The Age of Deep Specification

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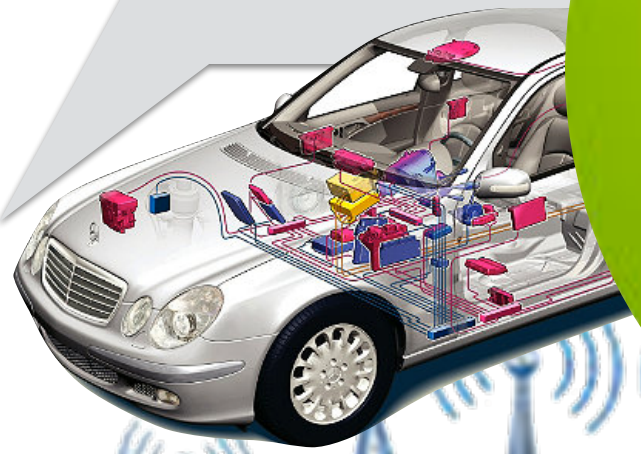
“We can’t build software that works…”

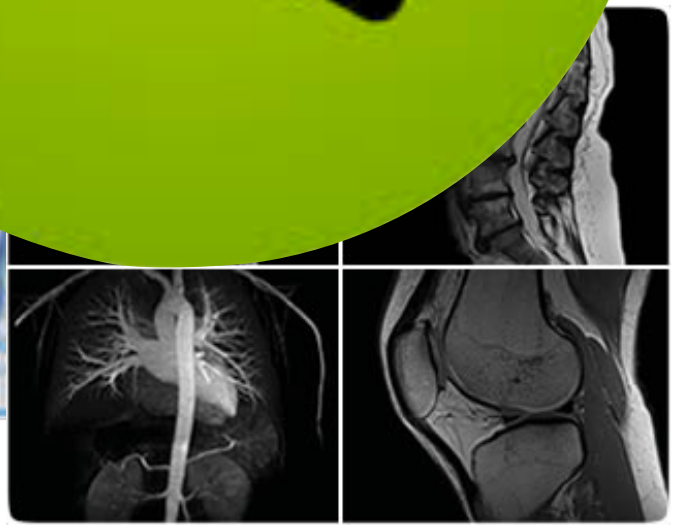
PWNED!

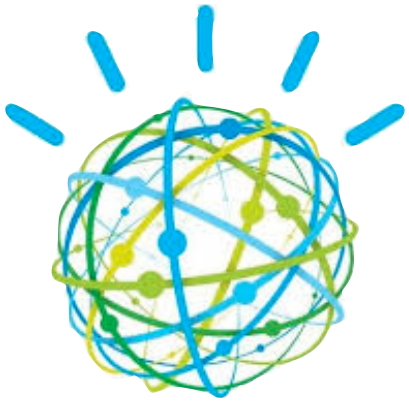
"We can't build software that works…"

But just look at all the software that *does* work!

But ju ll the
softw work!







How did that happen?

Lots of ways!

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- Better software development methodology

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- Better programming languages
  - Basic *safety guarantees* built in
  - Powerful mechanisms for *abstraction* and *modularity*

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I.e., descriptions of what software does (as opposed to the instructions for how to do it)

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Why are specifications useful?

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If you want to build software that works, it is helpful to know what you mean by "works"!

A Specification:

The "sort" function should take a list of items and return a list of the same items in increasing order.

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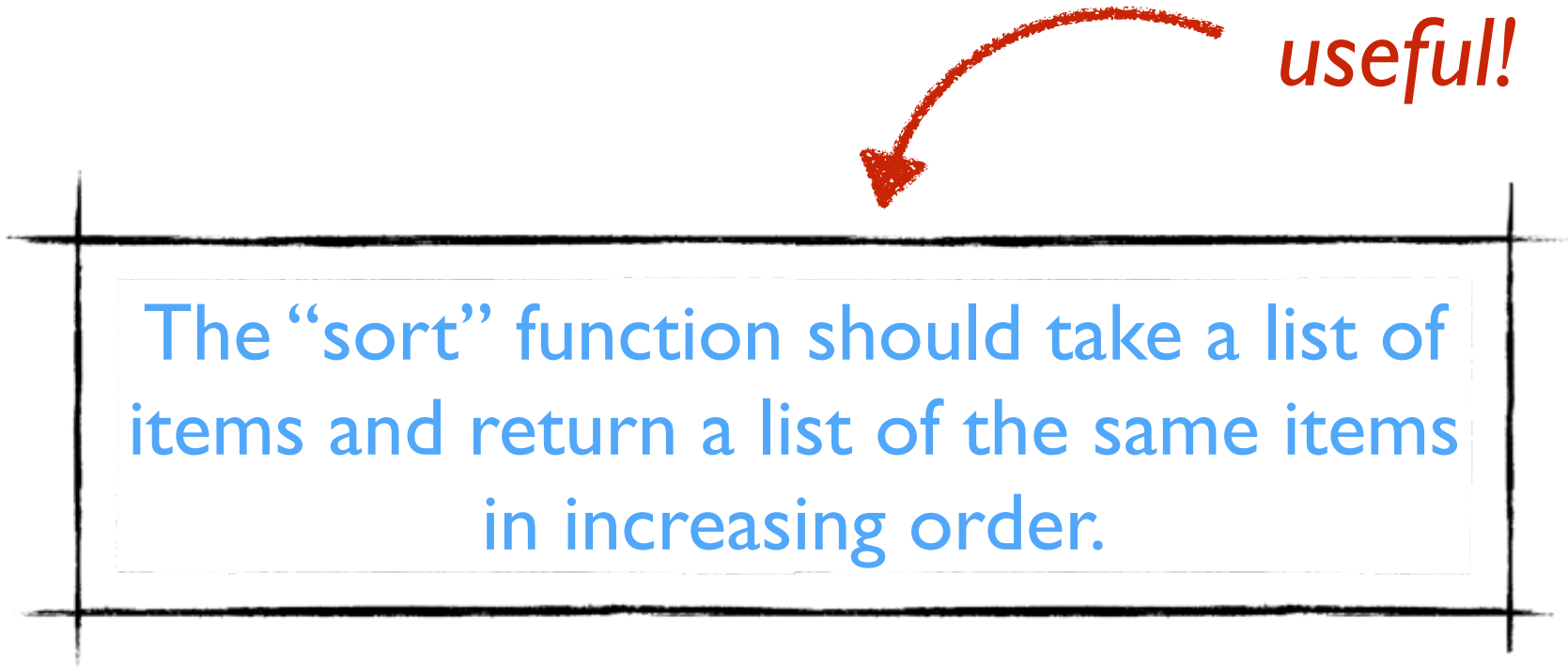

