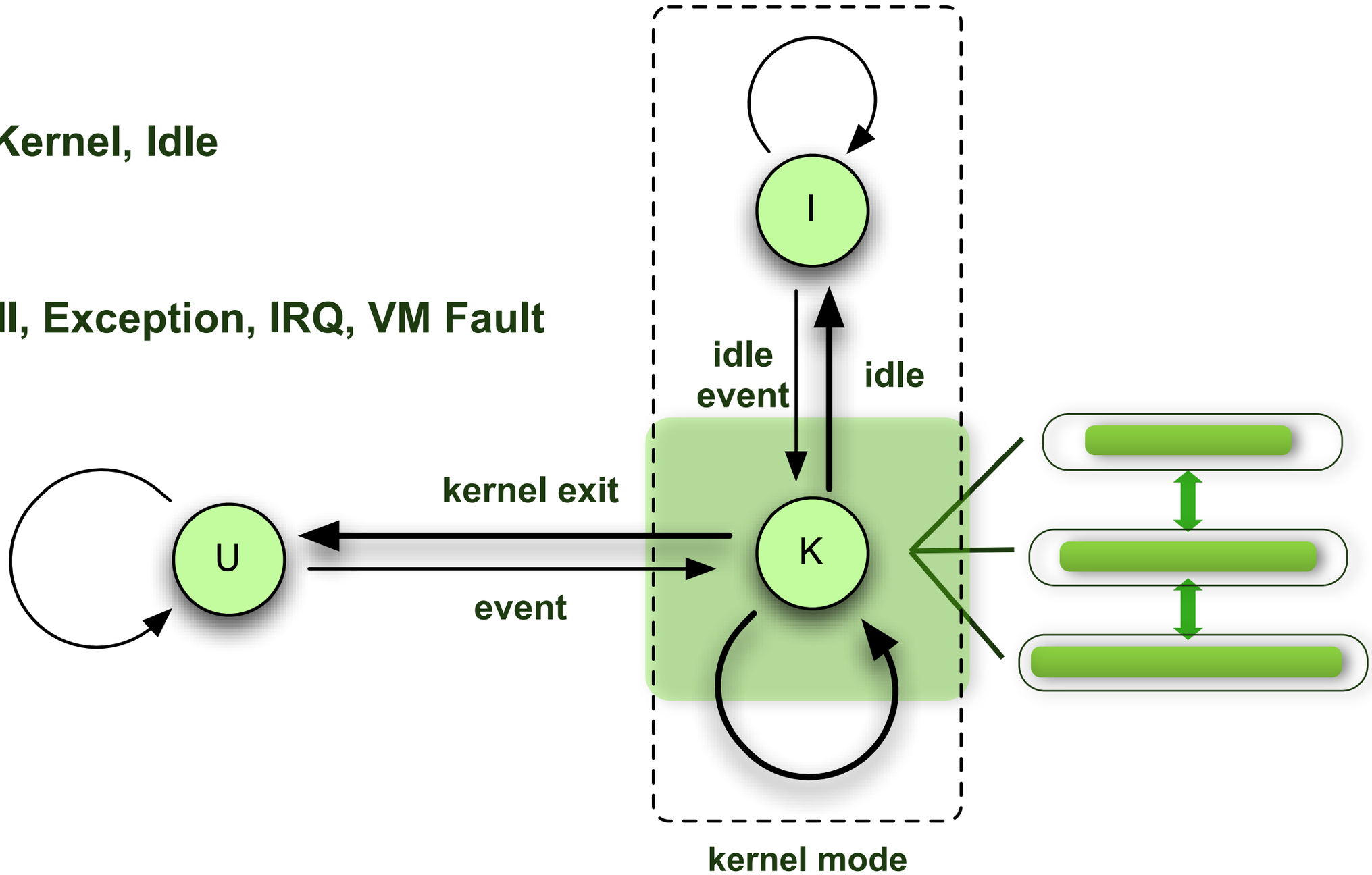

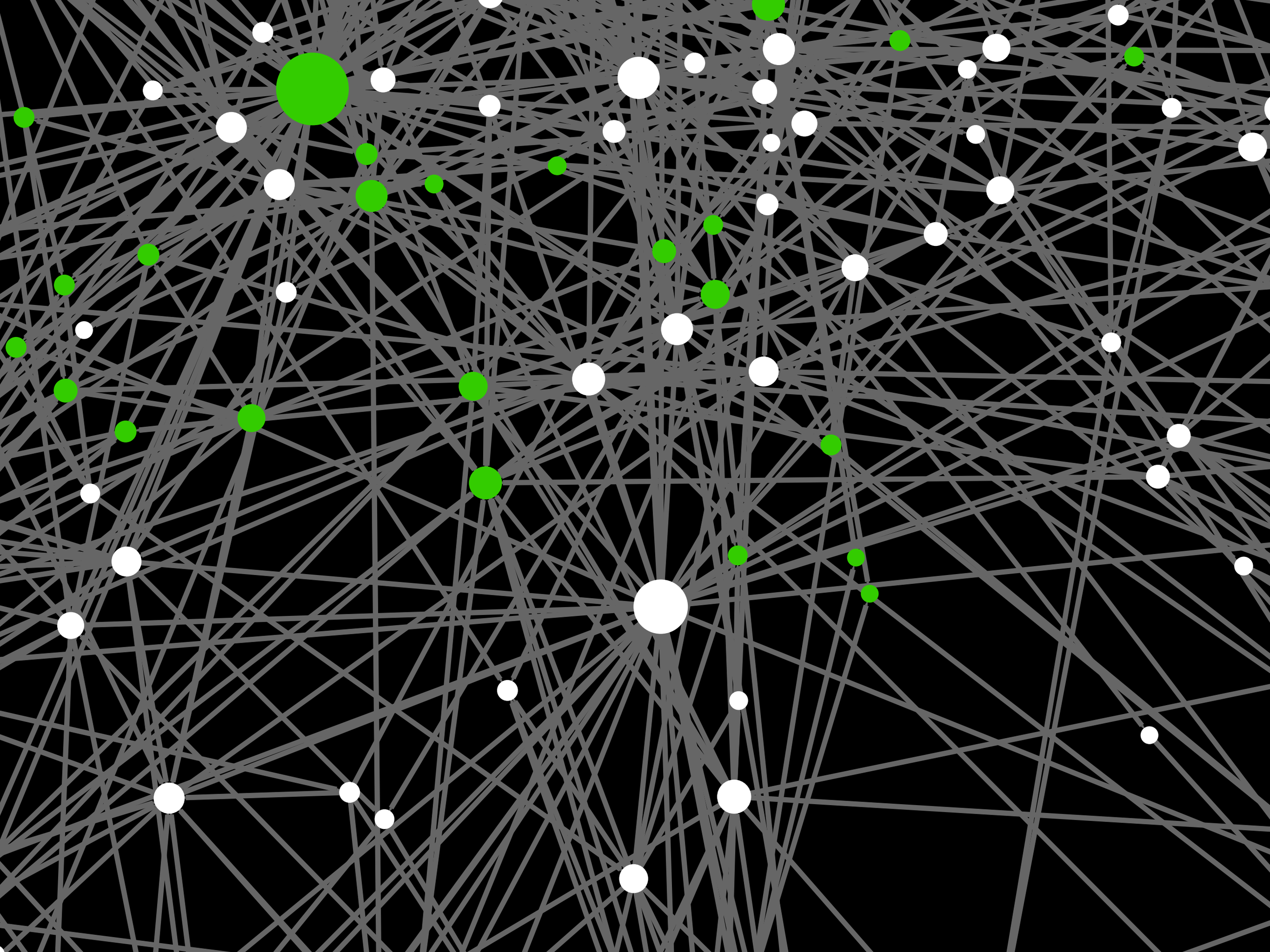

