C++ Development in the Safety Critical Domain

An introduction & lessons learned from a large automotive product

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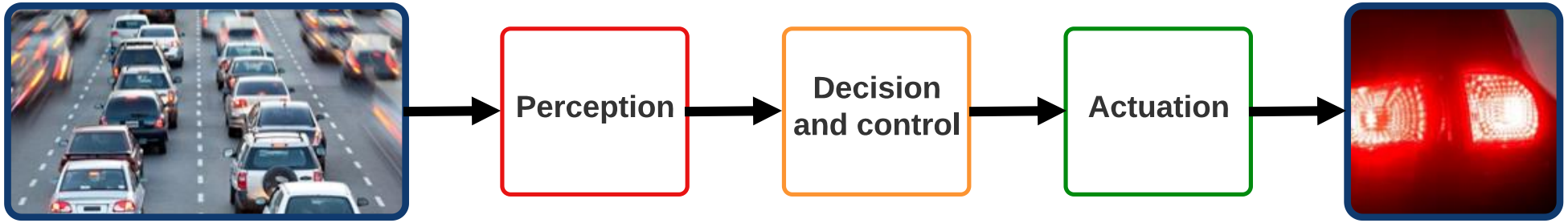
Agenda

- ✓ A brief introduction *functional safety* and a safety-critical product
- ✓ Architectural levels, activities and associated effort
- ✓ *Language safety*: safety critical C++ & language subsets
- ✓ Memory safety
- ✓ Core libraries
- ✓ Unit testing and the search/struggle for test sufficiency
- ✓ A few words on requirements
- ✓ Human factors and safety culture
- ✓ Safety vs software engineering: perceived contradictions

A brief introduction to a (simplified) safety-critical product



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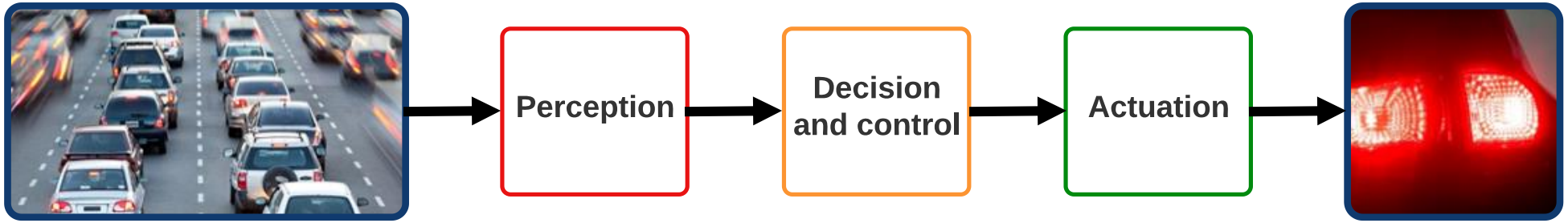

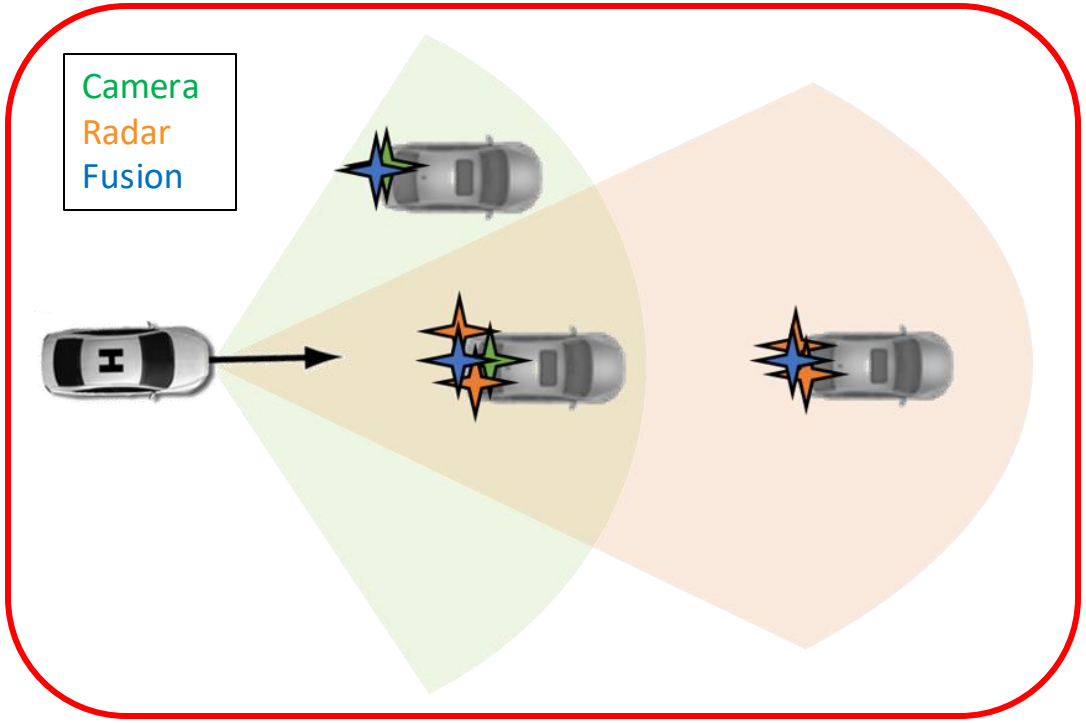

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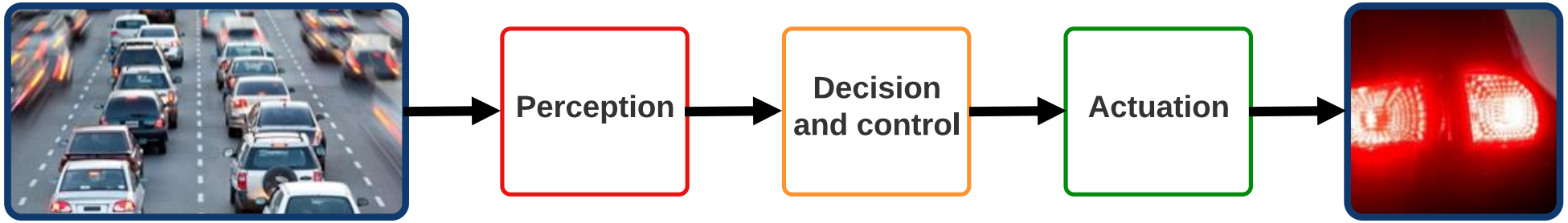

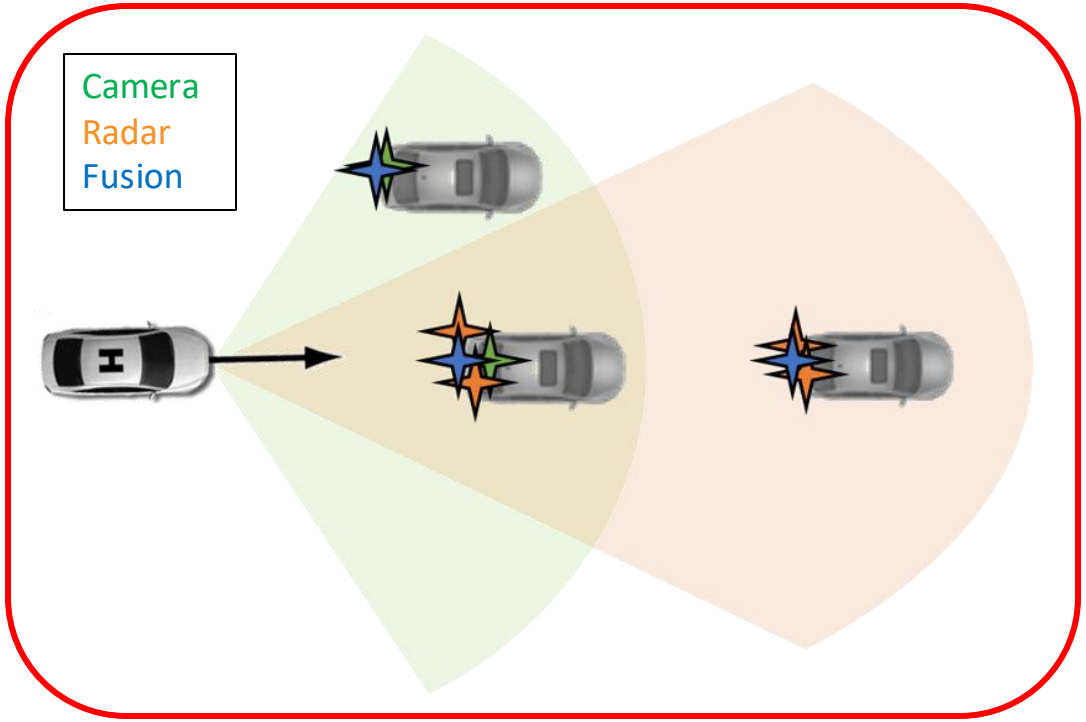

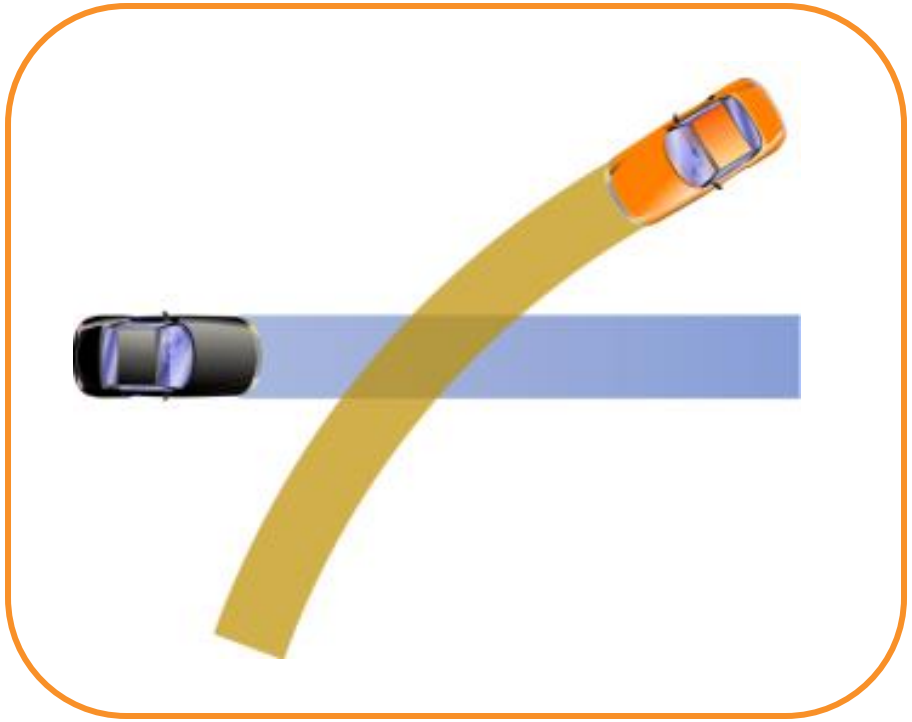

Functional safety: end-to-end (system & environment)

Perception

Decision and control

Actuation

Feature at the vehicle level

Hazard Analysis & Risk Assessment (**HARA**)

Any resulting **Safety Goals**?