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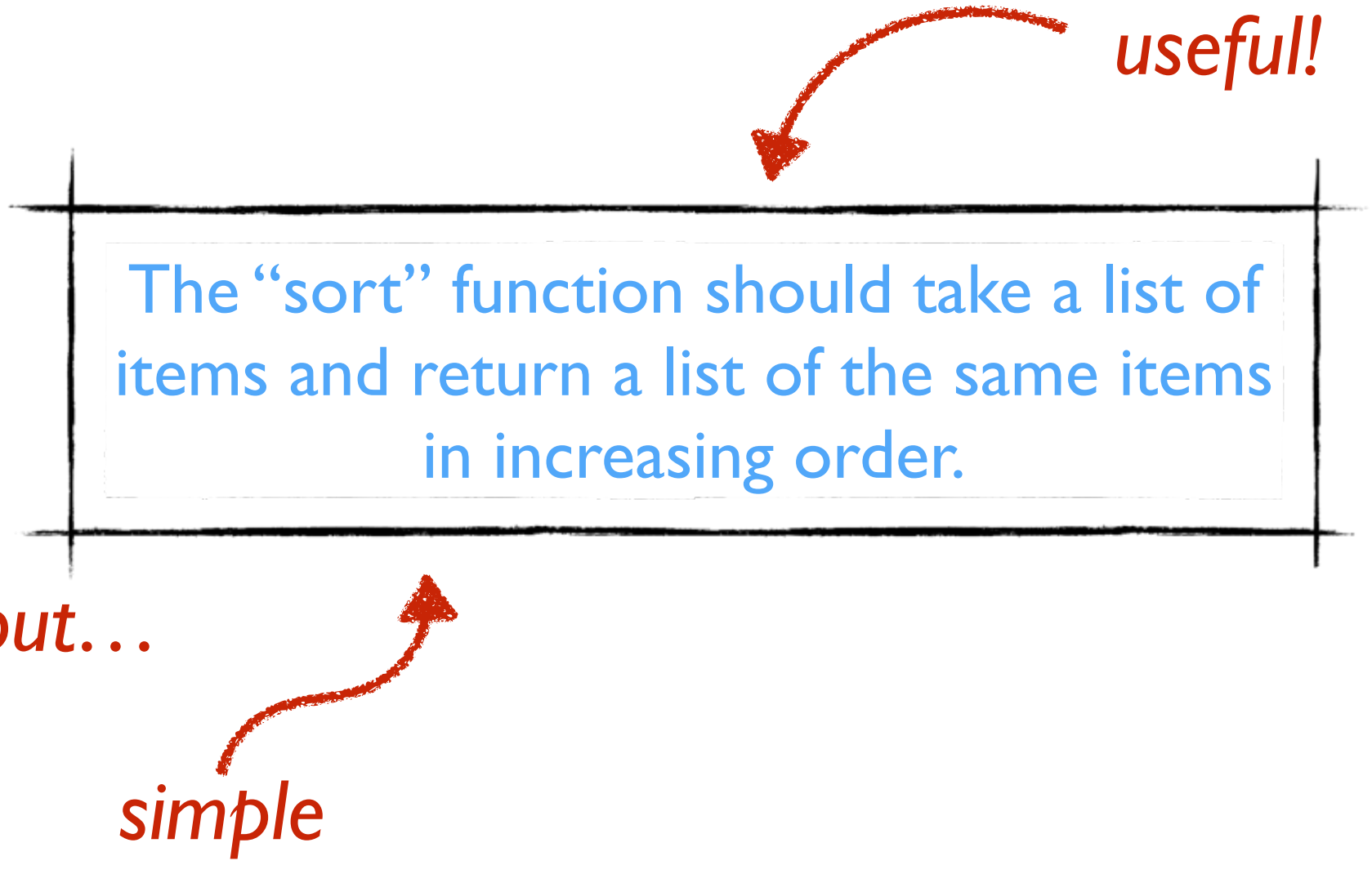

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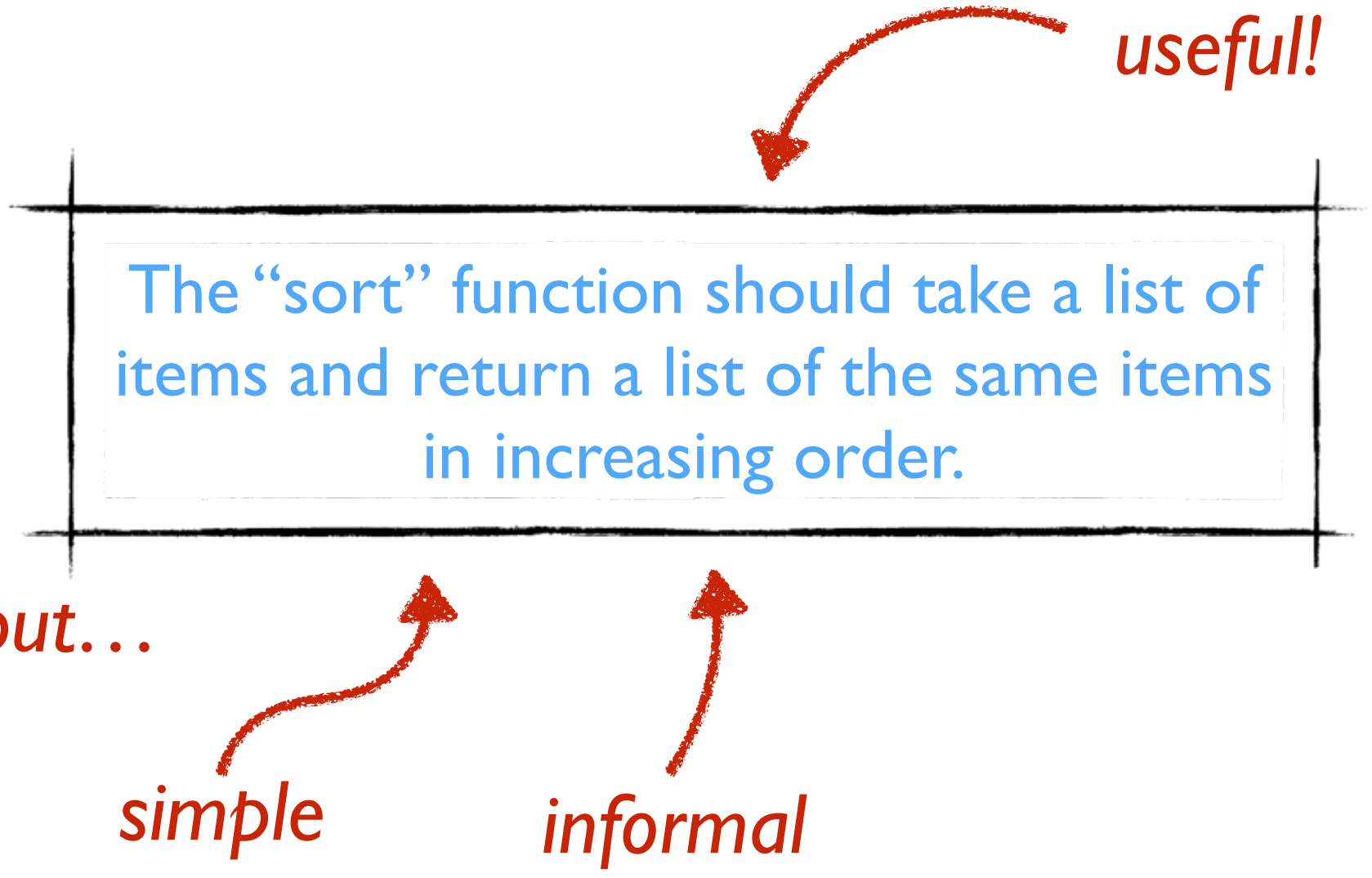

