Adapting to demand

seL4 proofs and engineering practice

Matthew Brecknell | Sep 2020

The impact of history

Microsoft Windows:

- 1981: MS-DOS
- 1985: Windows 1.0
- 1993: Windows NT 3.1
- …
- 2014: Windows 10

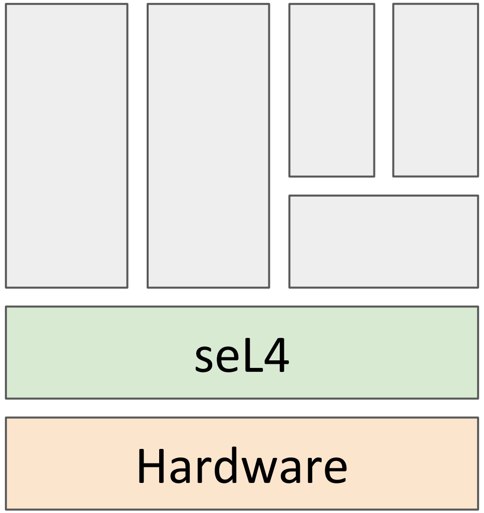
How is this possible?

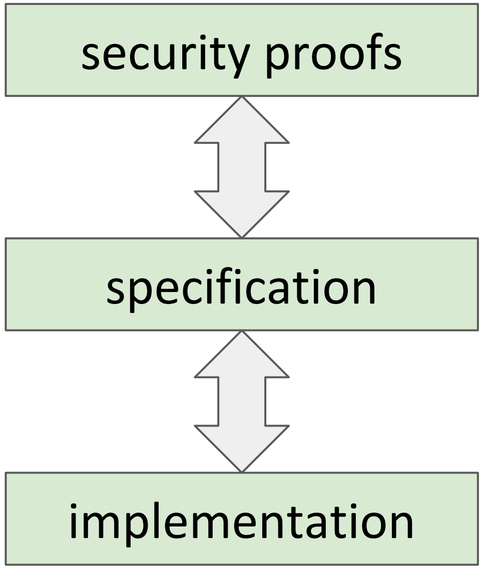
What were the challenges?

Today’s talk

- Current challenges in seL4 proof engineering
- History and its impact
- What we’re doing with those challenges

What is seL4?


seL4
Hardware


security proofs
specification
implementation

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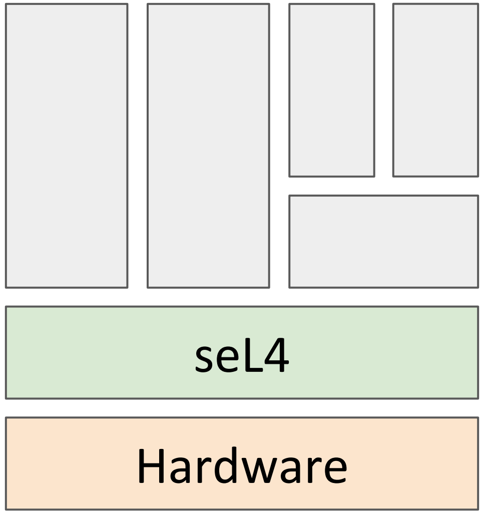
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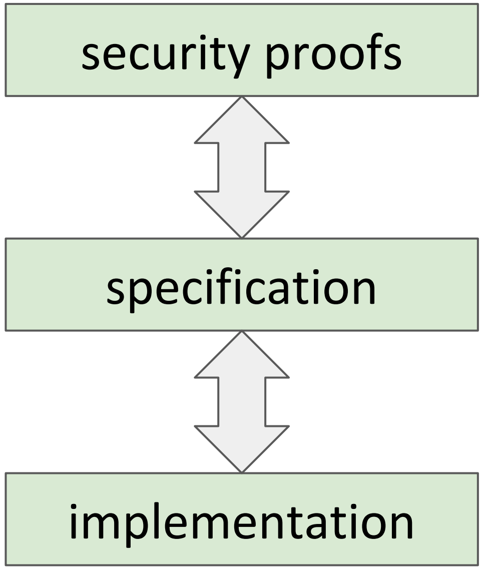
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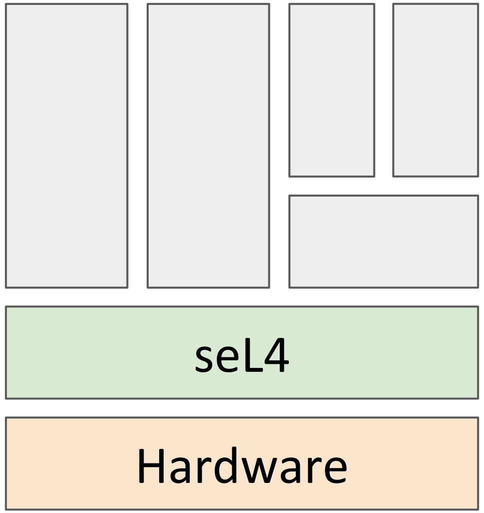
seL4
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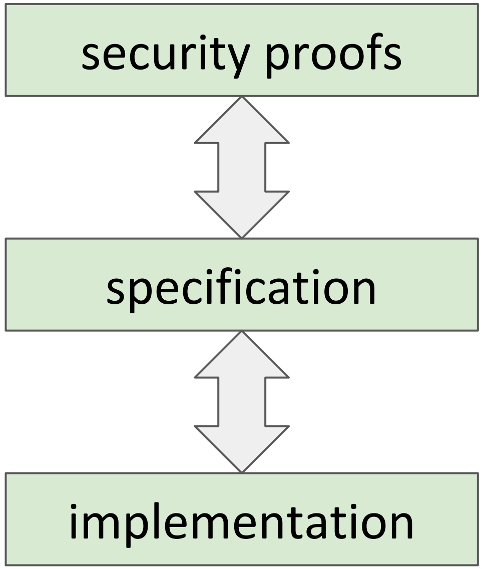
security proofs
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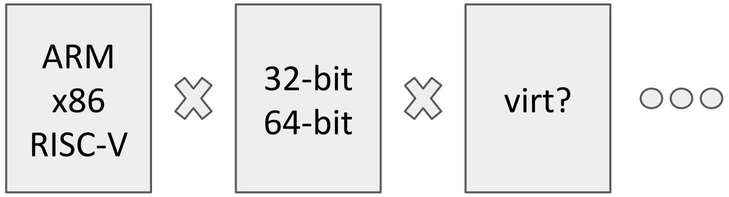
Current challenges in seL4 verification