No

Yes

Requirements

QM (Quality Management)

ASIL (Automotive Safety Integrity Level)

Safety **Requirements**

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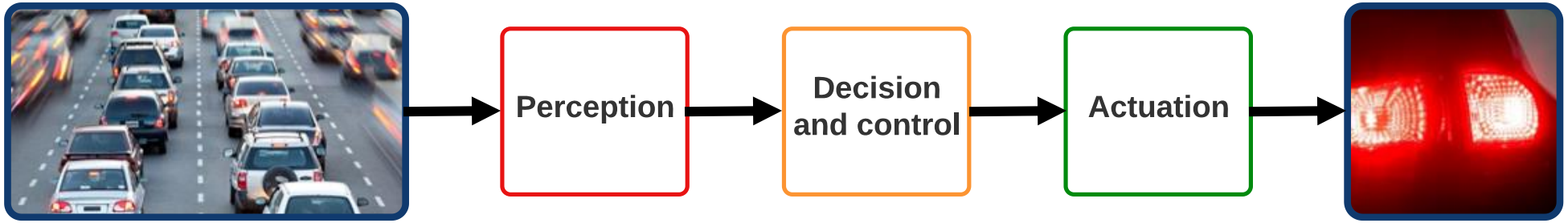

The infamous „ghost detection"

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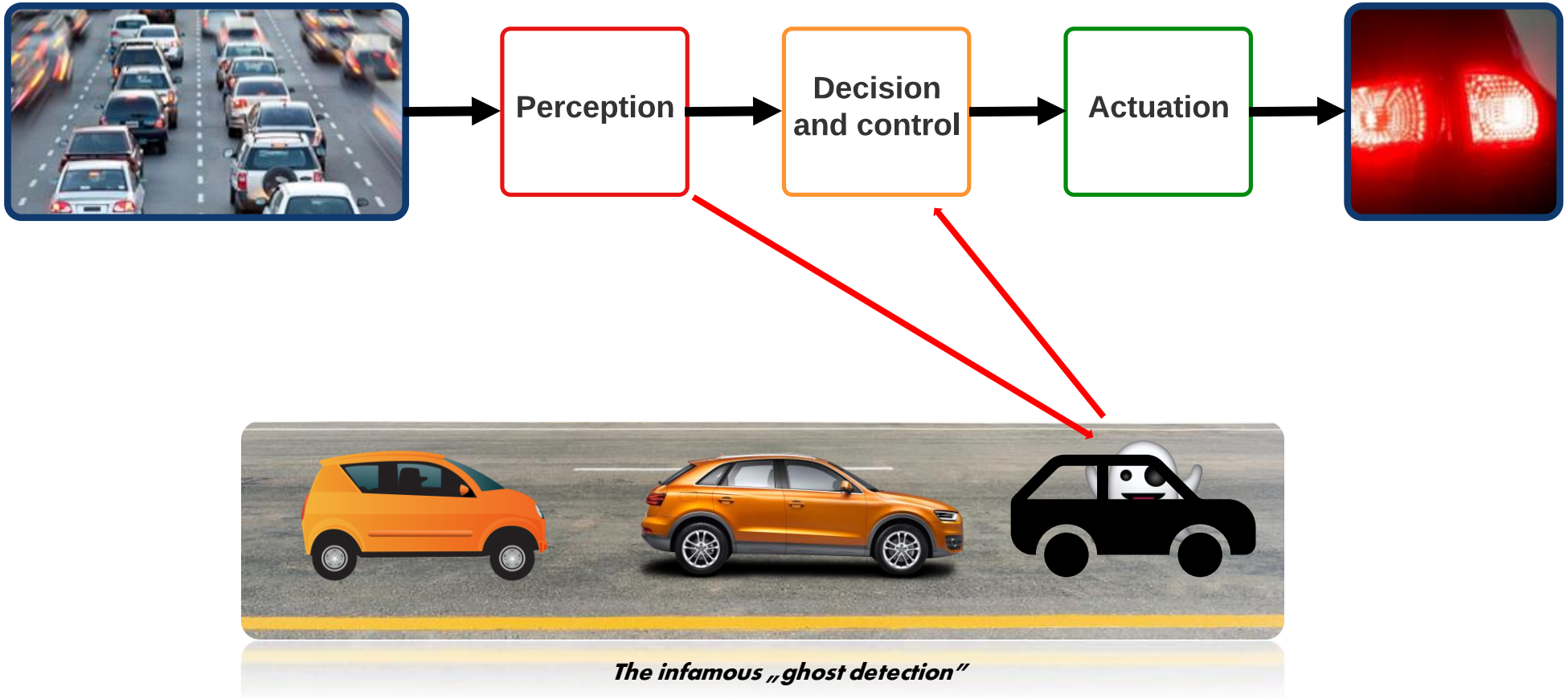

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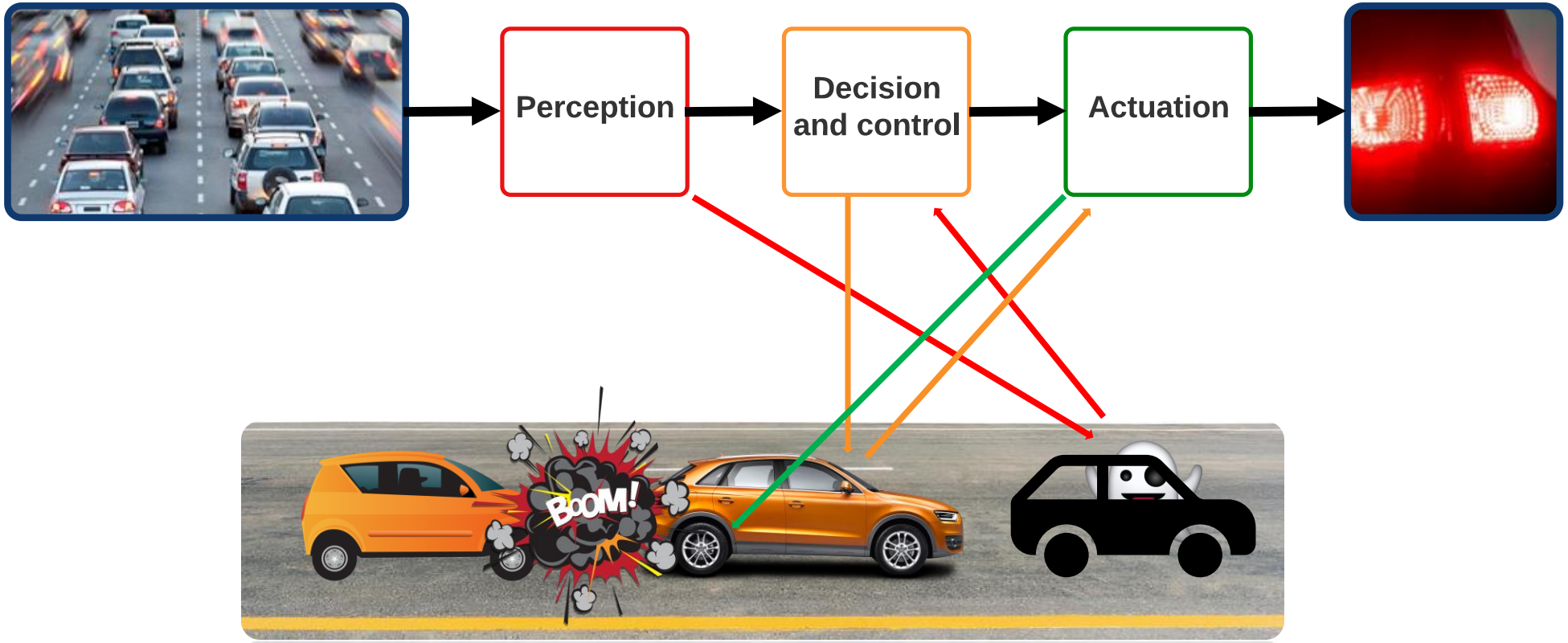

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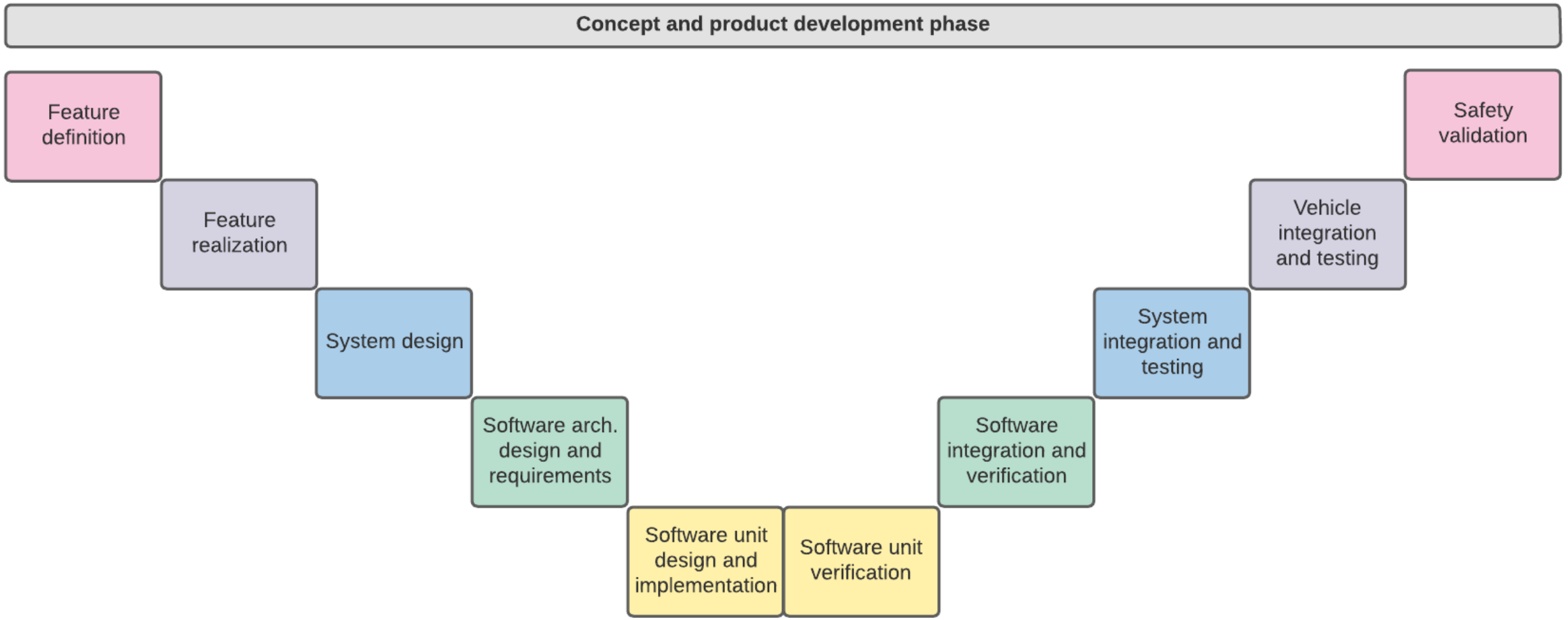
Architectural levels, activities and associated effort



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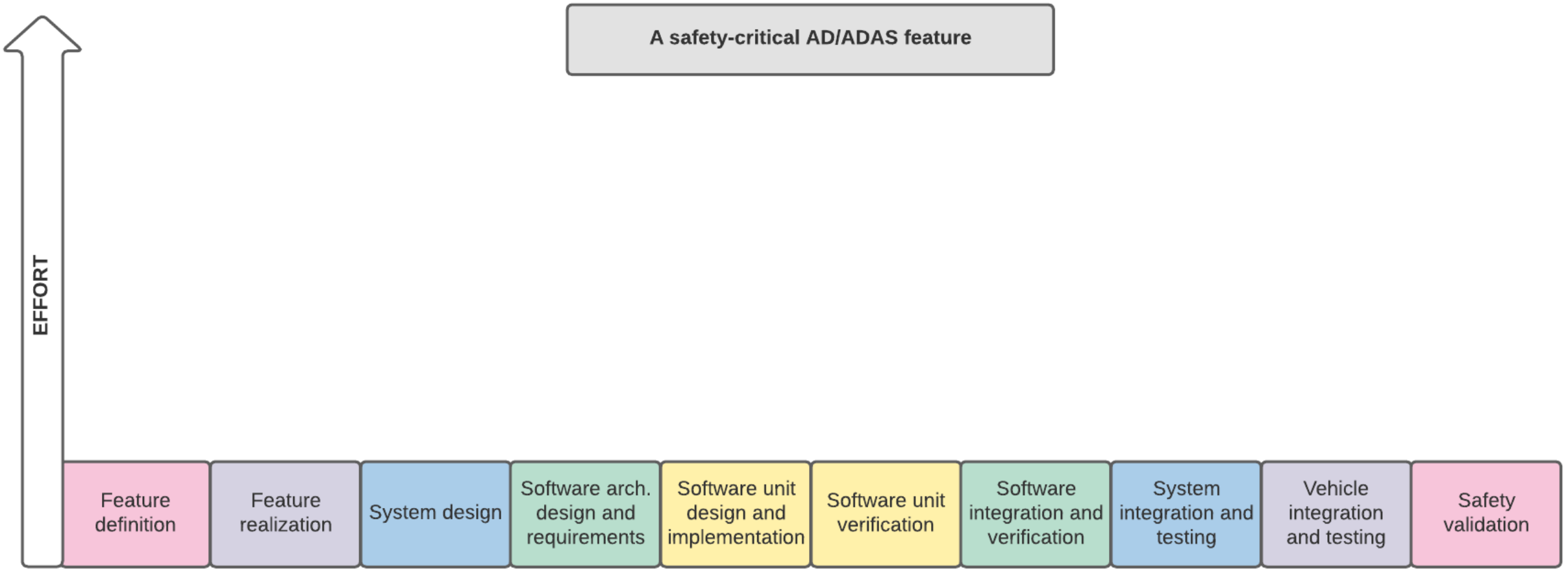