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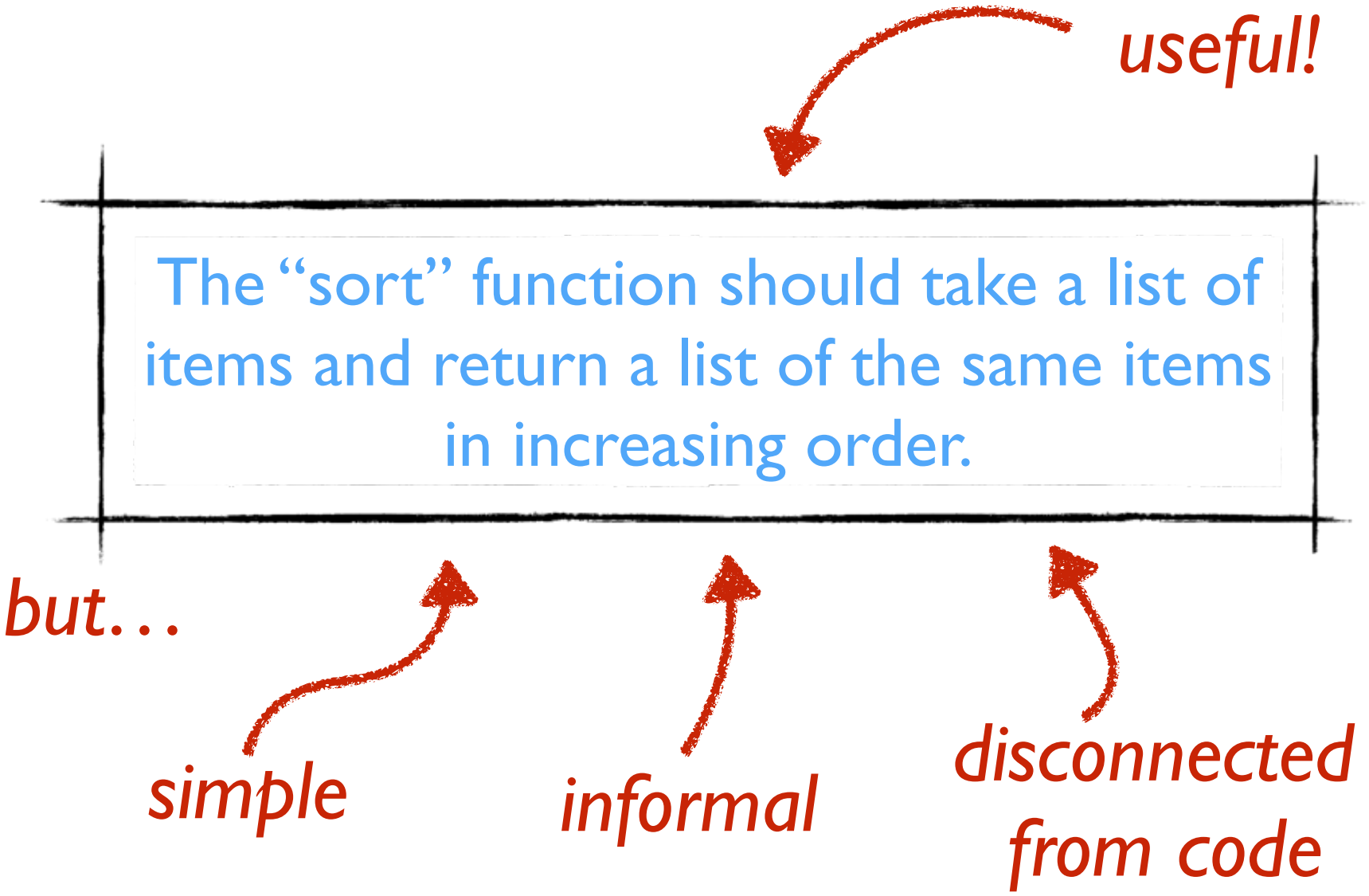
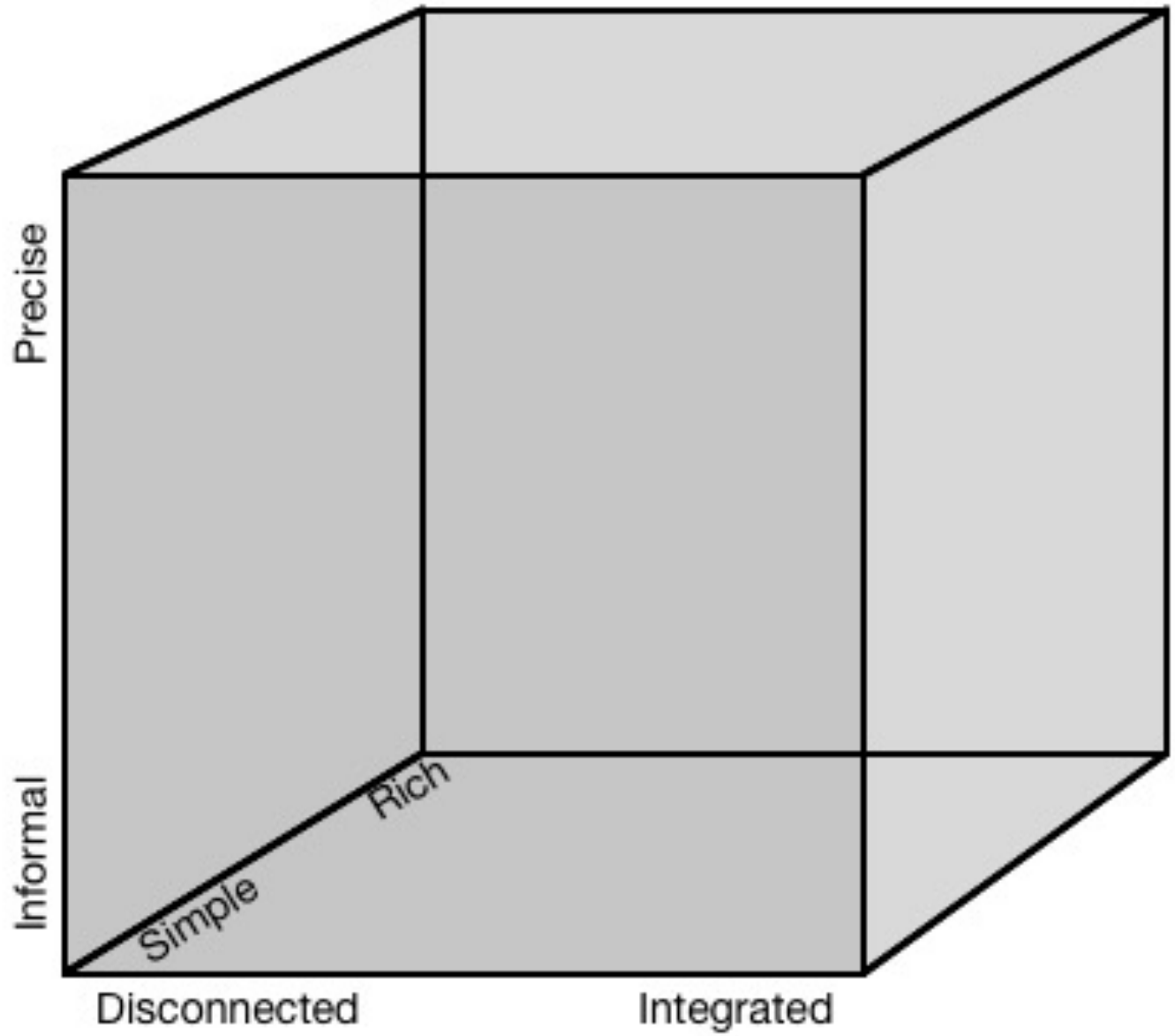