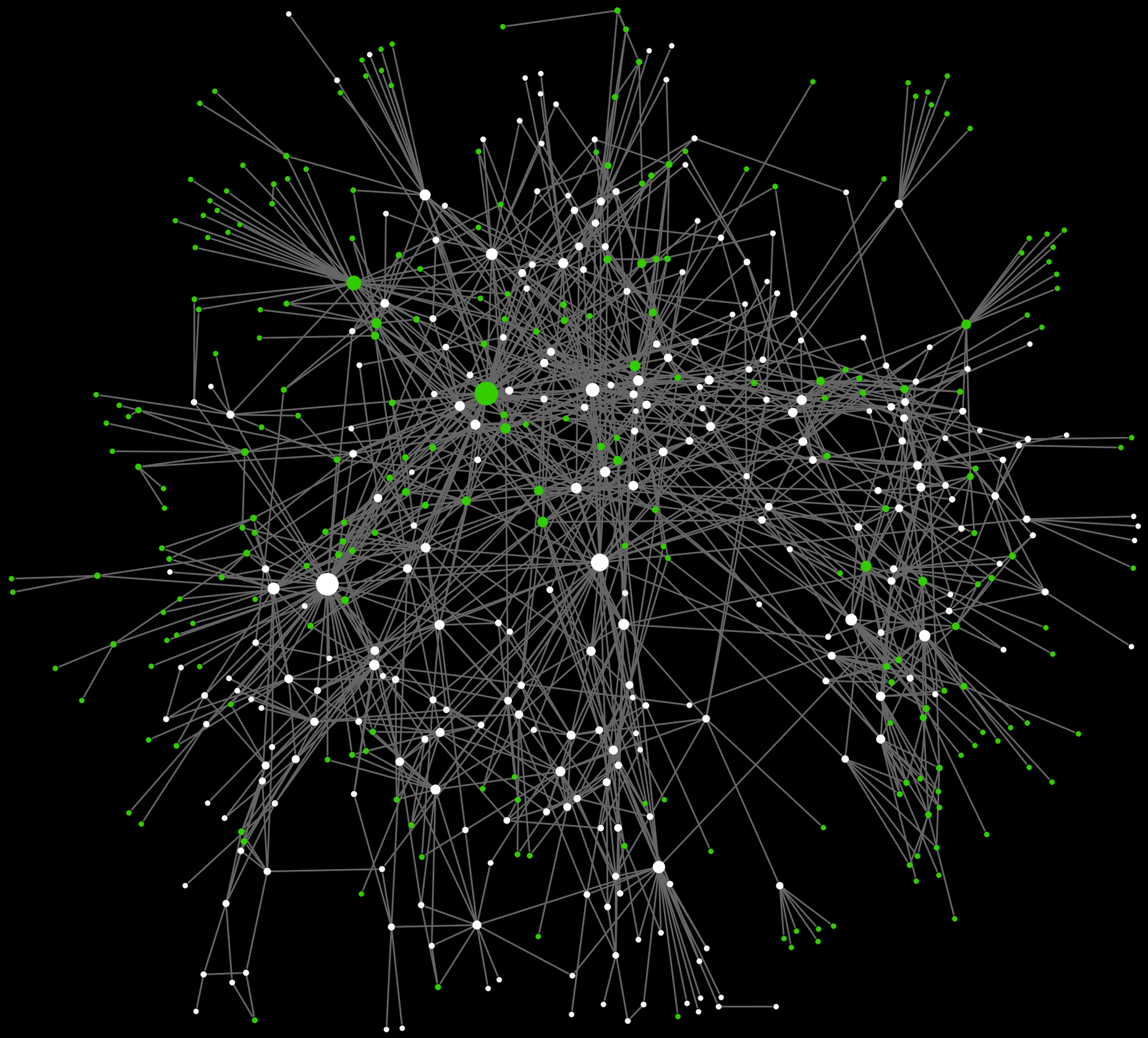

seL4

Kernel Design for Verification