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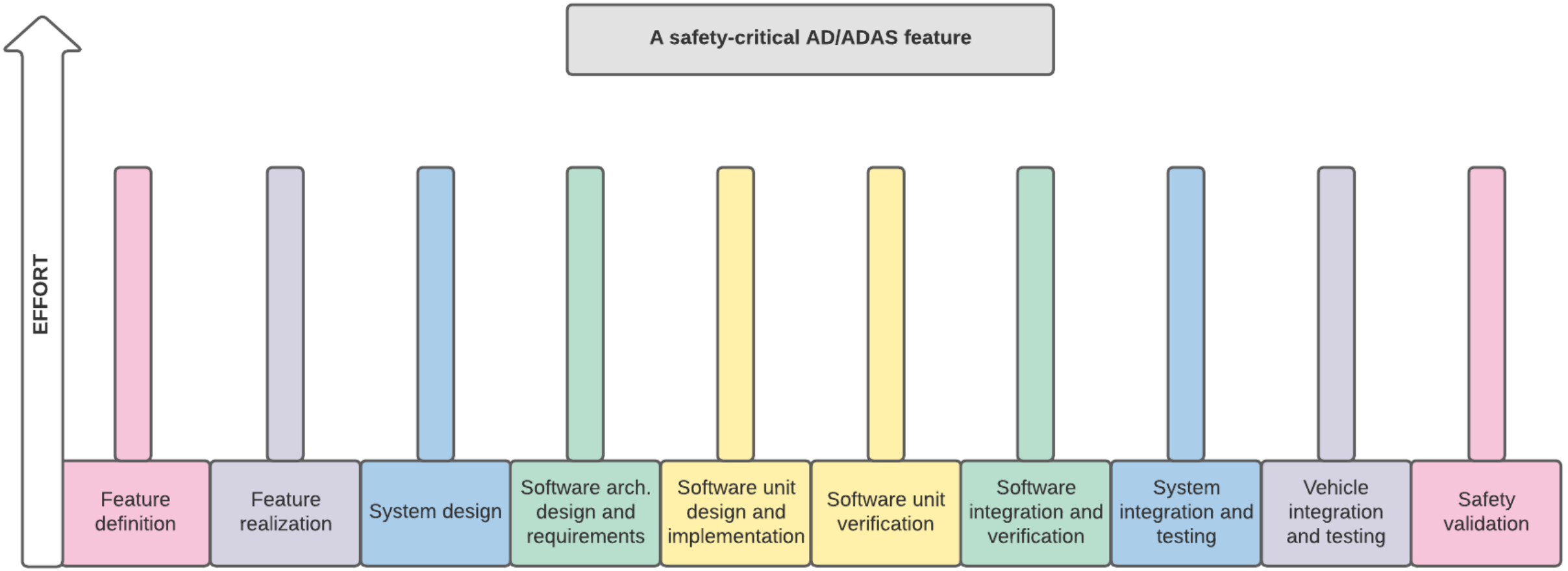

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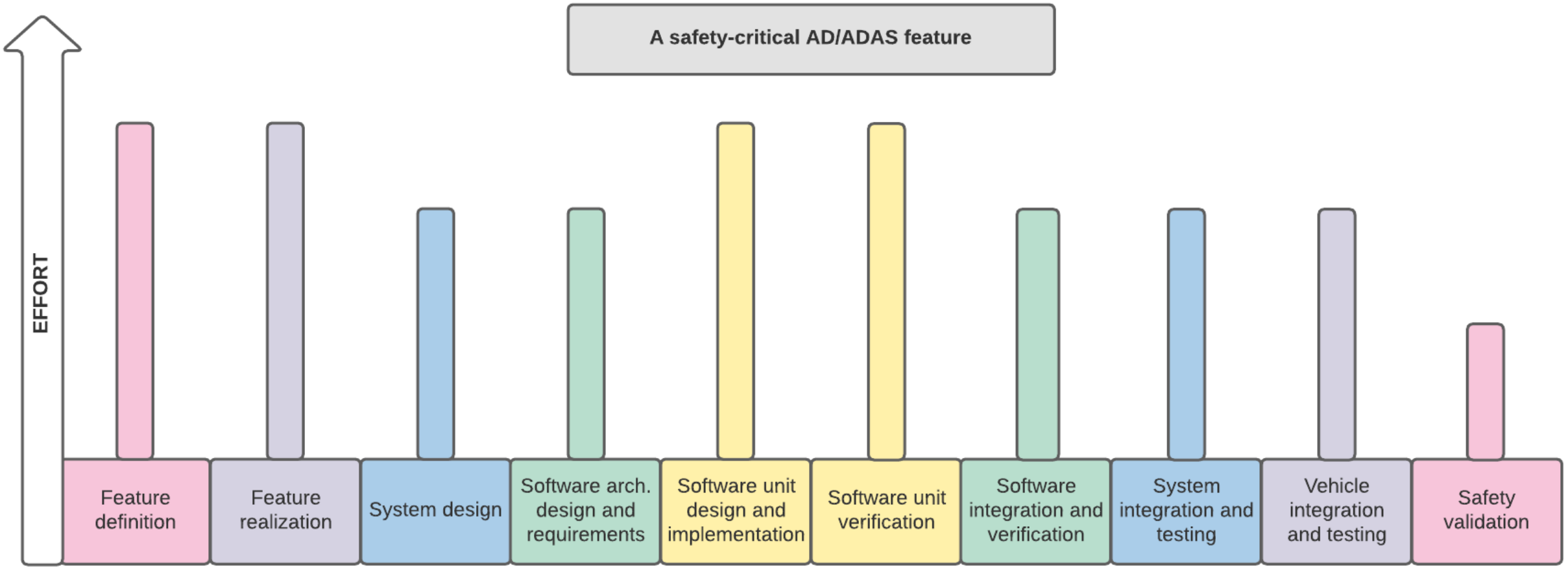

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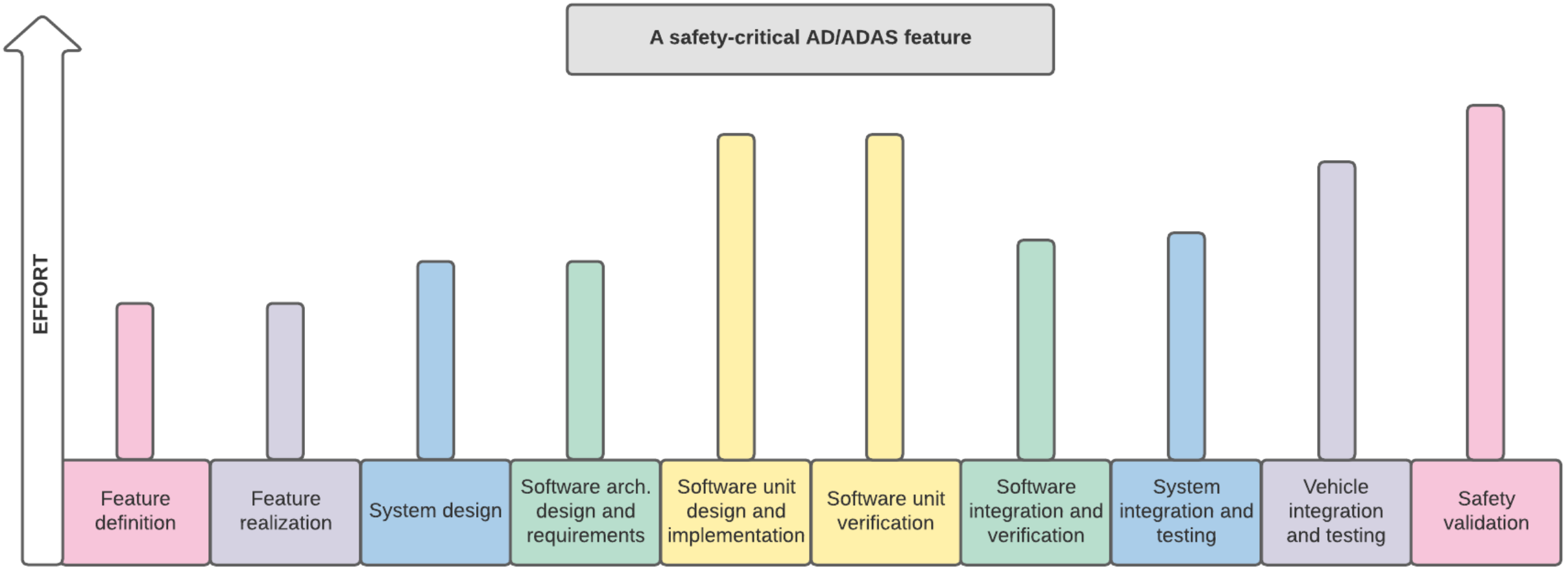

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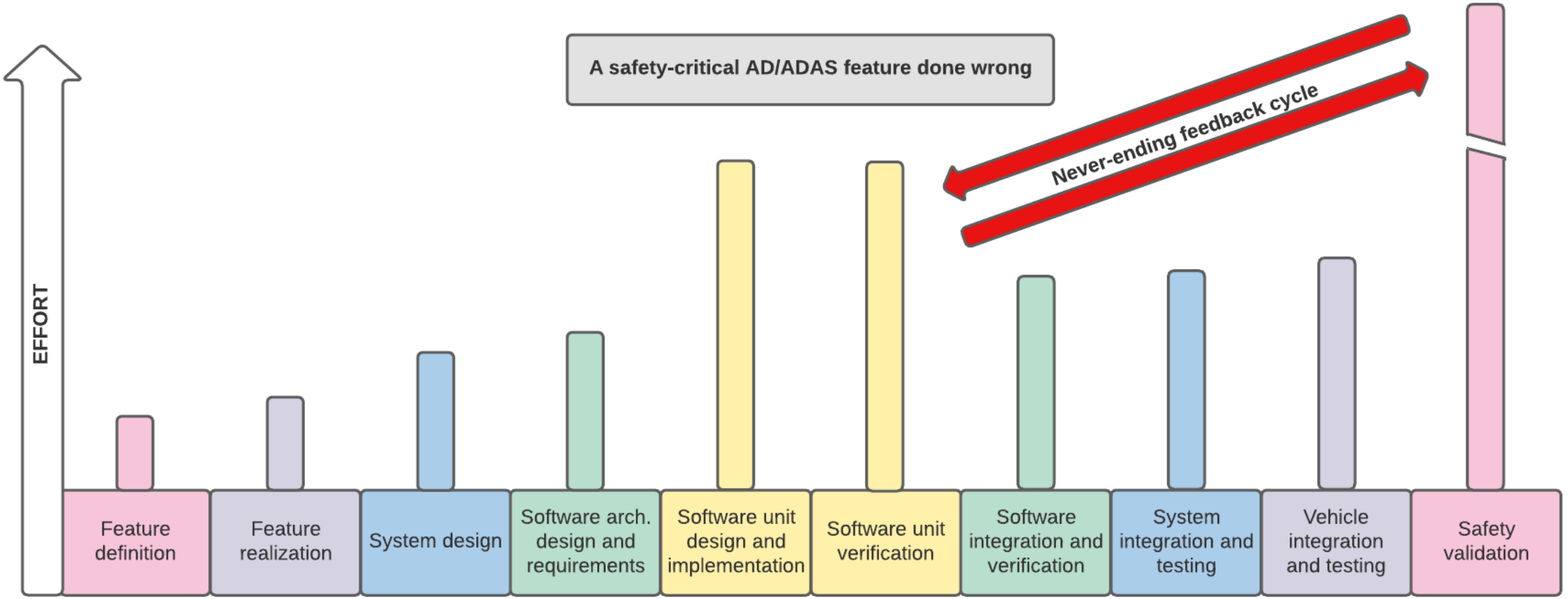