Precise
Informal
Simple
Rich
Disconnected
Integrated

Simple ⟶ Rich

- C Language Reference
  - 592 pages
  - also Java (792 pages), C++ (1354 pages, etc.
- x86 CPU reference
  - 1499 pages
- AUTOSAR standardized automotive architecture
  - 3000 pages

AUTOSAR

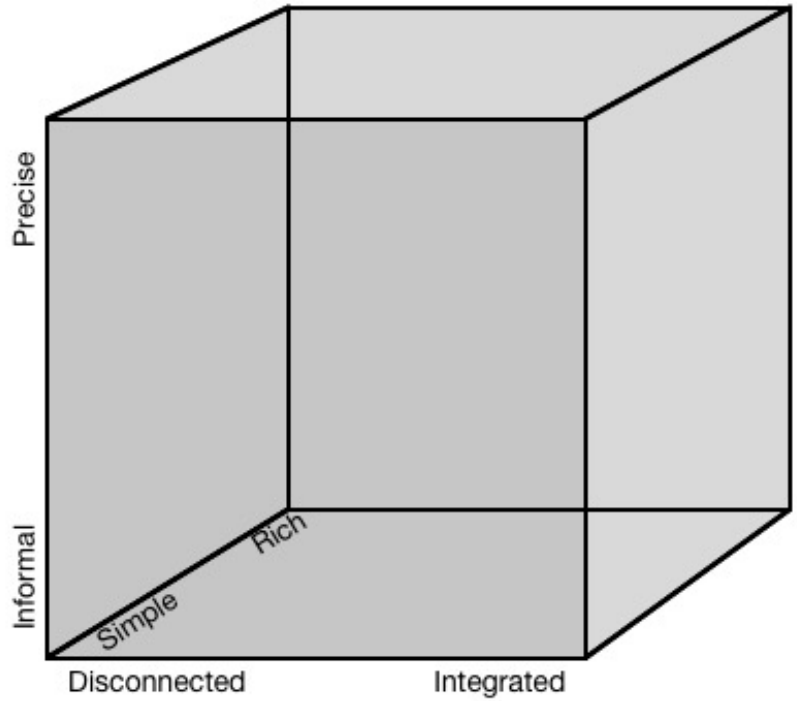
Informal ⟶ Precise

- Z, Alloy, VDM, ACL2, Coq, Isabelle, …
  - x86 instruction set (and many others)
  - Ada, Java virtual machine, C, JavaScript, …
  - …