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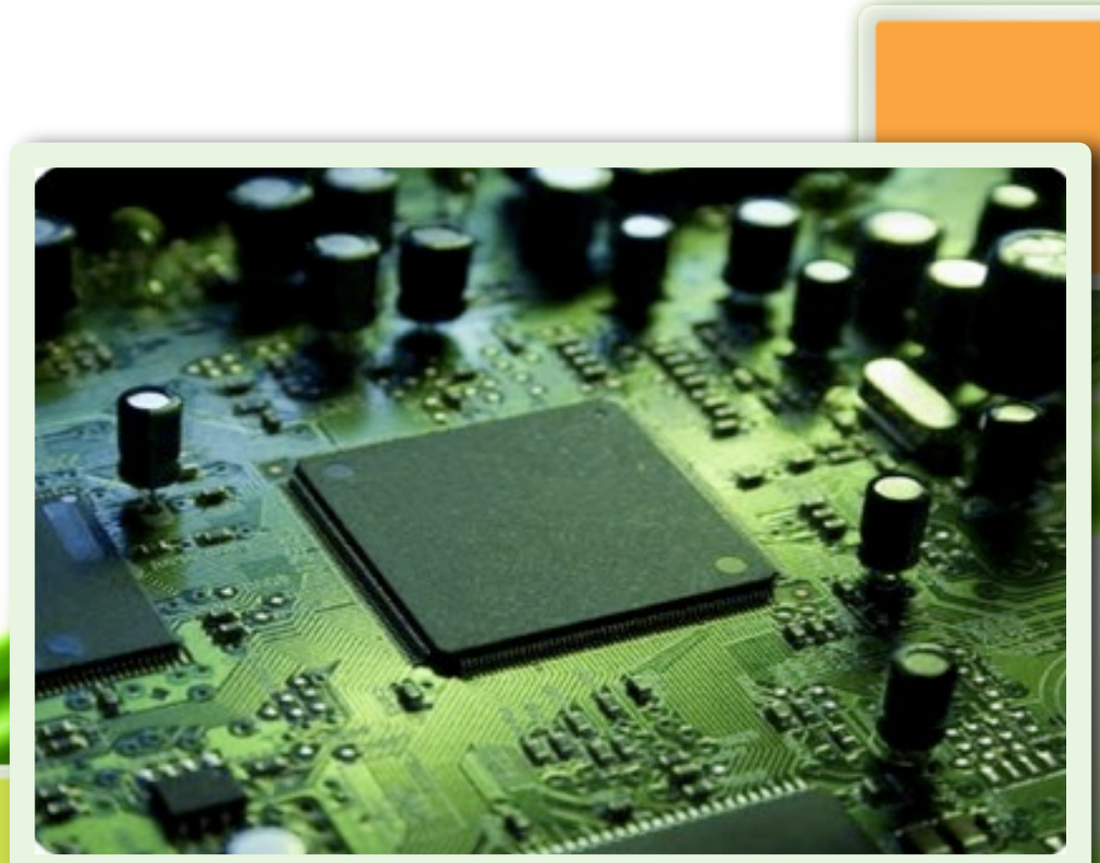

Two Teams

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Formal Methods Practitioners