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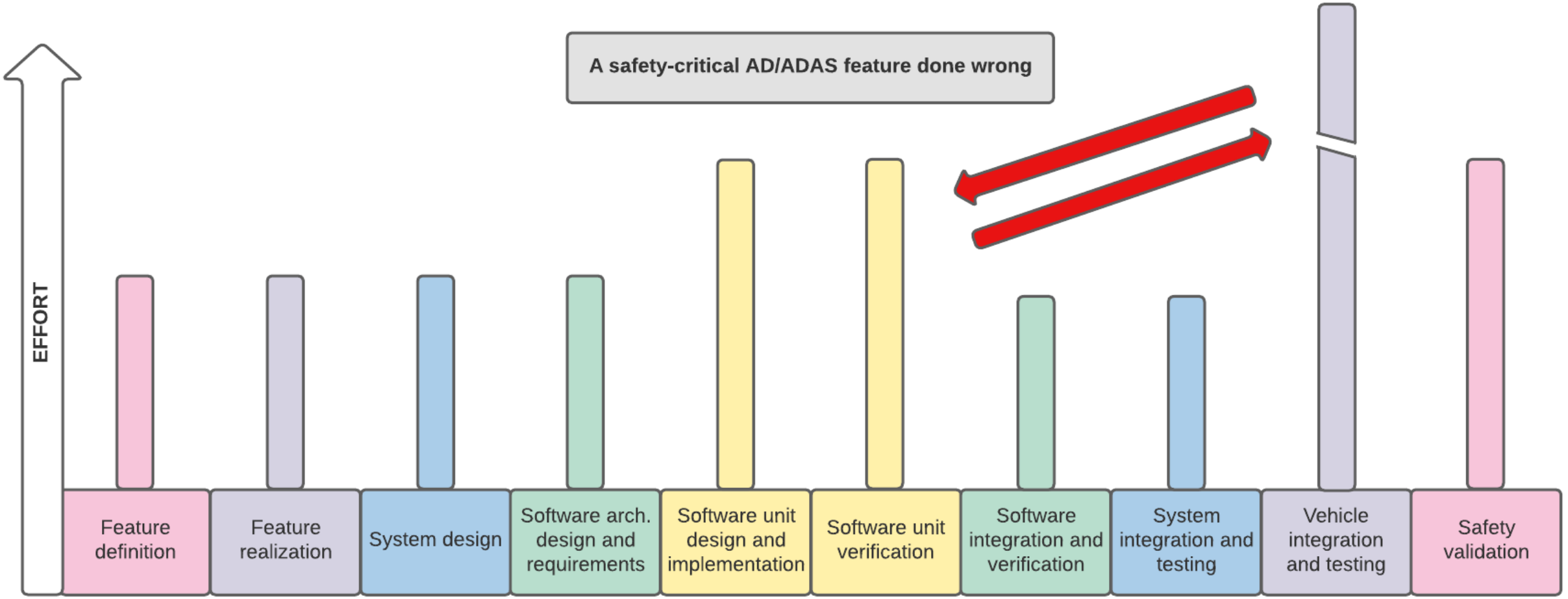

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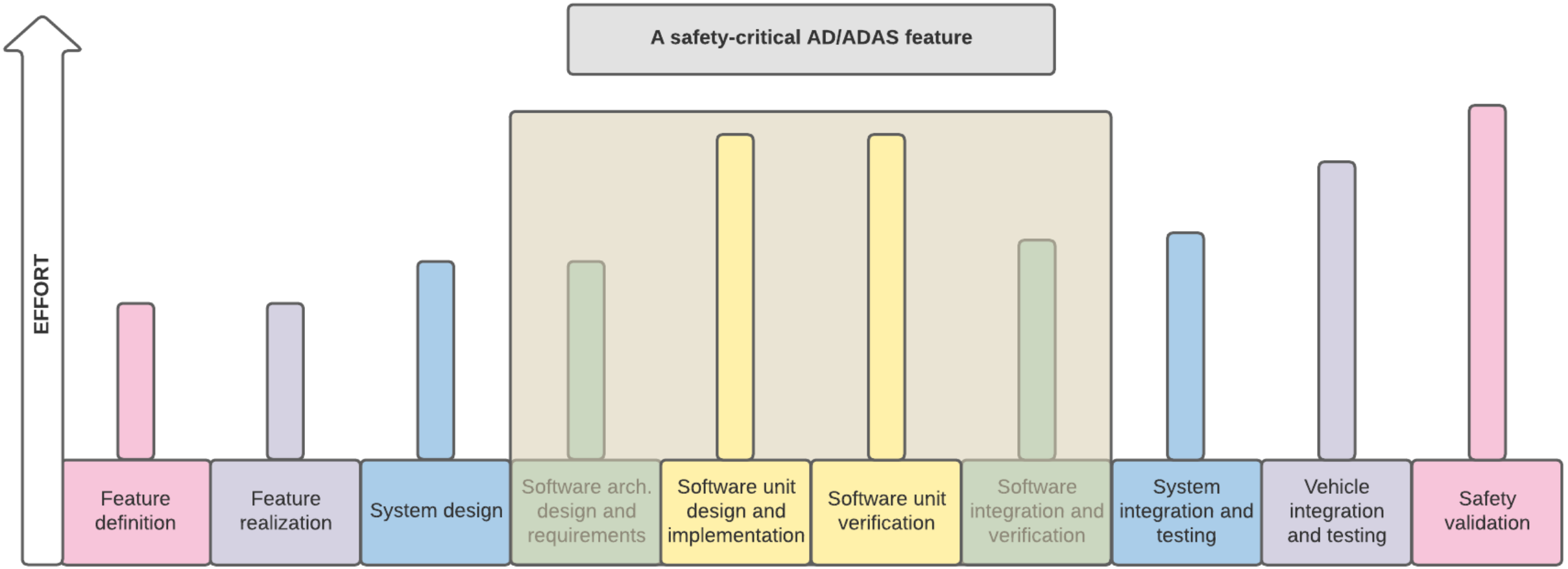
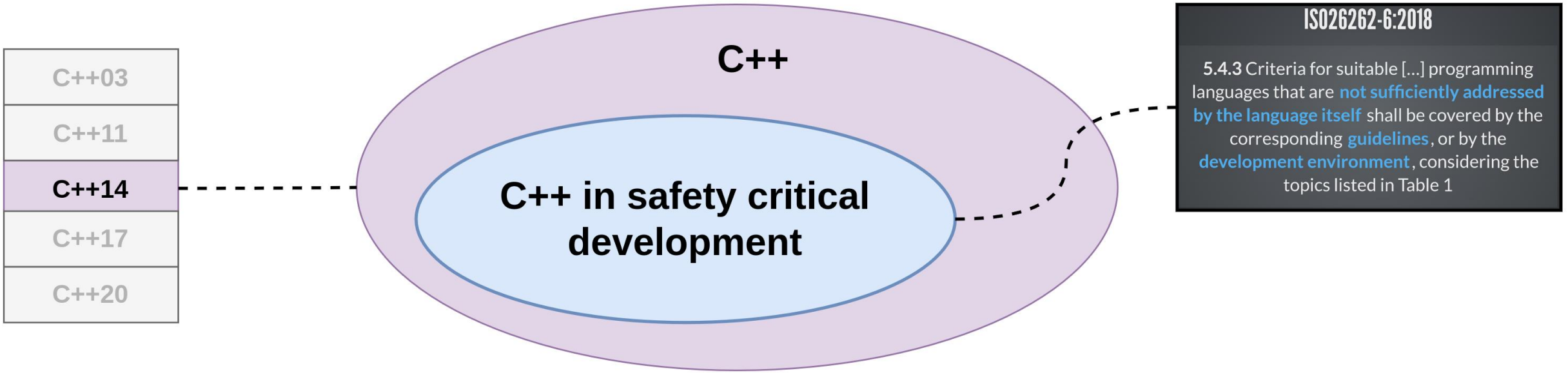
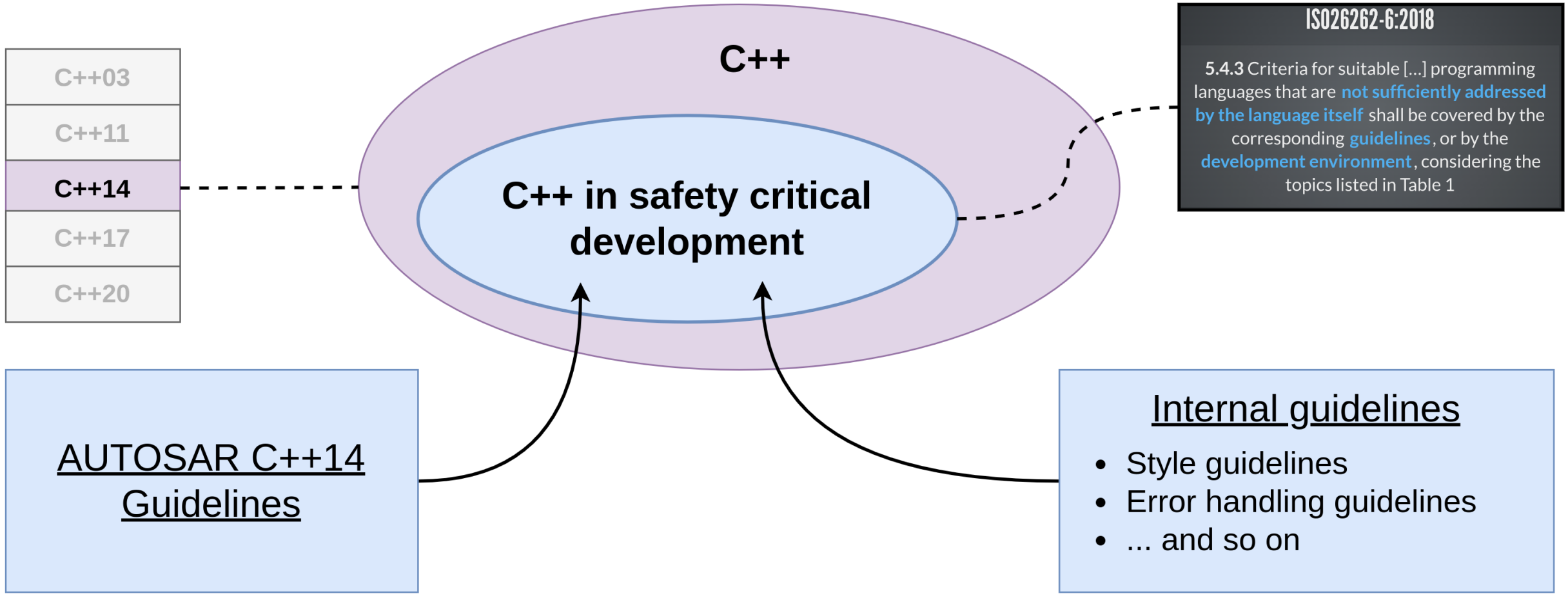