Research and development

- Multicore
- Time
  - Integrity: mixed-criticality real time
  - Confidentiality: timing channels

Engineering practice

- Achieving agility
- Matrix problem



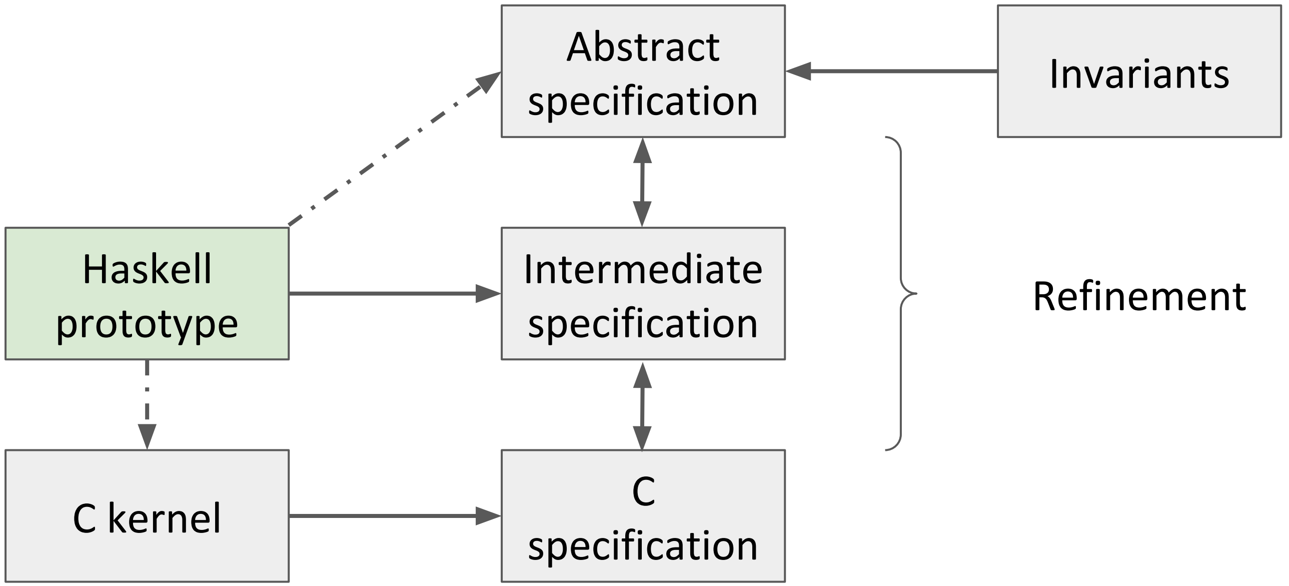
The impact of history (seL4 edition)

- Our proof architecture reflects our initial prototype.
  - Artefacts become overheads.

- In the beginning, we had to limit scope.
  - The priority was getting something done.

- We knew less then than we know now.

History: prototype



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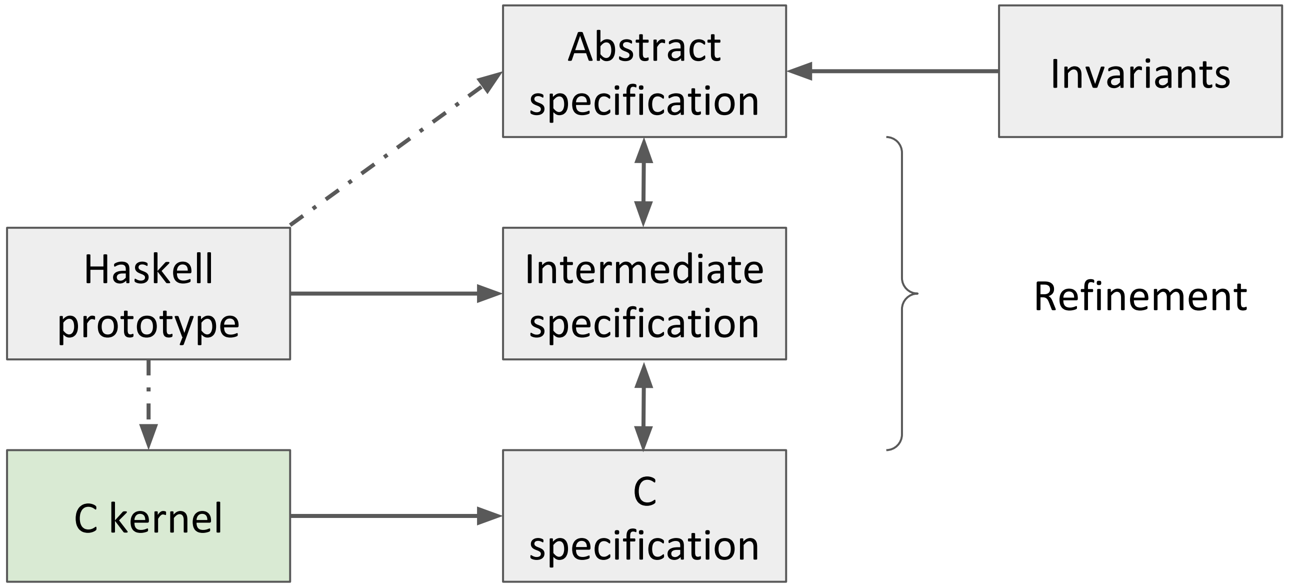