Kernel Developers

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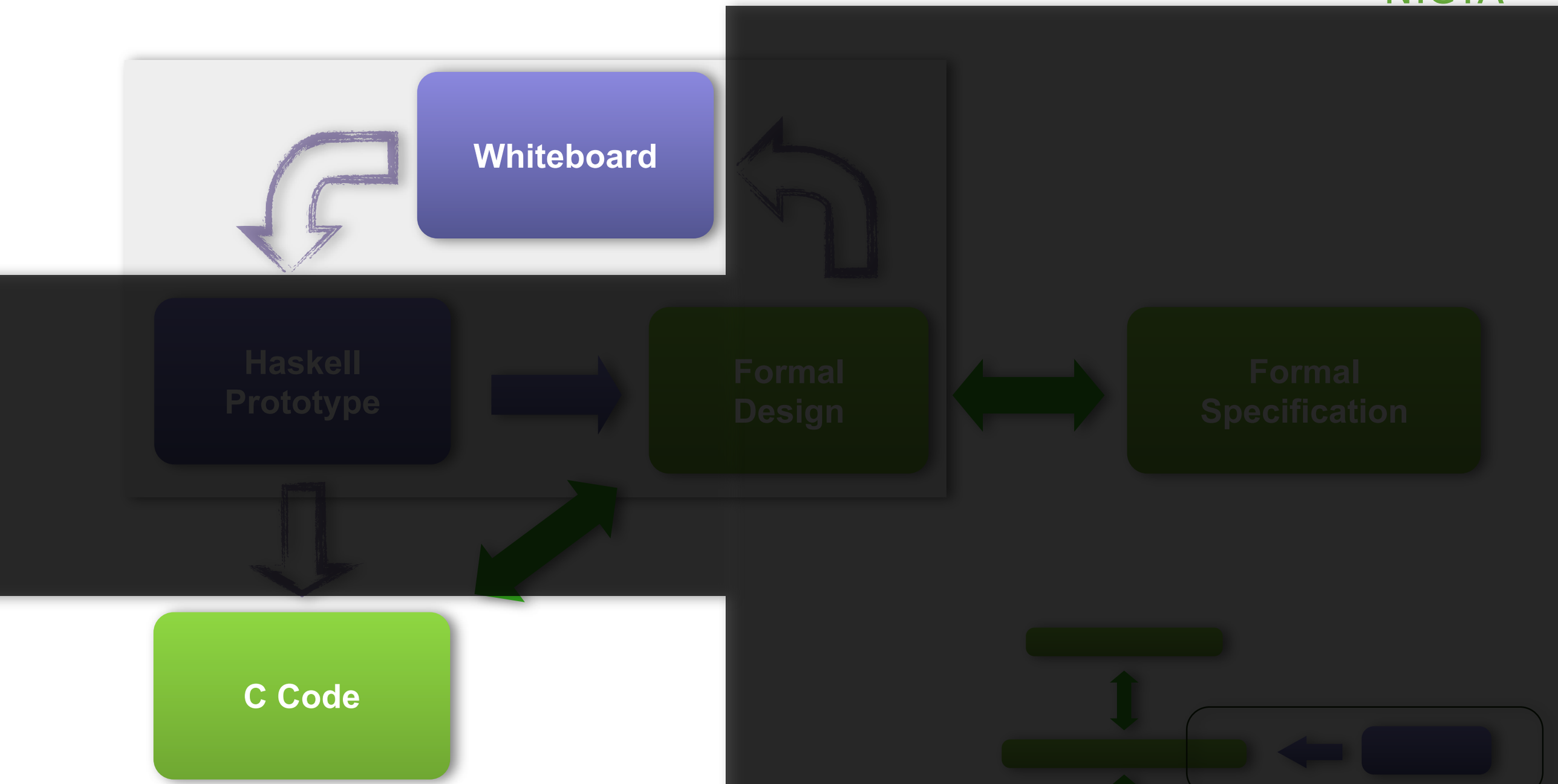
The Power of Abstraction

(Liskov 09)

Exterminate All OS Abstractions!

(Engler 95)