Programming language safety: C++ language subsets


C++03
C++11
C++14
C++17
C++20
C++
C++ in safety critical development
ISO26262-6:2018
5.4.3 Criteria for suitable [...] programming languages that are not sufficiently addressed by the language itself shall be covered by the corresponding guidelines, or by the development environment, considering the topics listed in Table 1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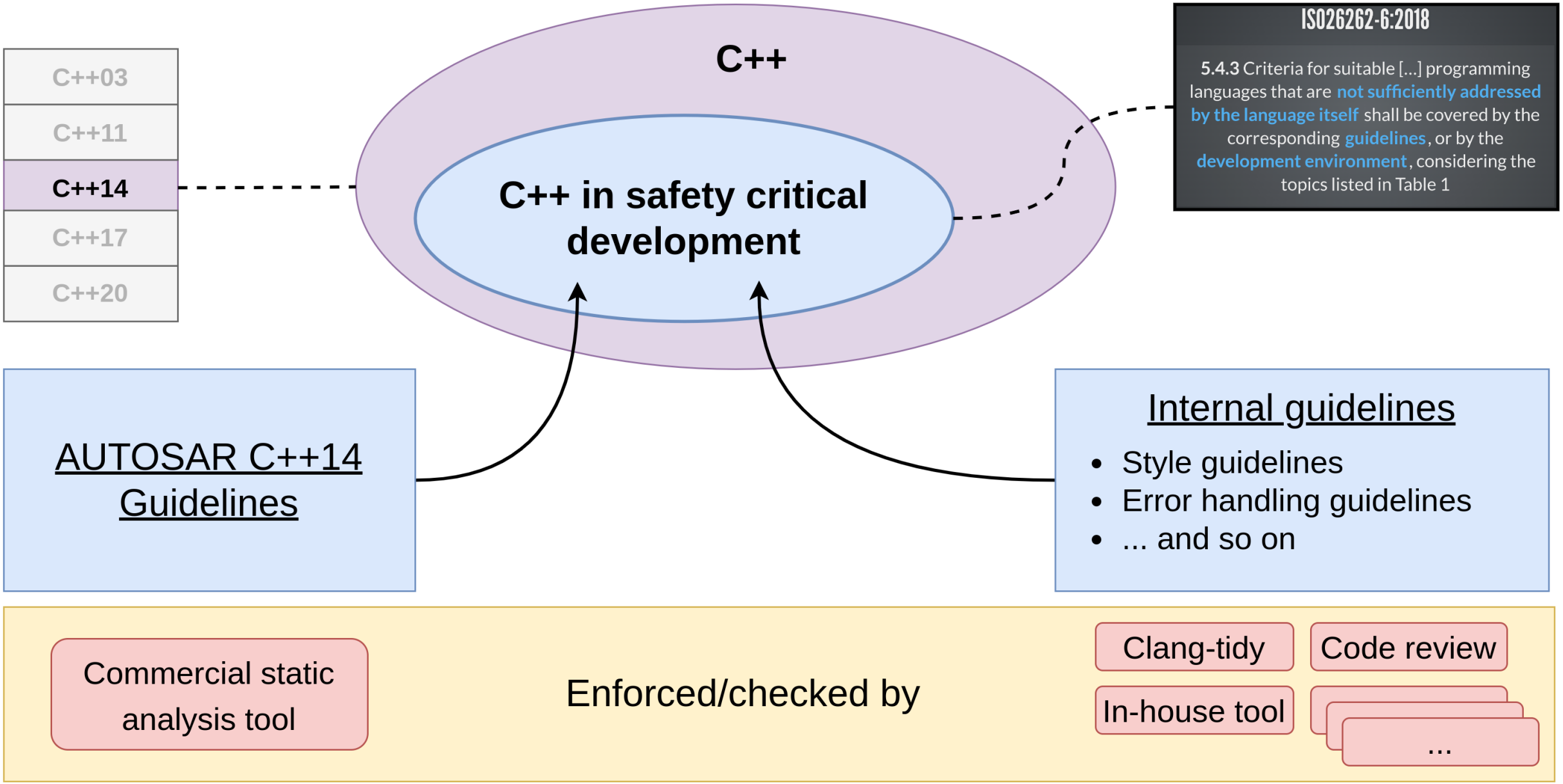
Internal guidelines
• Style guidelines
• Error handling guidelines
• ... and so on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Commercial static analysis tool
Enforced/checked by
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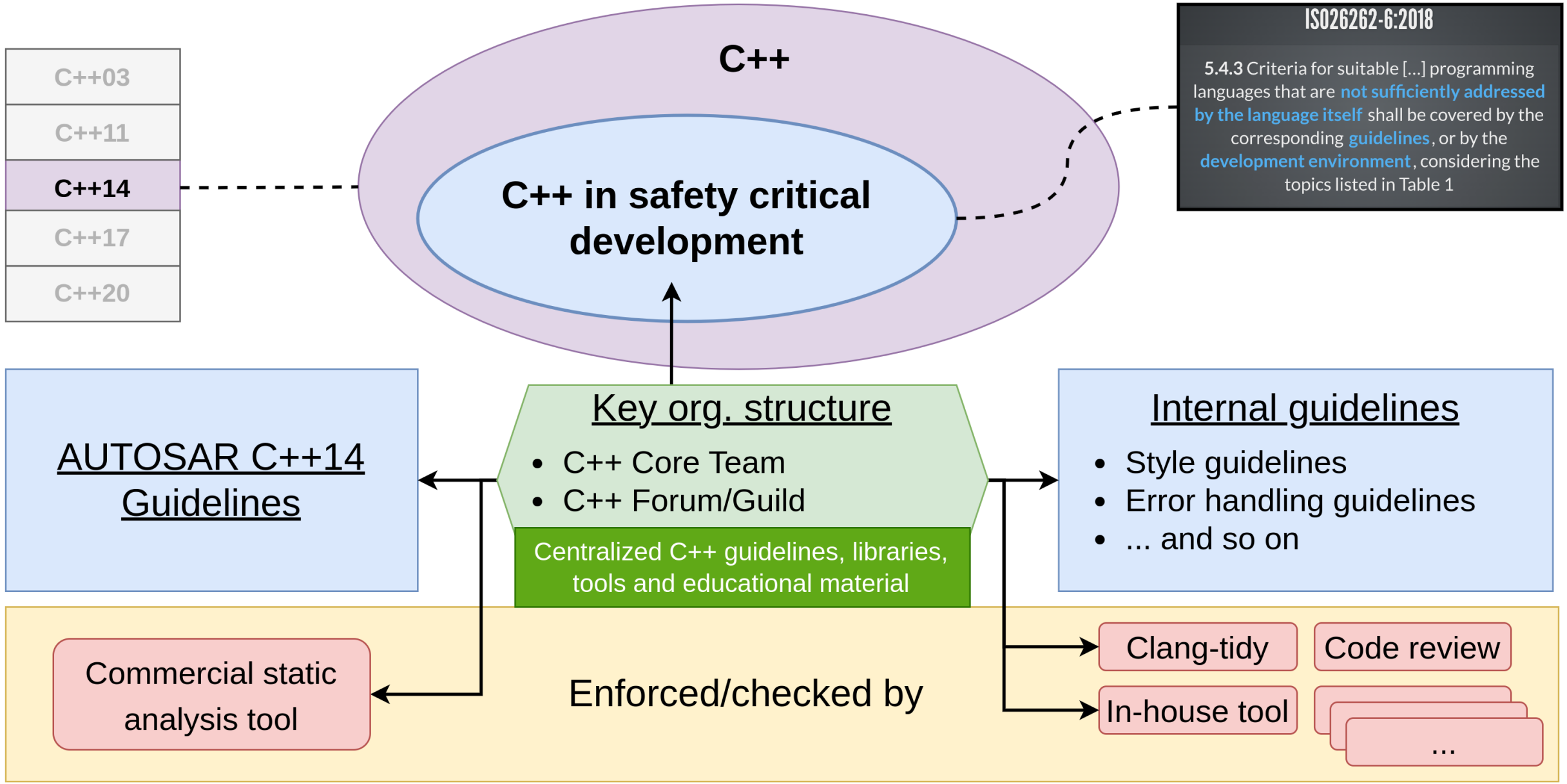
Code review
In-house tool
...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AUTOSAR C++14 Guidelines
Key org. structure
C++ Core Team
C++ Forum/Guild
Centralized C++ guidelines, libraries, tools and educational material
Internal guidelines
Style guidelines
Error handling guidelines
... and so on
Commercial static analysis tool
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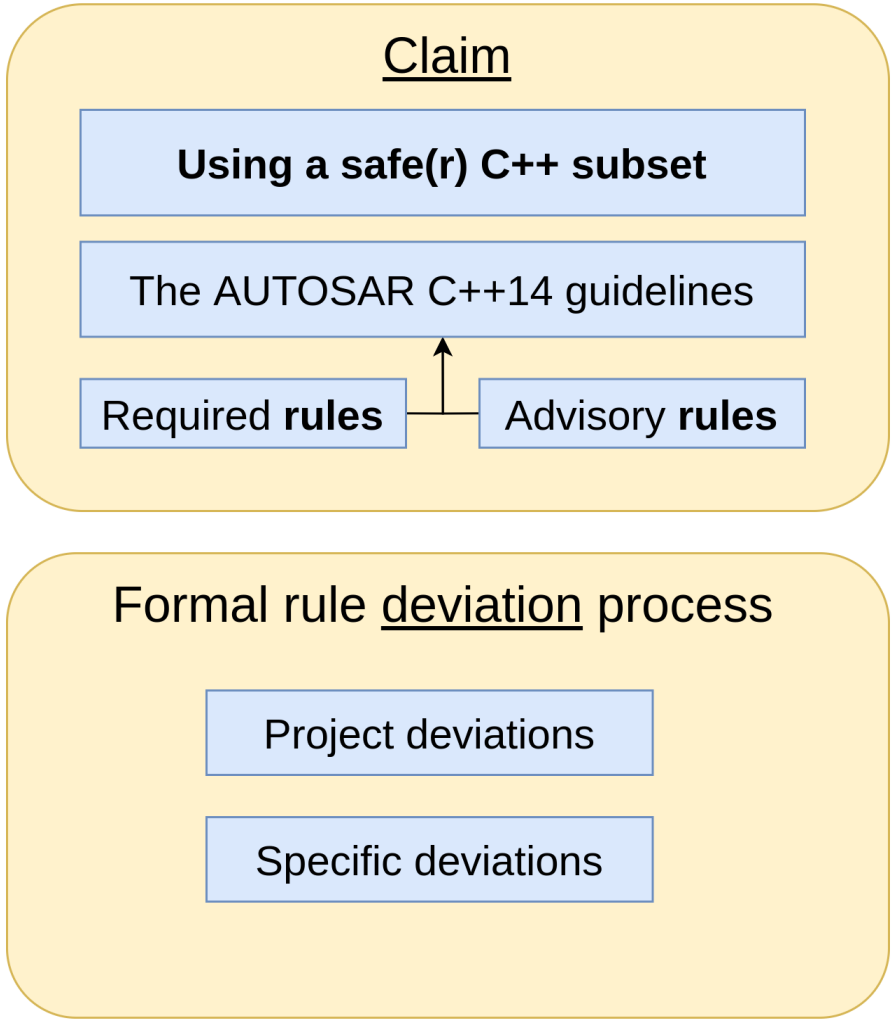
...