Formal *specification languages*

Disconnected ⟶ Integrated

- Formal verification tools
  - Human constructs "proof script"; computer checks it
  - Capable in principle of establishing connections between arbitrary specifications and code
  - Challenging to use at scale
- Type systems
  - Highly successful "lightweight formal methods"
  - Built into programming languages
  - Limited expressiveness, but "always on"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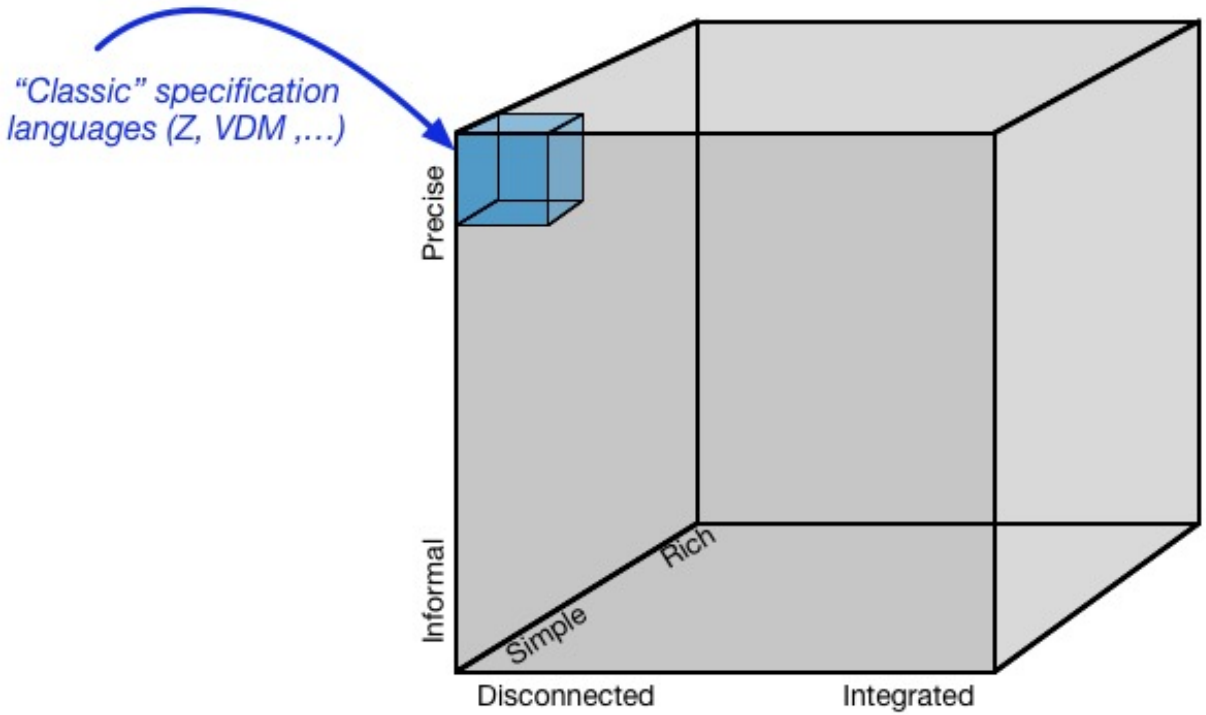
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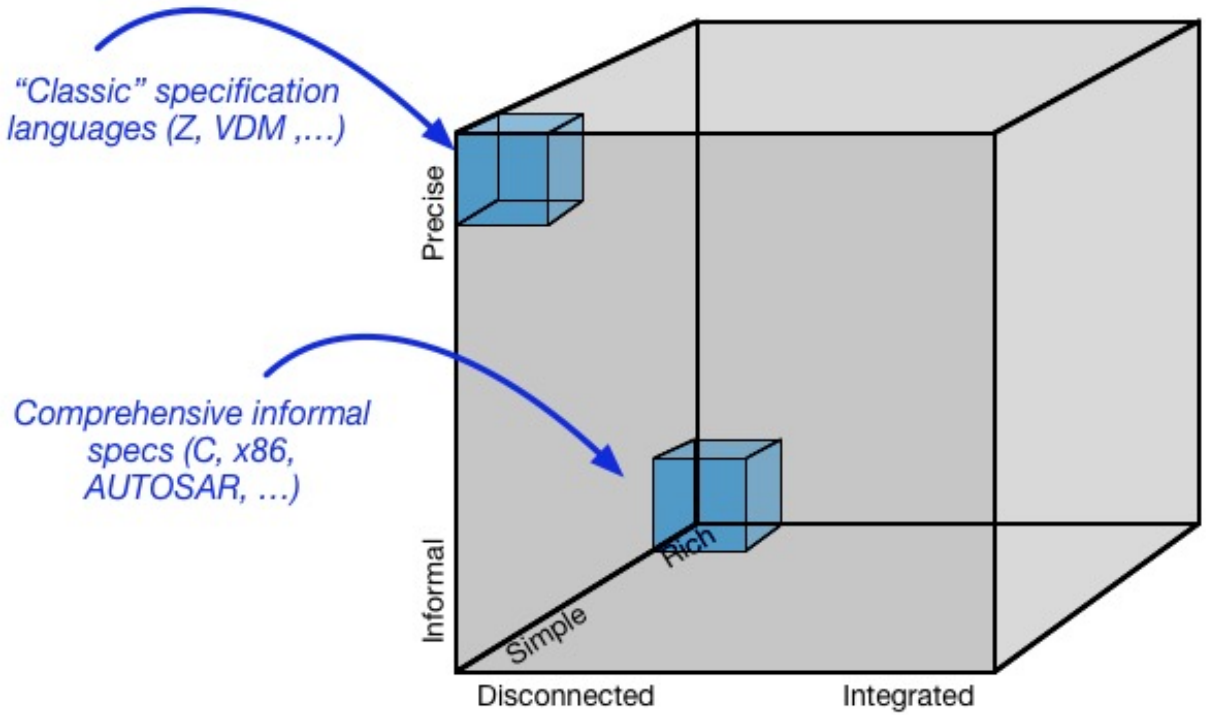
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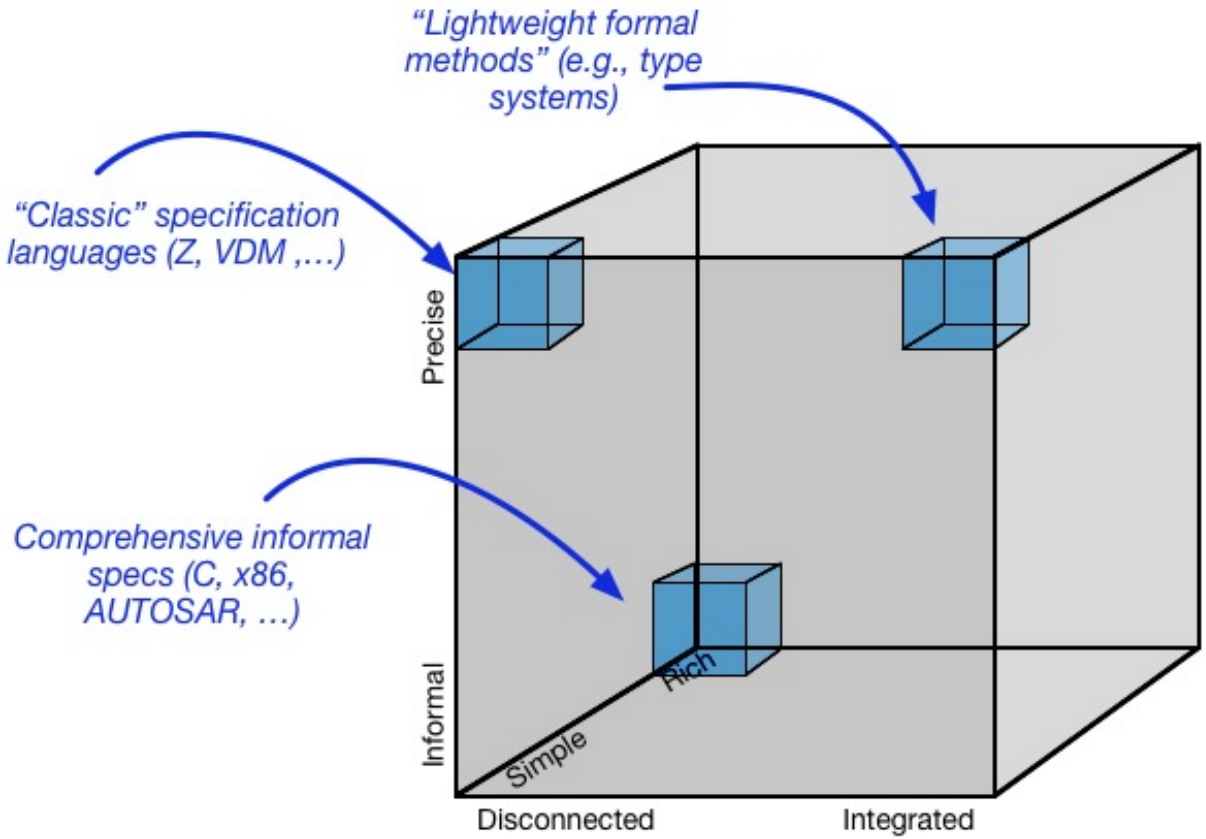