Iterative Design and Formalisation



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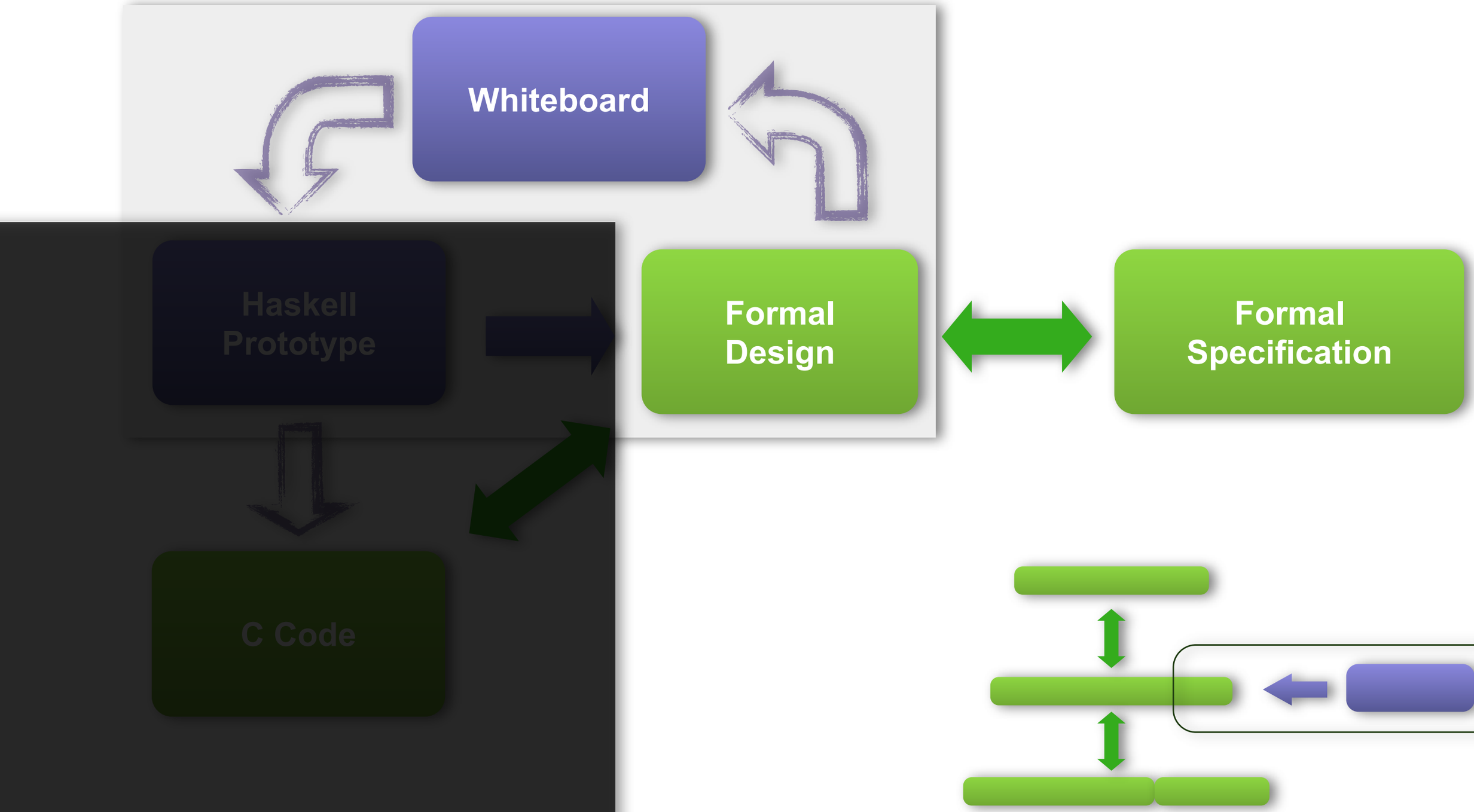