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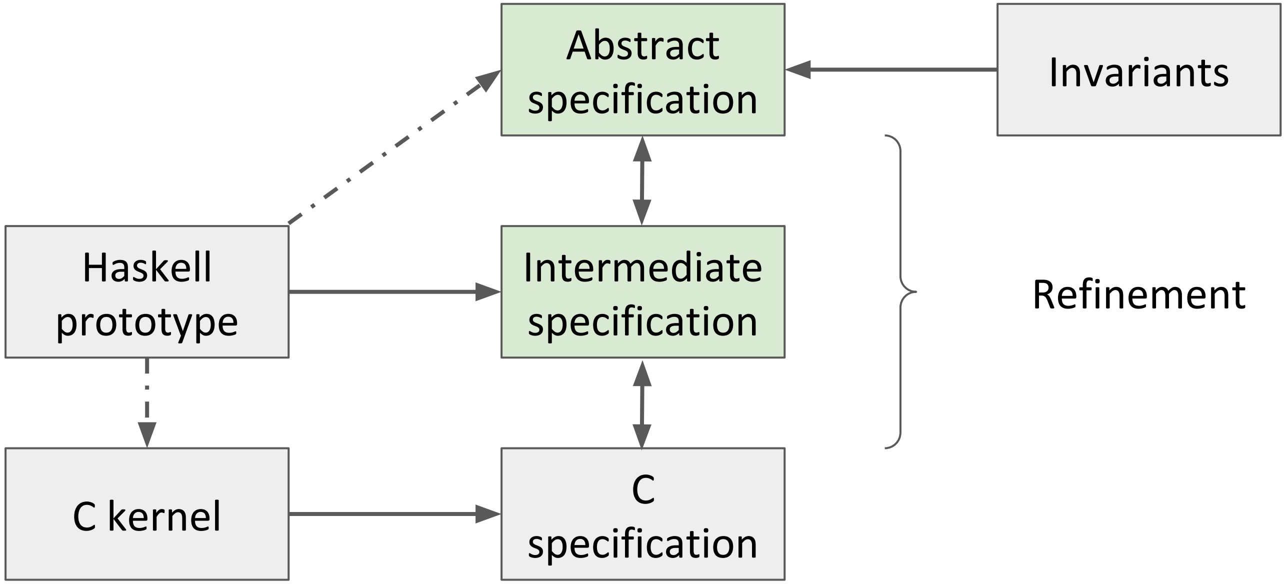

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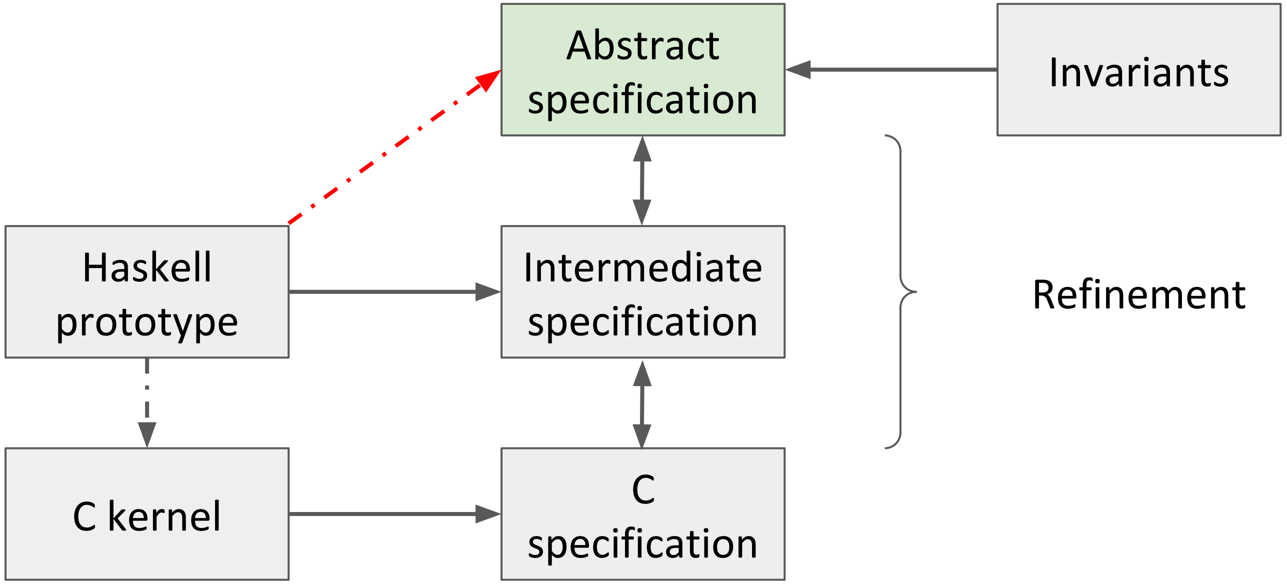