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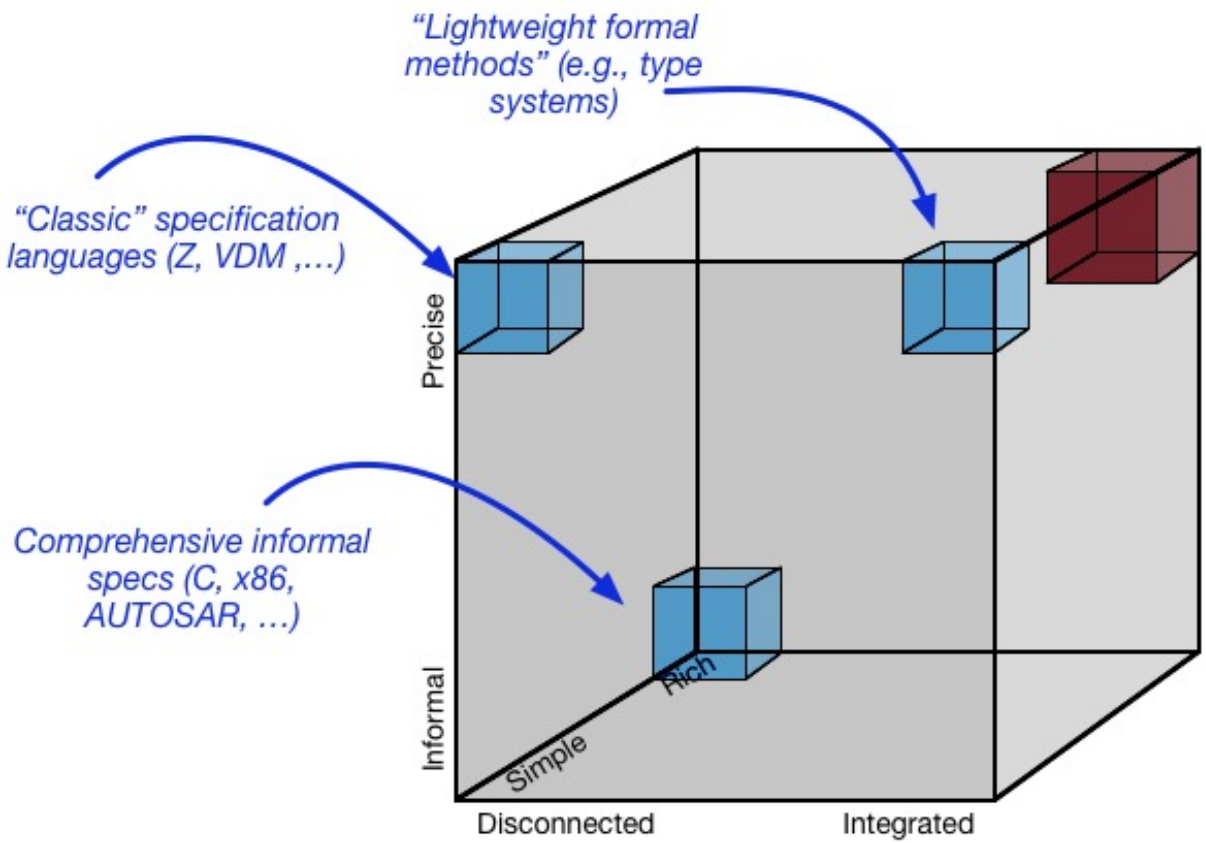
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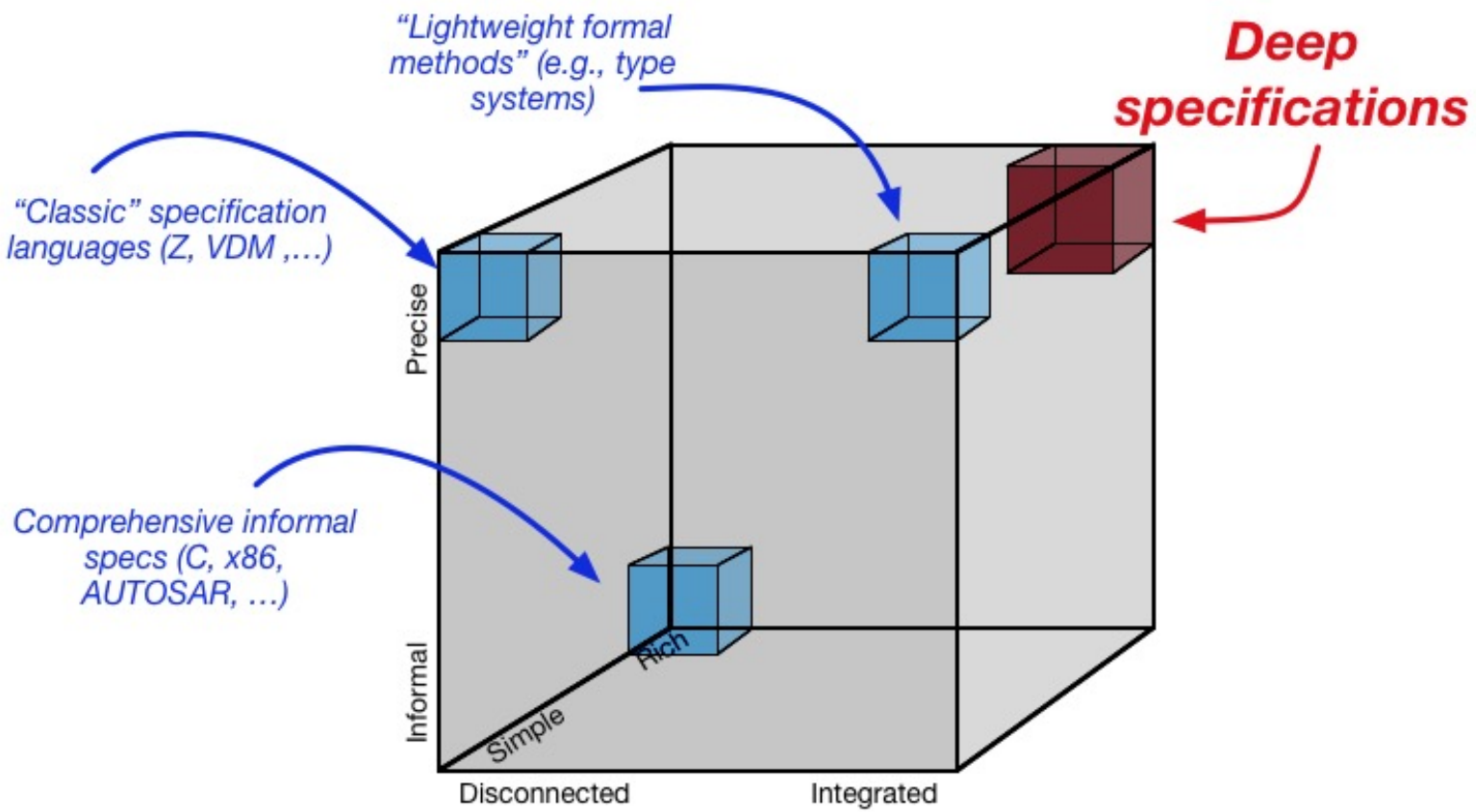
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Deep specifications
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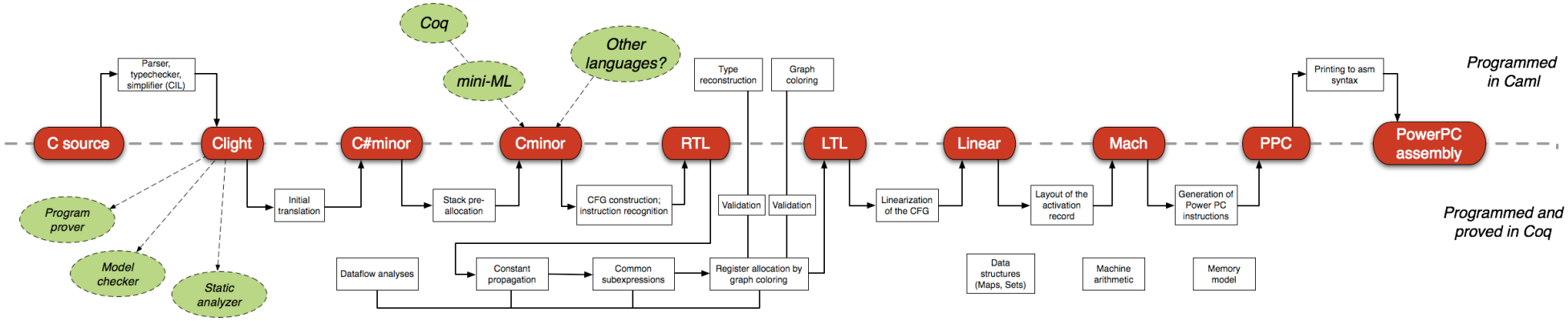
Deep specifications