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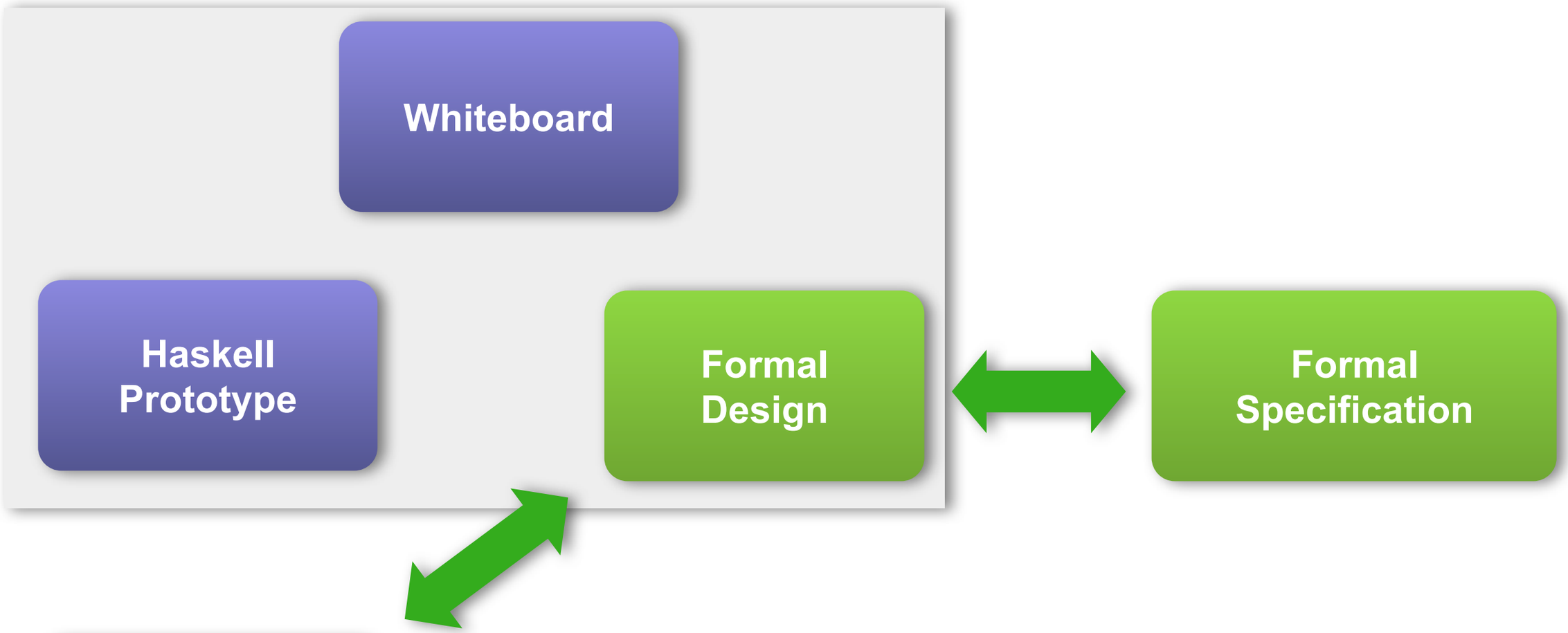