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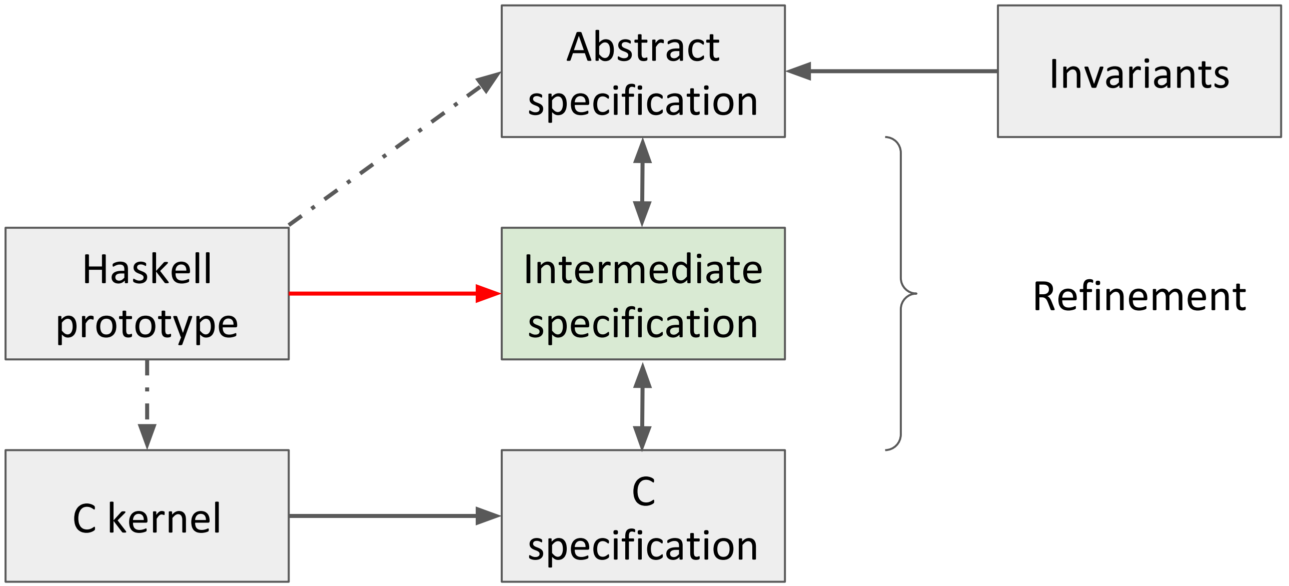

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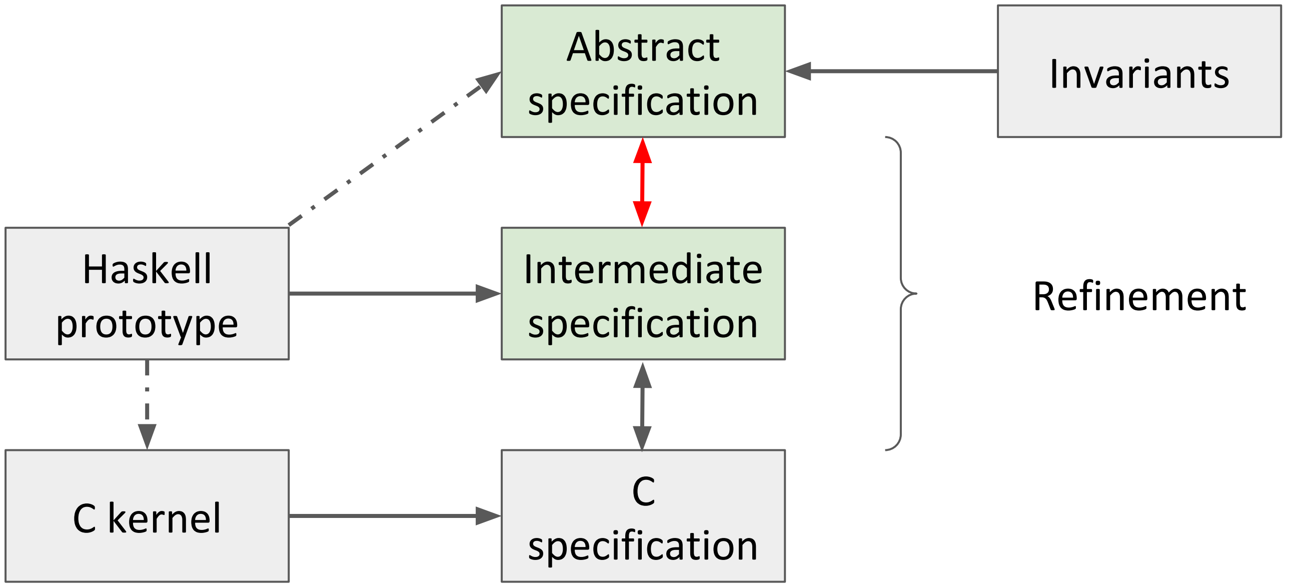