Rule compliance vs static analysis tools' diagnostics



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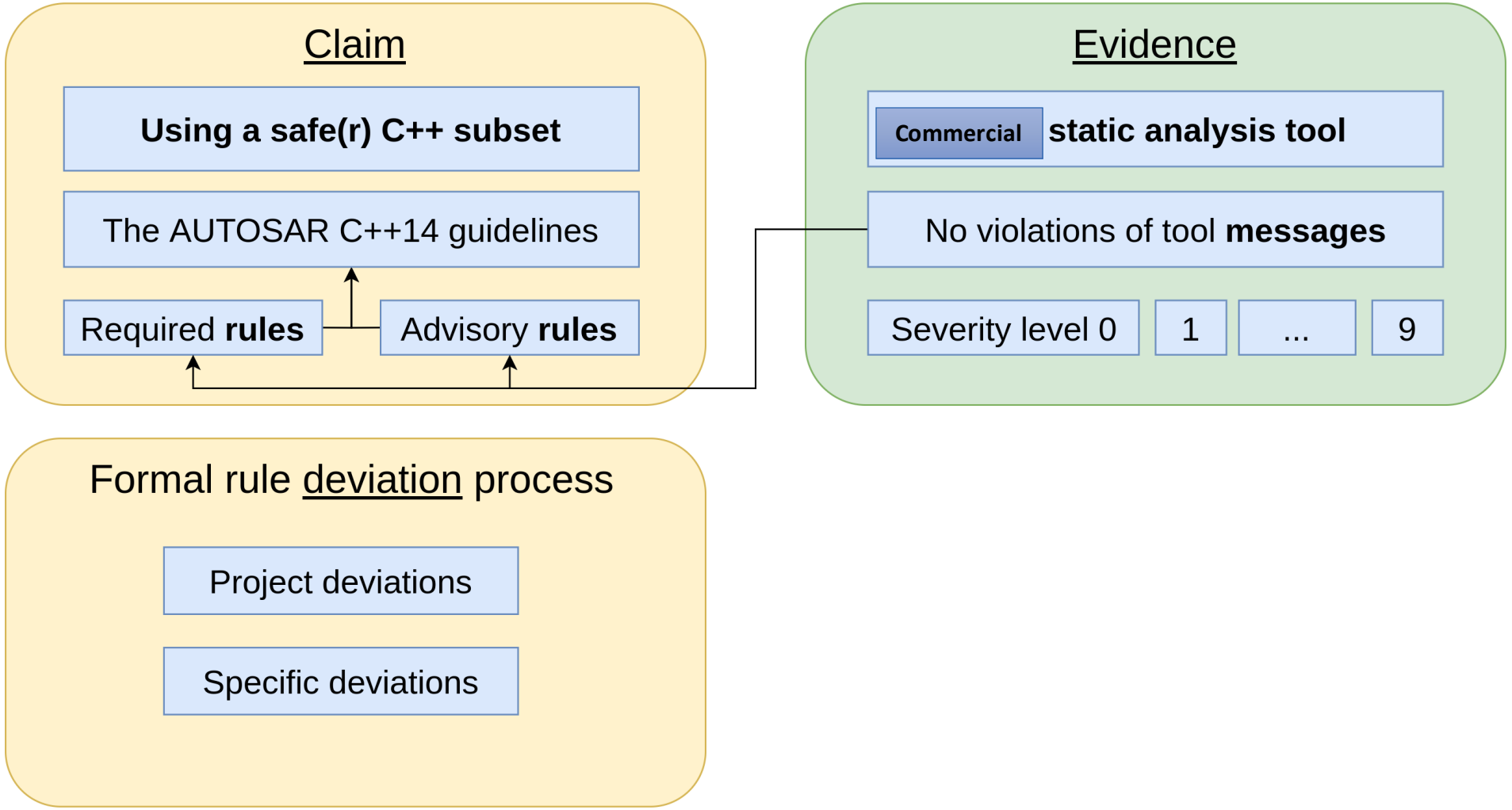

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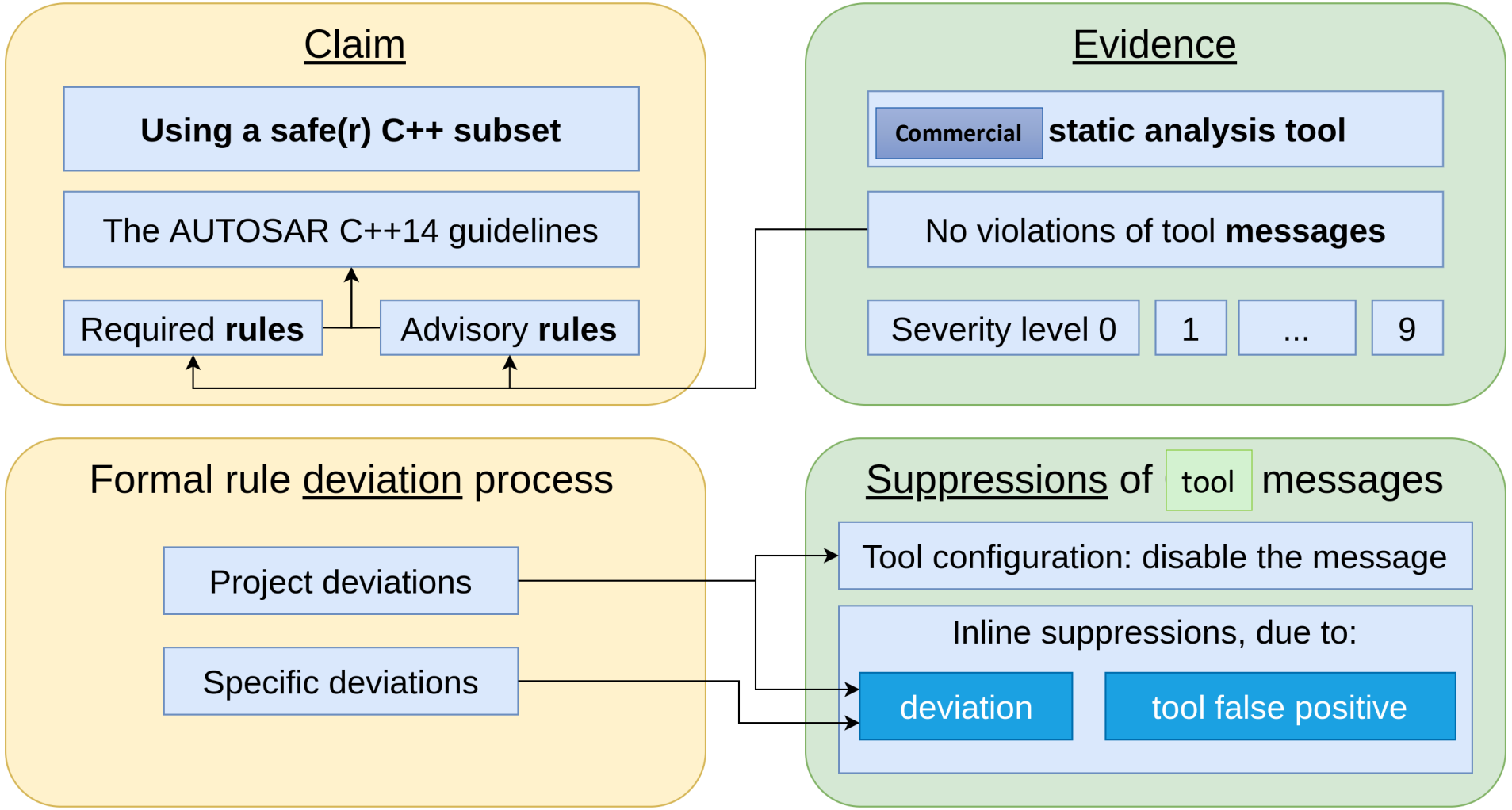

Memory safety

- ✓ Dynamic memory allocations?
  - ✓ Init-phase vs run-phase
  - ✓ In-house mallblocker tool

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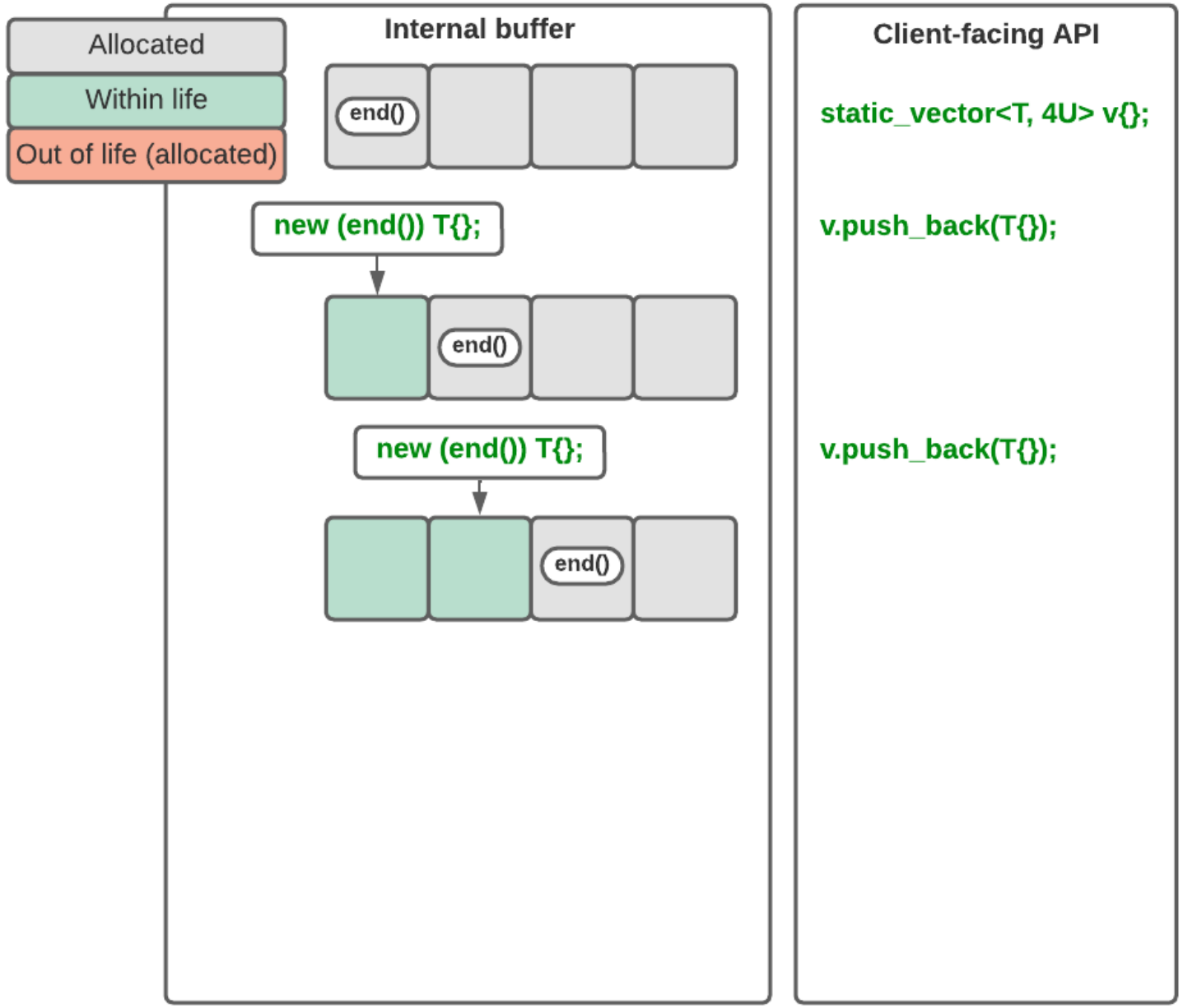
  - ✓ Init-phase vs run-phase
  - ✓ In-house mallblocker tool
- ✓ Valgrind & AddressSanitizer (ASan)
  - ✓ (Example) Needs some help in lack to capture a wider scope of error