1. Rich
2. Formal
3. Integrated with code

early *tours de force*…

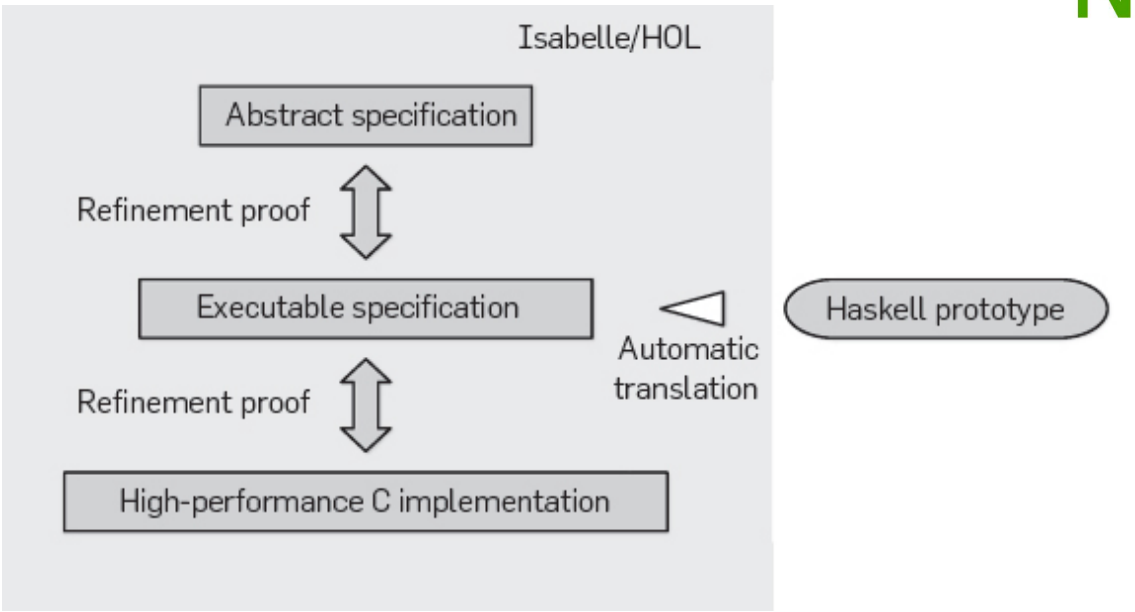
CompCert C compiler



- Fully verified translator from C to machine code
- Accepts most of ISO C 99
- Produces machine code for PowerPC, ARM, and IA32 (x86 32-bit) architectures
- 90% of the performance of GCC (v4, opt. level 1)

seL4

NICTA



Real-world operating-system kernel with an end-to-end proof of implementation correctness and security enforcement

Emerging trends…

New specification / verification tools

- Coq
- Isabelle
- ACL2
- …

Powerful
proof assistants and
program logics

- F*
- Dafny
- Boogie
- …

Quasi-automatic verifiers
based on SMT solvers

Formal verification of real software

- Verified TLS implementation
  - (Core technology for secure web communications)
- Verified compilers
  - CakeML, Bedrock, CompCertTSO, …
- Verified distributed systems
  - Verdi, …
- Verified operating systems and OS components
  - CertiKOS, Ironclad Apps, Jitk, …
- Verified cryptography
- …

Expressive type systems

- security types
- session types
- component types / object types / module systems
- generalized abstract datatypes
- …

Property-based random testing

- TCP networking protocol suite [Sewell et al., Cambridge]
- Testable AutoSAR model [Quviq, Göteborg]
  - Found >200 faults in AUTOSAR Basic Software, including >100 inconsistencies in the informal standard
- Testable model of Dropbox and other synchronization frameworks [ongoing work with Quviq]
- …

Where are we going?

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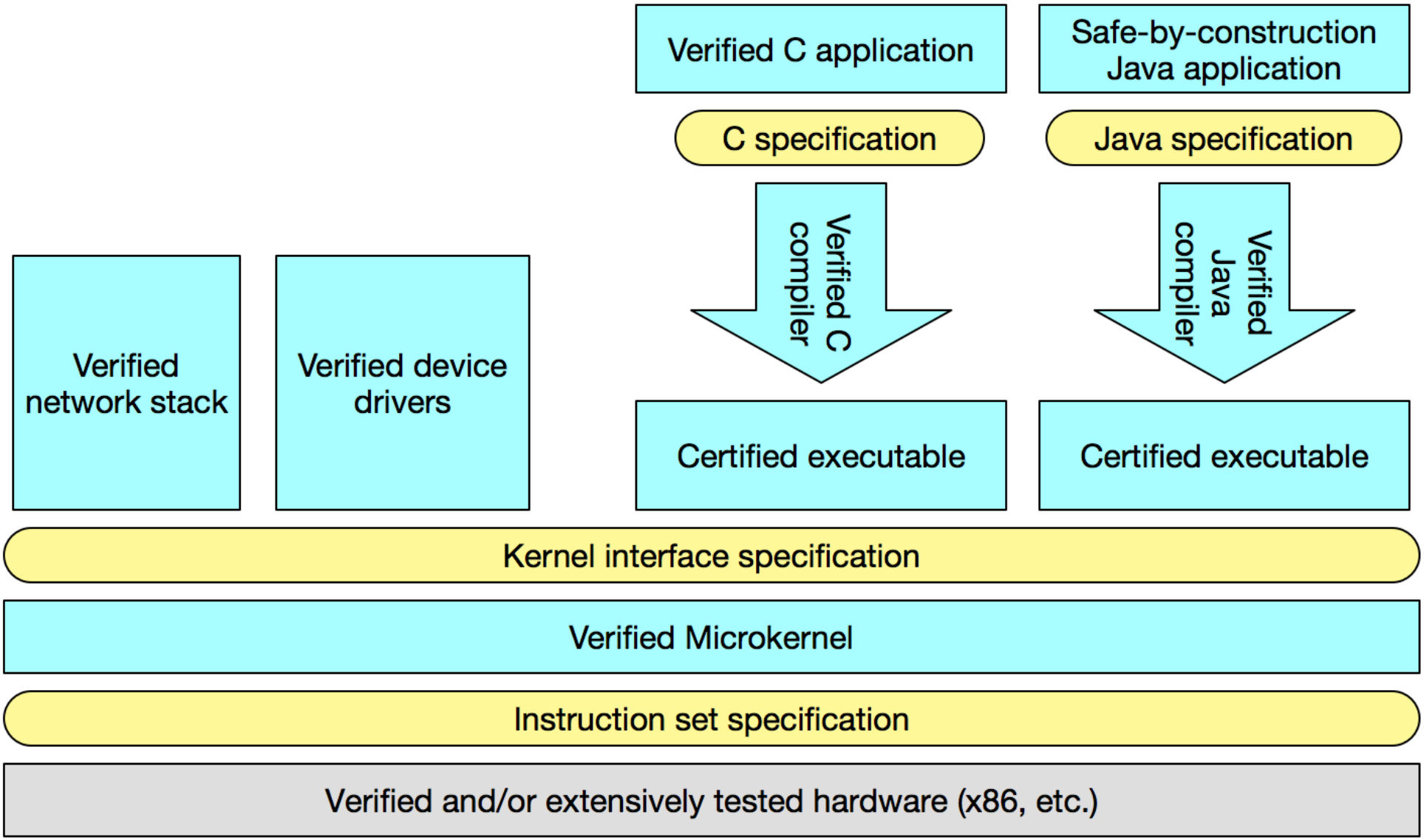
One possibility…

A zero-vulnerability software stack



A zero-vulnerability software stack

Thank you!

(Any questions?)