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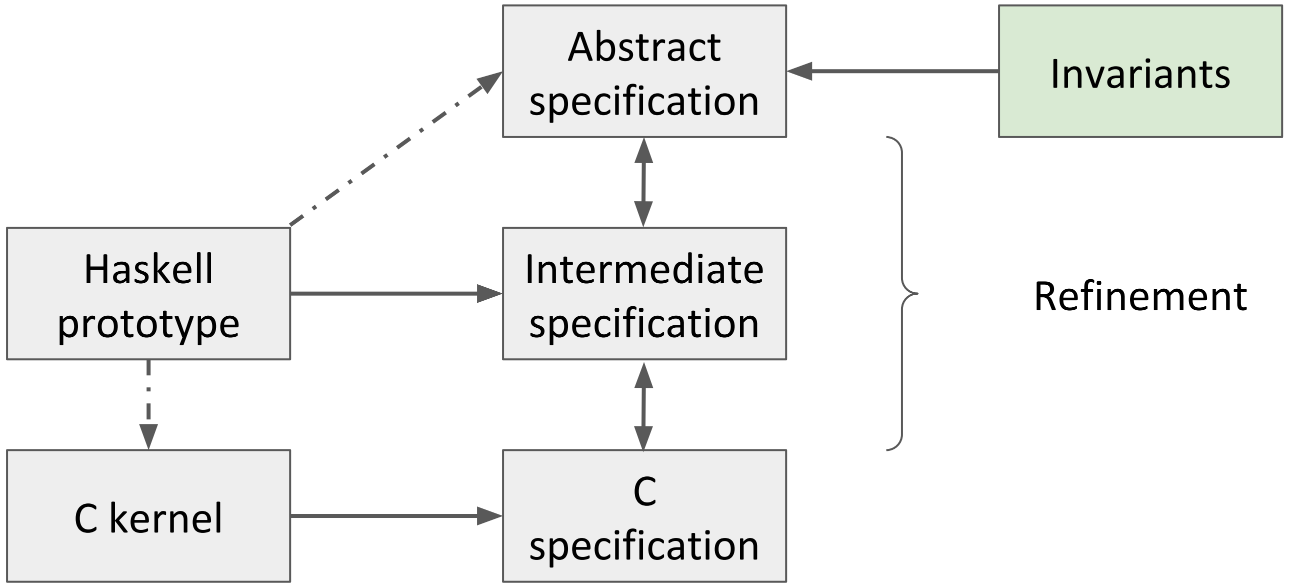

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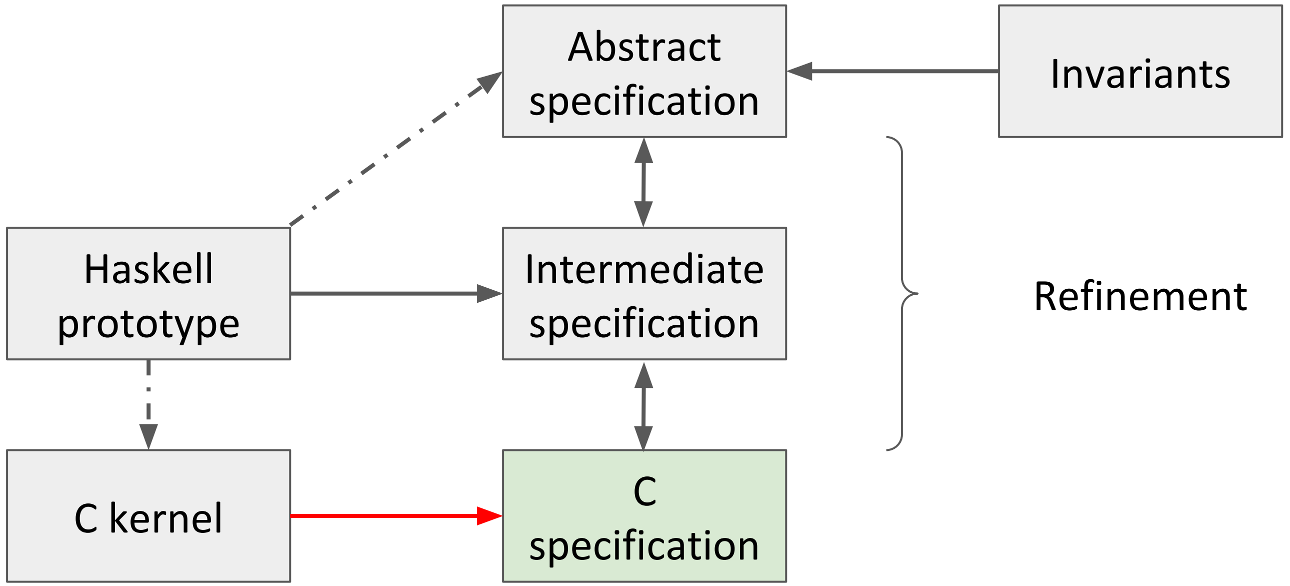

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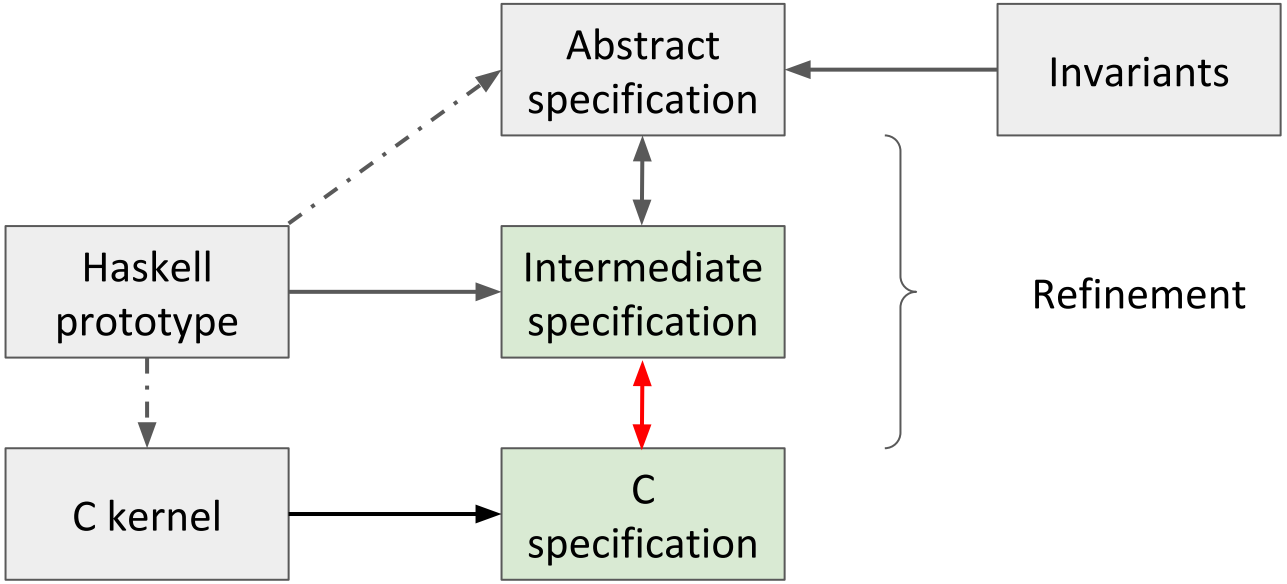