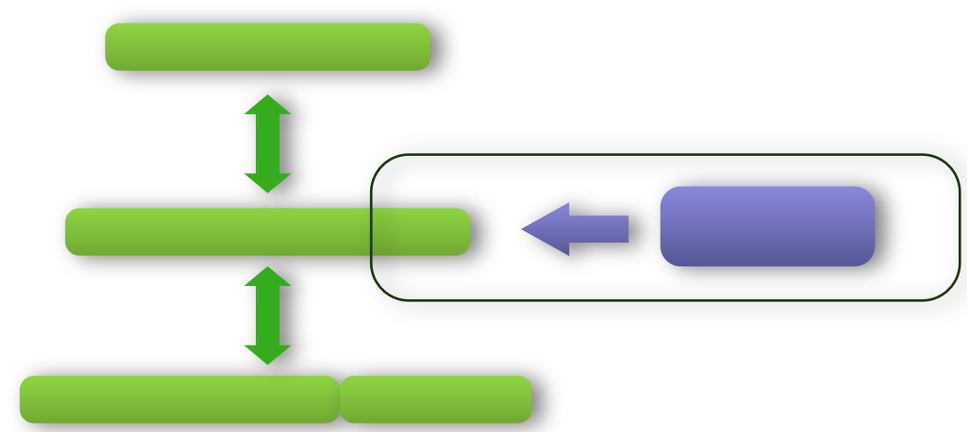

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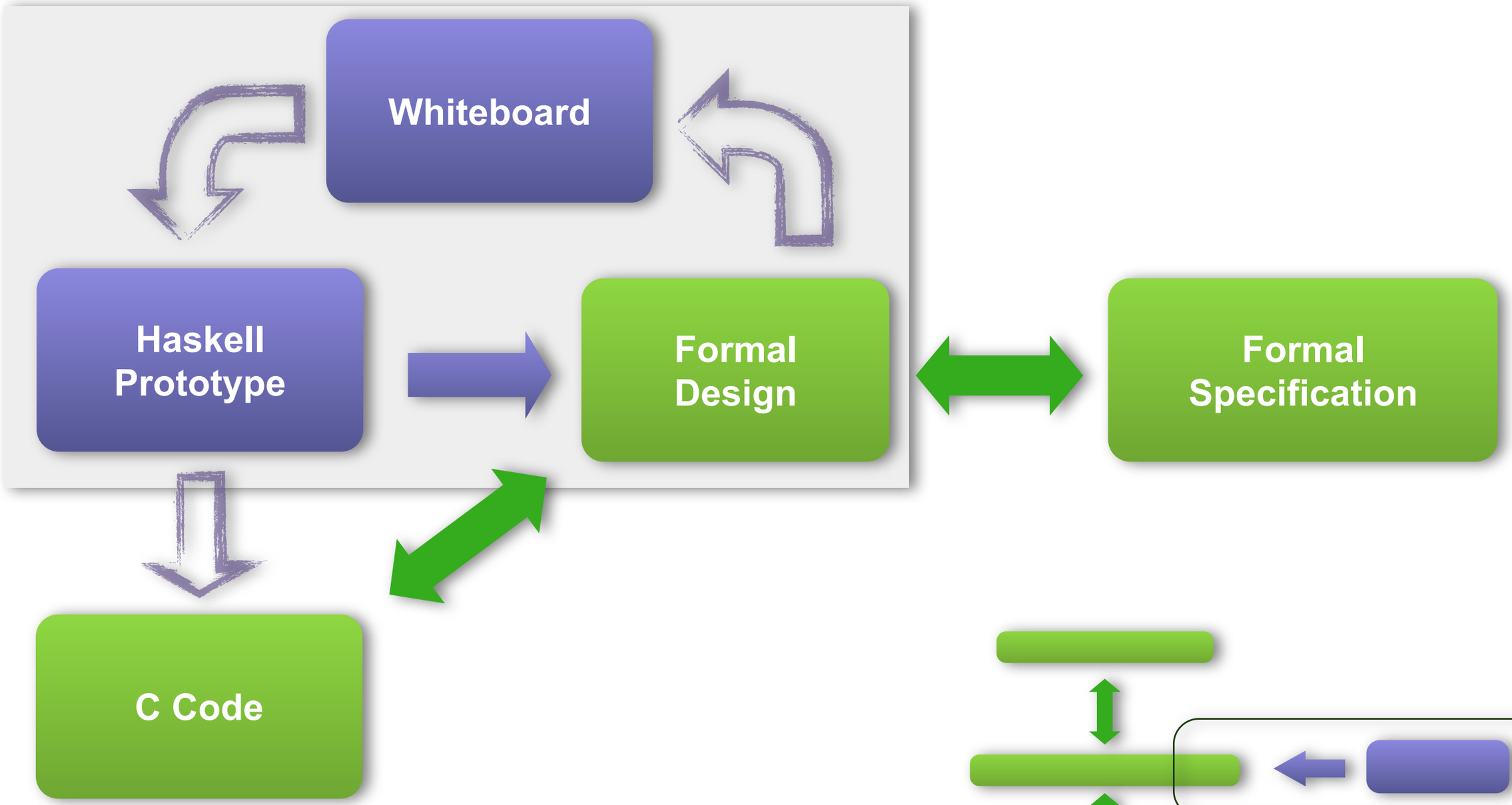

Design for Verification

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Reducing Complexity

Hardware

- drivers outside kernel

Concurrency

- event based kernel
- limit preemption

Code

- derive from functional representation

C subset

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Everything from C standard

- **including**:
  - pointers, casts, pointer arithmetic
  - data types
  - structs, padding
  - pointers into structs
  - precise finite integer arithmetic

- **minus:**
  - goto, switch fall-through
  - reference to local variable
  - side-effects in expressions
  - function pointers (restricted)
  - unions

- **plus** compiler assumptions on:
  - data layout, encoding, endianess

Did you find any Bugs?

NICTA

Bugs found

during testing: 16

during verification:

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

460 bugs

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

Cost

Common Criteria EAL6:	**$87M**
L4.verified:	**$6M**

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Summary

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Formal proof all the way from spec to C.

- **200kloc** handwritten, machine-checked proof
- **~460** bugs (160 in C)
- Verification on **code**, **design**, and **spec**
- **Hard in the proof** ➡ **Hard in the implementation**

Formal Code Verification up to 10kloc:

It works.
It's feasible.
It's cheaper.

(It's fun, too.
And we're hiring..)

Thank You

Thank You