Allocated
Within life
Out of life (allocated)
Internal buffer
Client-facing API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end()
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Client-facing API
static_vector<T, 4U> v{};
v.push_back(T{});
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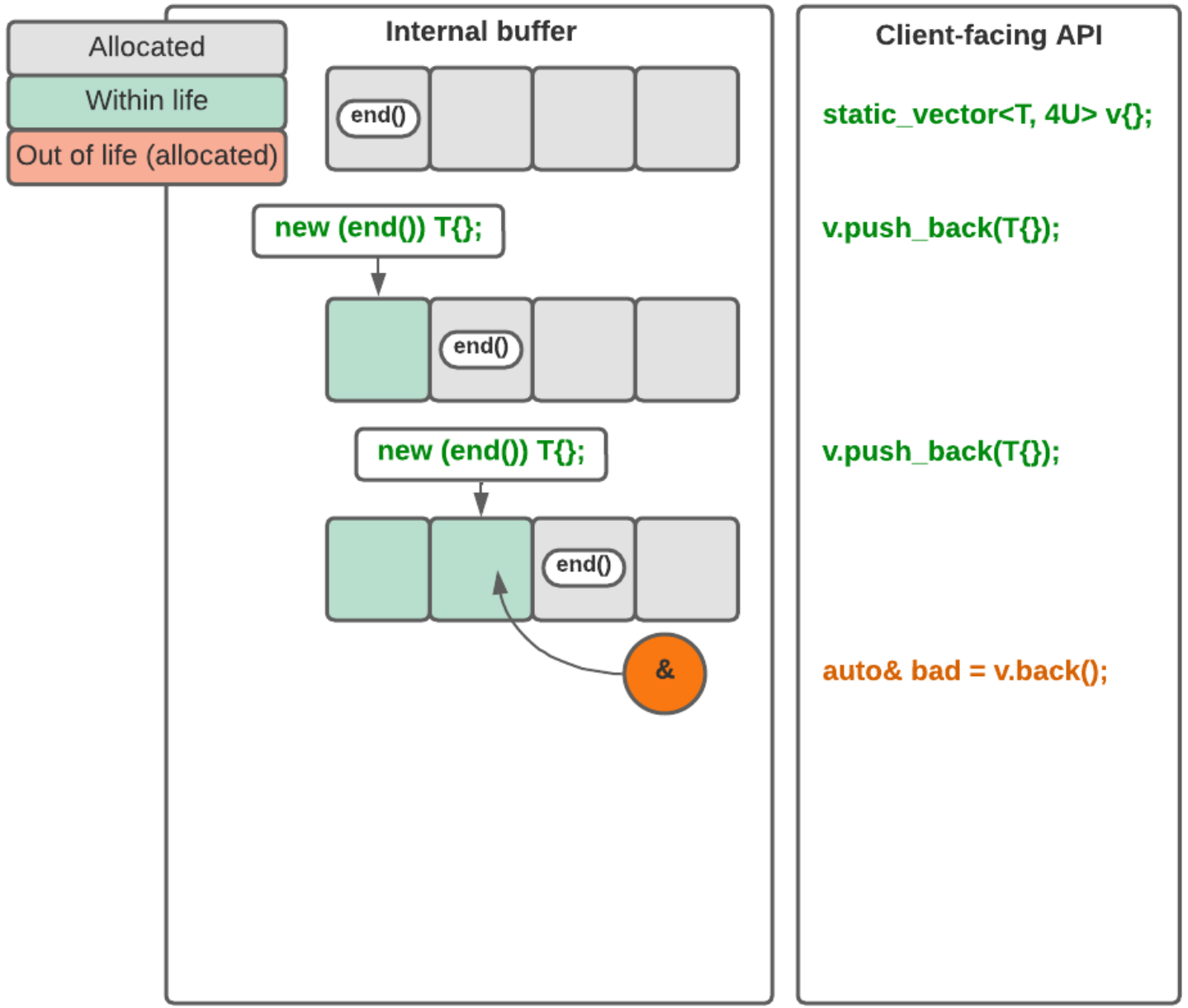
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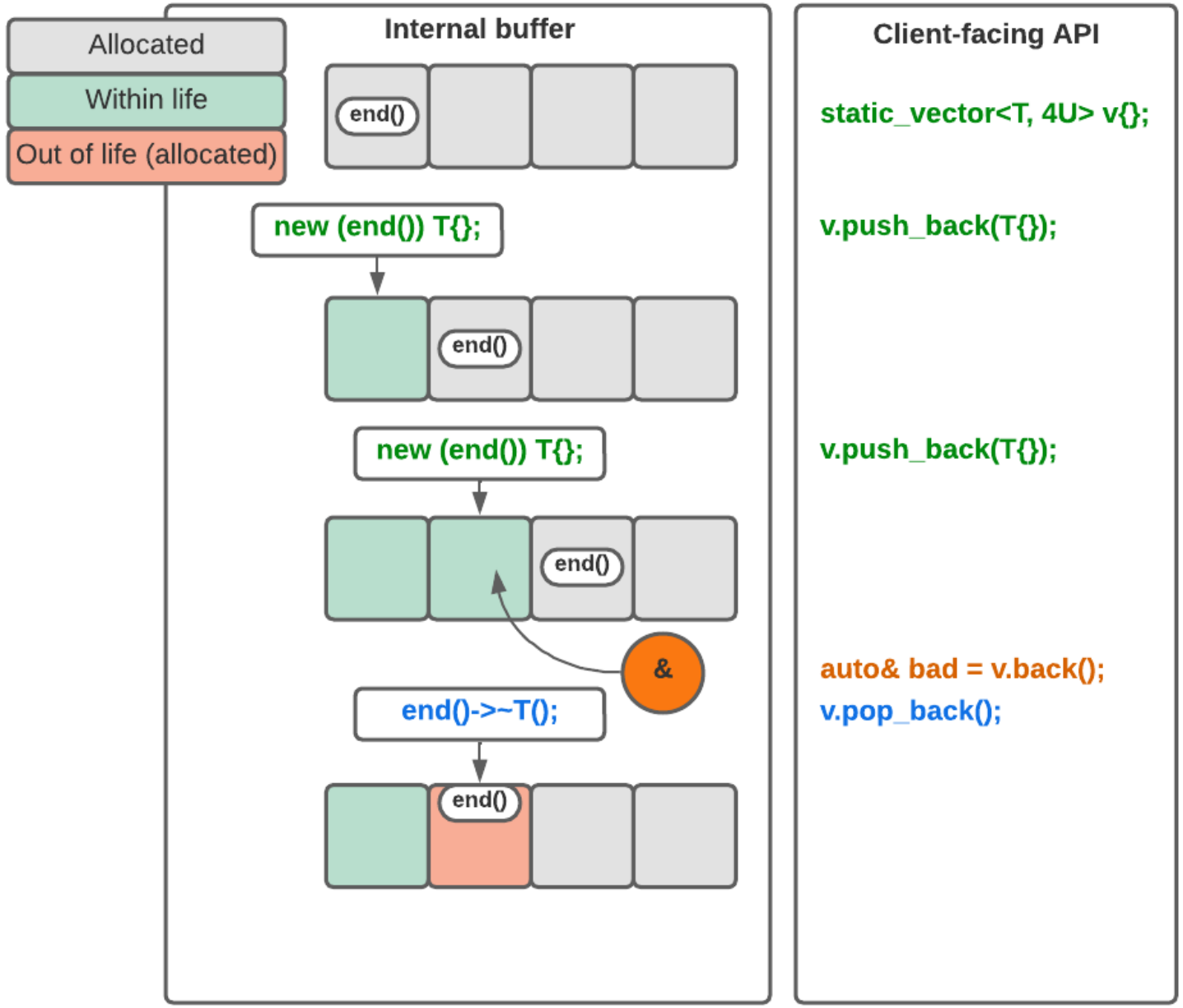
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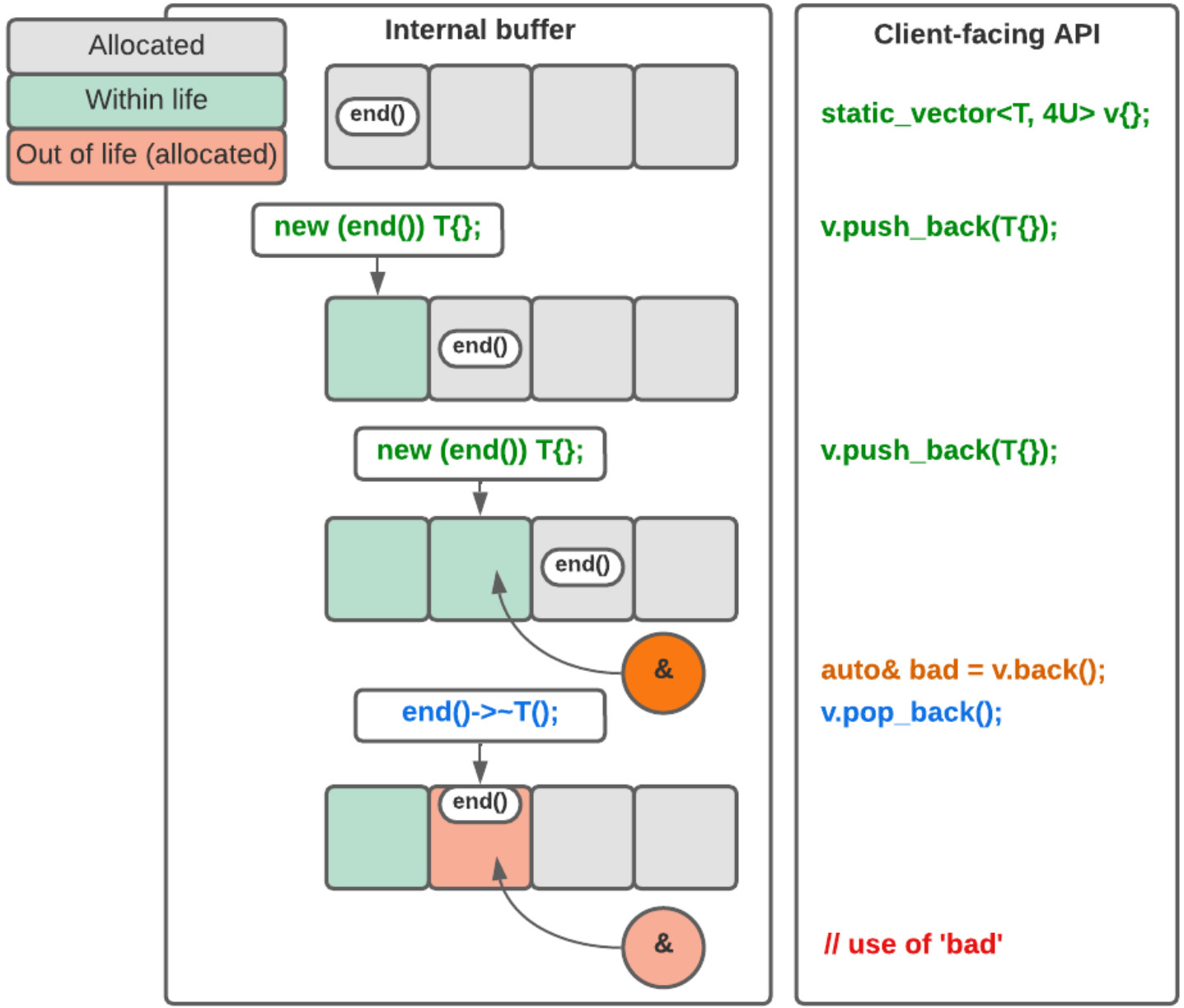
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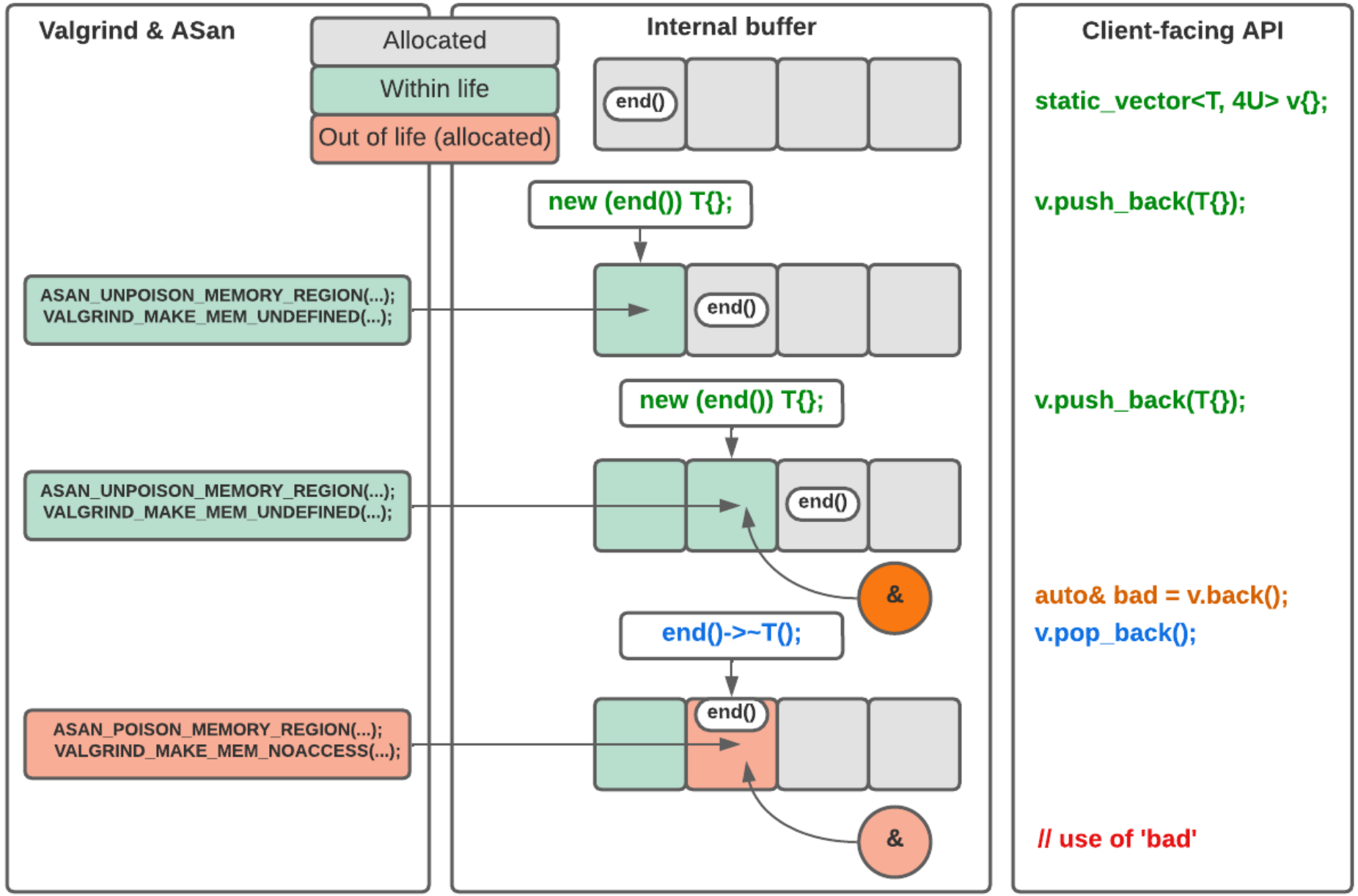
v.pop_back();
// use of 'bad'