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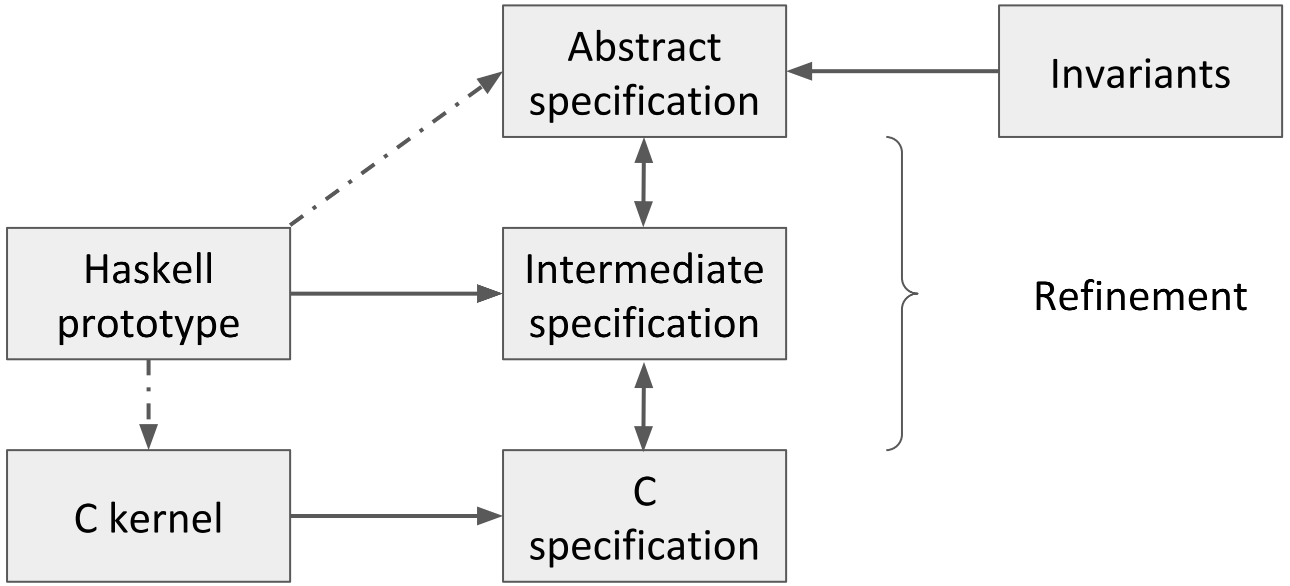


History: prototype

We still have the Haskell!

- But we don’t run it any more.
- Primarily a specification generator.

The upper refinement should be just a data refinement.

- But we spend time on artefacts of the prototype.

History: prototype

What to do?

- Get rid of the Haskell! Eventually.
- Increase sharing between the abstract and intermediate specifications.

History: scope

Originally:

- One instruction set architecture (ARMv7).
- One mode (32-bit).
- One platform configuration.
- One core.

History: architecture split

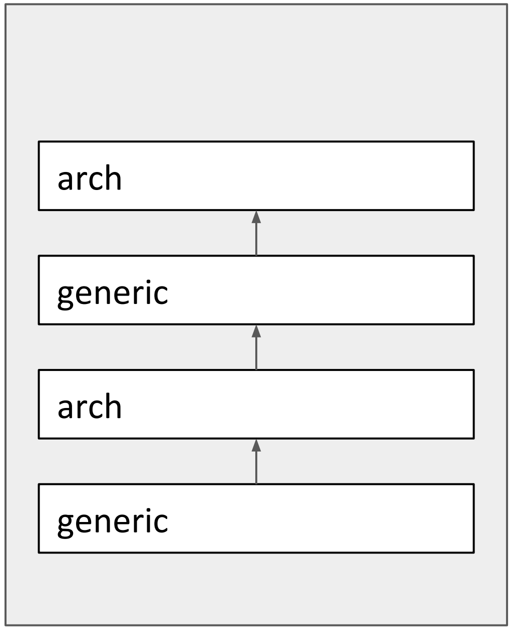
Haskell prototype
C kernel
Abstract specification
Property definitions

Conventional separation of generic and arch-specific aspects (even though only one configuration)

Virtual memory structures $\longrightarrow$ arch
Everything else (threads, IPC) $\longrightarrow$ generic

What about the proofs?

History: architecture split

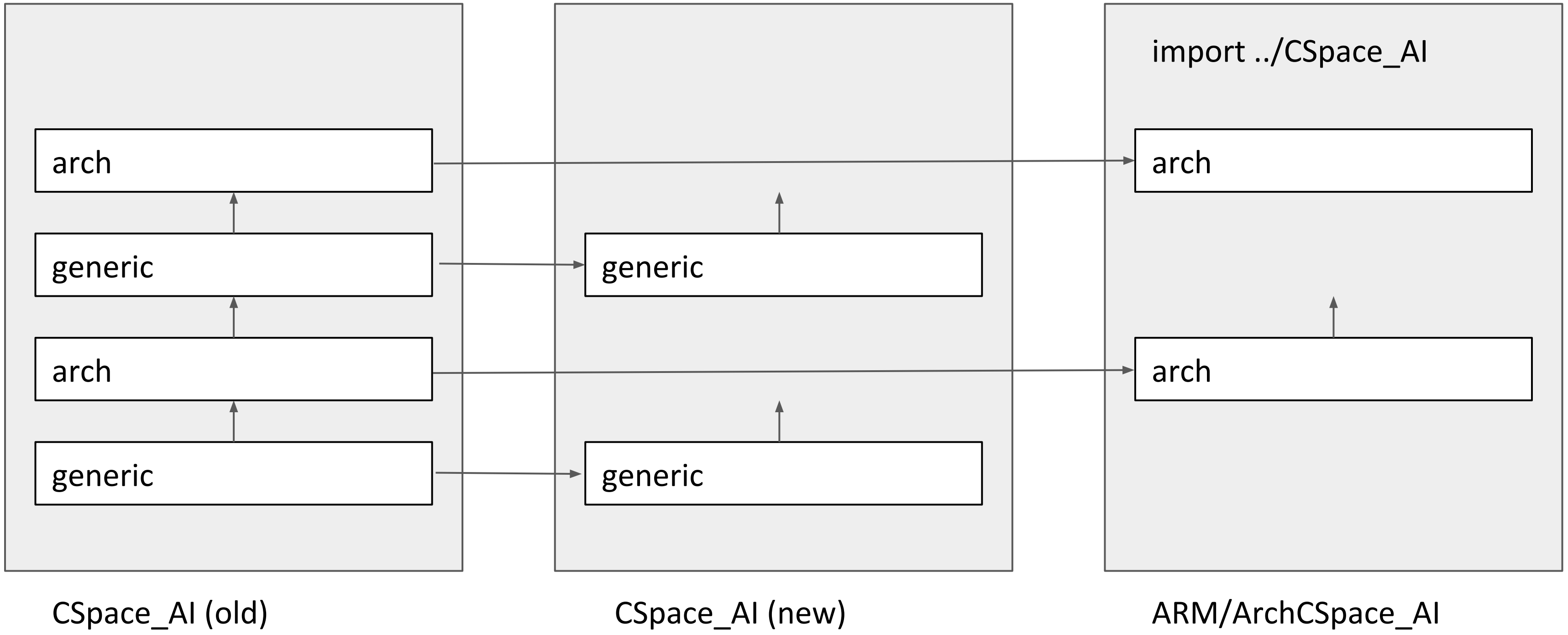


CSpace_AI (old)

Proofs were very interdependent.

Challenge: verify more configurations (hypervisor, x86-64, RISC-V)

History: architecture split



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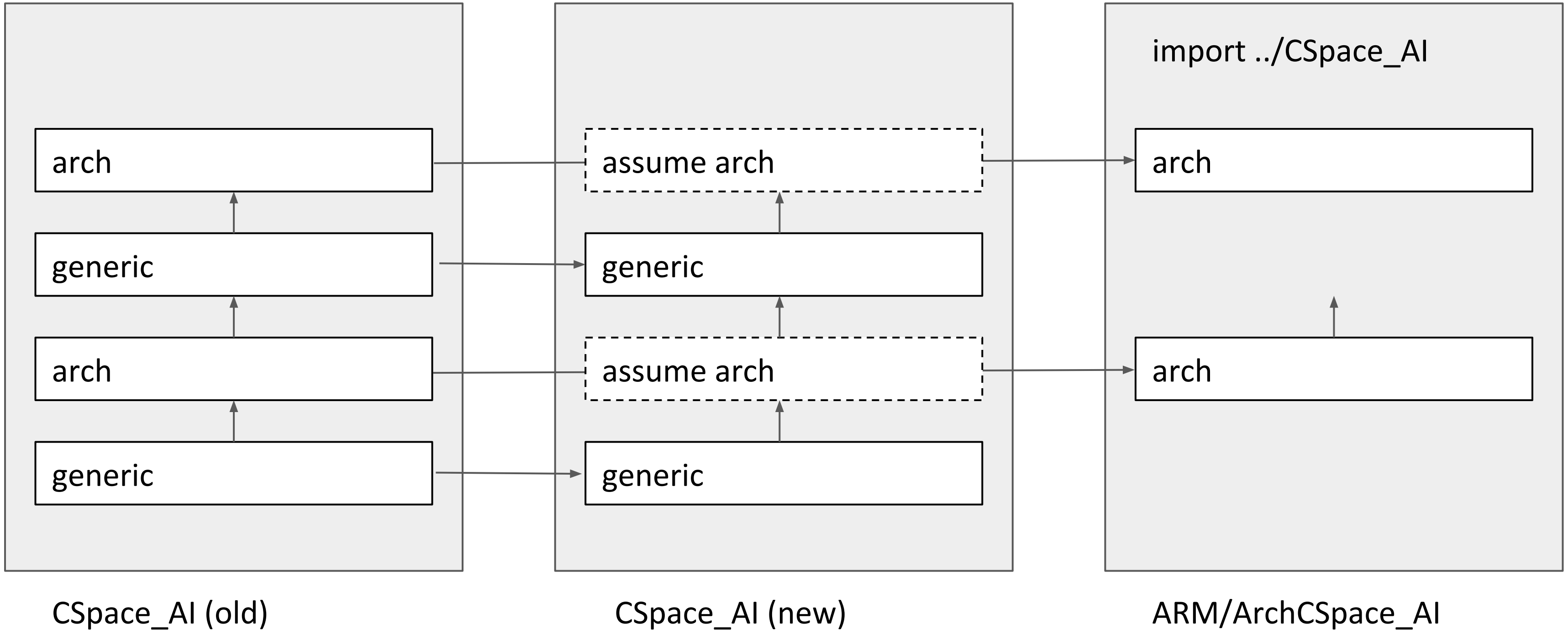

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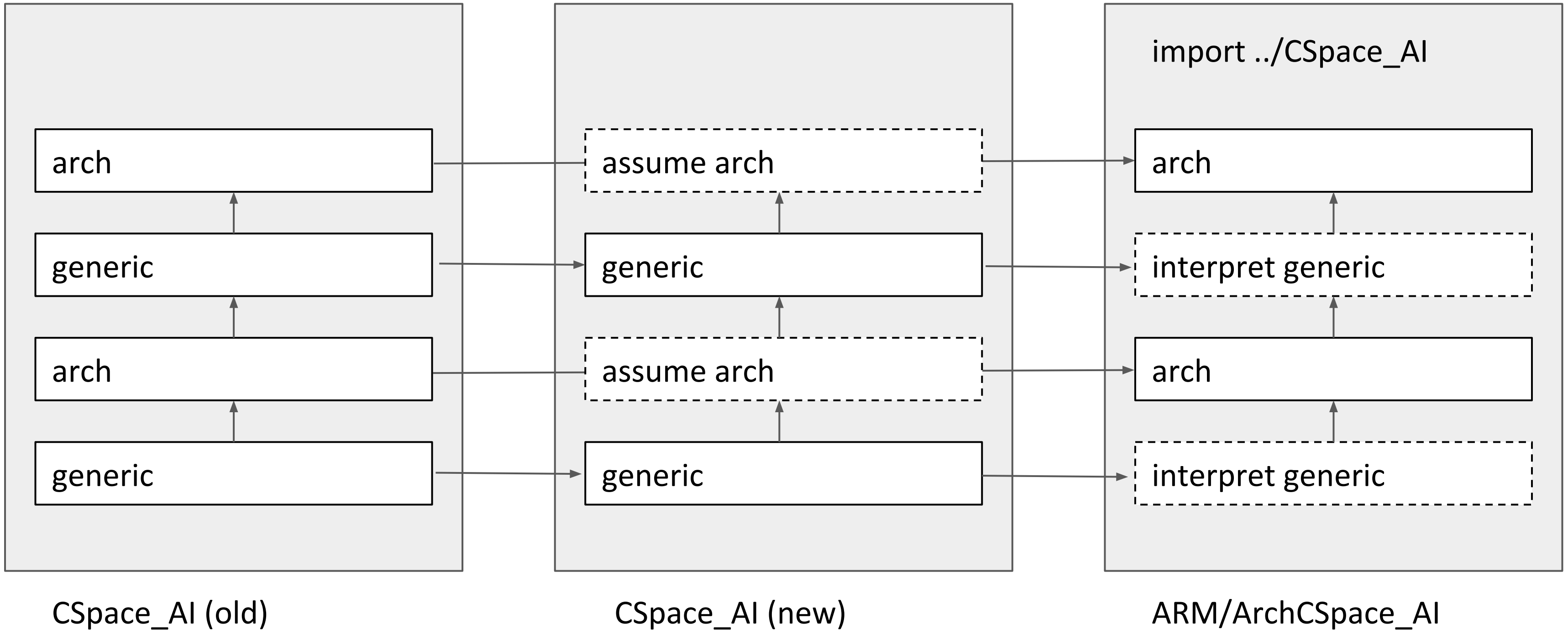

History: architecture split

- + Lots of shared generic invariant proofs.
- + Explicit statements of what we assume about architectures.
  - - Even though we didn't look for nicer abstractions.

- - We need to check the shared proofs for each architecture.
- - Limited support for fine-grained configurability.

Configurability wish list

Easy

- Addresses of kernel base and global structures.

More challenging

- Word size: affects generic kernel structures!
- Feature switches: virtualisation, page table structures.

Impossible

- Mixed-criticality, multi-core.

Page table abstraction

Almost all arch-specific proofs are about virtual memory.

- And all VM proofs are arch-specific!

Wanted: generic theory of virtual memory mappings.

- Specialisations to ARM, x86, RISC-V.

Page table abstraction: progress

ARM

- Irregular page table structure.

RISC-V

- Perfectly regular page table structure.

RISC-V showed us how to reimagine our treatment of virtual memory mappings.

- In both code and proofs.

Page table abstraction: progress

RISC-V page table walk:

- Single recursive function.
- Not even monadic!
- Requires only a “projection” of all page table entries in the heap.
- Used in both the specification and in properties to be proved.

Page table abstraction: future

Wanted: other architectures:

+ Yes!
+ "Just" need to parameterise by a page table entry encoding.
+ Proofs about generic page table walks can be shared.
+ Makes it easier to solves problems with the architecture split.
  - But doesn't solve them directly.
+ Incremental: x86, then ARM.

Page table abstraction: future

How this helps with the architecture split:

+ Narrower and clearer interface between arch-specific and generic proofs.
+ Fewer arch-specific proofs.
- Still need to recheck all the proofs for each configuration.
+ But a clearer path to truly generic proofs.

The end goal

- + One specification, parameterised by:
  - - Page table structure.
  - - Feature options (virtualisation).
  - - Data refinement level.
- + One proof of abstract invariants.
- + One proof of the first data refinement.
- - We’ll see about the C refinement.

Conclusion

Past decisions:

+ Were right at the time.
- Have different consequences in the present.
+ But we can adapt.

We’ve made it to the point where we can have mundane software engineering concerns in formal verification!