Valgrind & ASan
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Memory safety and beyond (language safety)

- ✓ Strong industry focus (beyond safety-critical domain) on memory safe languages
- ✓ C++ & WG21: P2816R0
  - ✓ Emphasis on type and resource safety
  - ✓ Many different notions of what "safety" encompasses
  - ✓ *Safety profiles*: "A cocktail of techniques" comes with a cost (cognitive complexity)

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- ✓ Strong industry focus (beyond safety-critical domain) on memory safe languages
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  - ✓ Emphasis on type and resource safety
  - ✓ Many different notions of what "safety" encompasses
  - ✓ *Safety profiles*: "A cocktail of techniques" comes with a cost (cognitive complexity)
- ✓ Not necessarily initially a focus on topics that are essential to the safety-critical domain
  - ✓ E.g.: **contracts** is a high-value target for safety-critical space, but not necessarily the highest prioritization for the C++ language safety space

Standard and core libraries

- ✓ Vendor-shipped
  - ✓ Pros: written by the pros, ...
  - ✓ Cons: need of qualification evidence, not aimed at safety-critical domain to begin with, ...

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- ✓ Inhouse versions
  - ✓ Pros:
    - ✓ Poor man's contracts
      - ✓ The Lakos Rule
    - ✓ Allows removing inherently unsafe APIs
    - ✓ Backporting yet-to-be implemented (e.g. in C++14) libs
    - ✓ Consolidation of in-house non-STL core libs and in-house STL implementations
  - ✓ Cons: reinventing the wheel, sub-par (non-vendor) implementations, ...

Standard and core libraries

- ✓ Open-source libs and STL backports?
  - ✓ Challenging to use in context of safety-critical applications
    - ✓ … even for the parts/software components that are not safety-critical (more on this later)
  - ✓ Bazel and Bazel meta-data can be used to protect from unintentional misuse

Unit testing & test sufficiency

- Some basic premises:
  - Dijkstra on **test sufficiency**: "Program testing can be used to show the presence of bugs, but never to show their absence"
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- ✓ Test integrity
  - ✓ Apply coding guidelines also for tests (to a reasonable extent)
  - ✓ -Werror on tests
  - ✓ Promote a testing first mentality (TDD, …)
- ✓ Test sufficiency: we need something other than the tests themselves

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  - Goodheart's Law: "Any observed statistical regularity will tend to collapse once pressure is placed upon it for control purposes"

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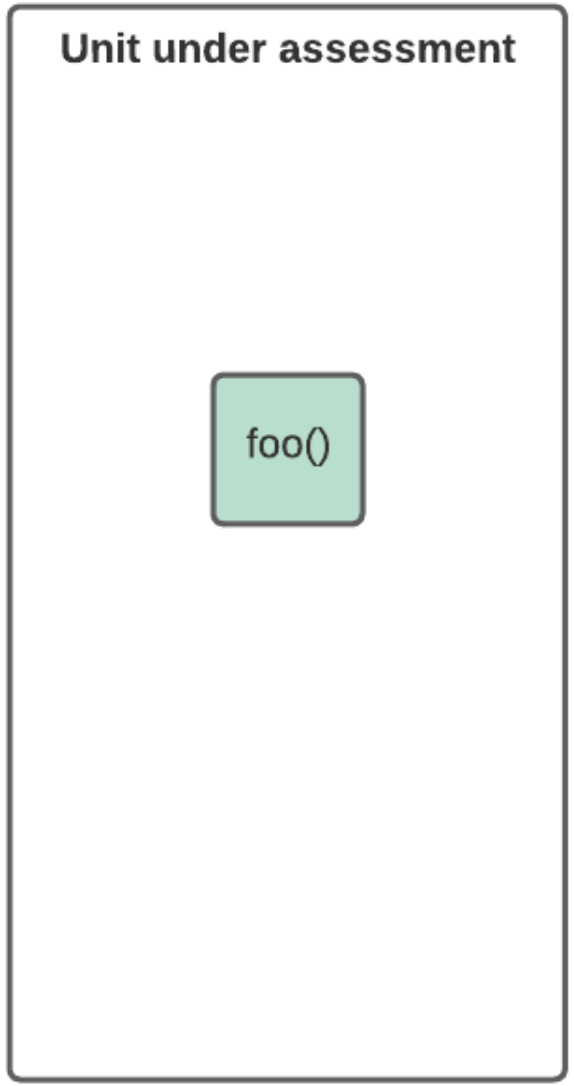
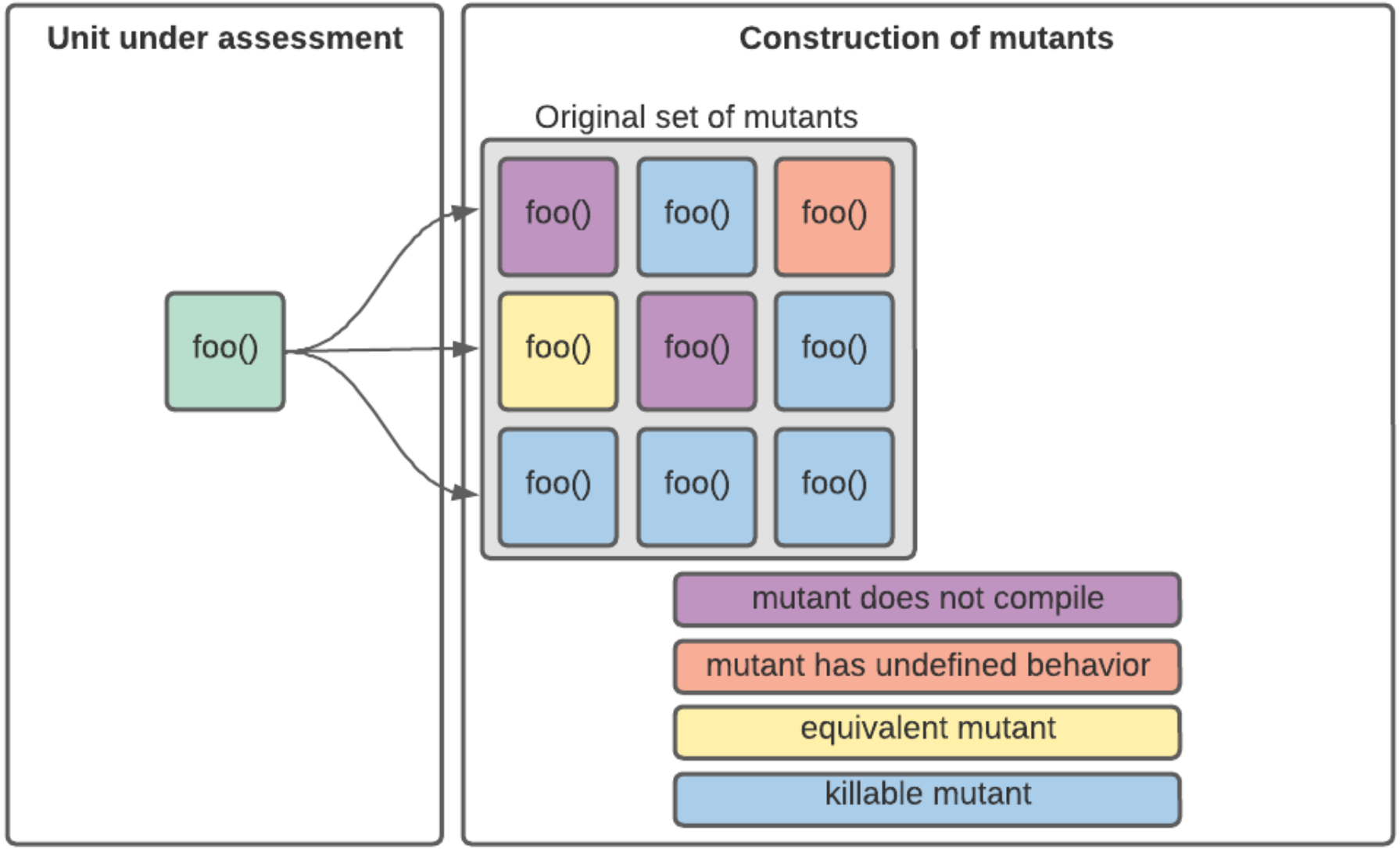
- ✓ Metric: code coverage
  - ✓ Not a silver bullet
  - ✓ Highly and arguably overly so relied on by safety standards
- ✓ Metric: mutation score (mutation testing)
  - ✓ Highest fault revelation among all common structural testing criteria
  - ✓ Difficult to use in practice

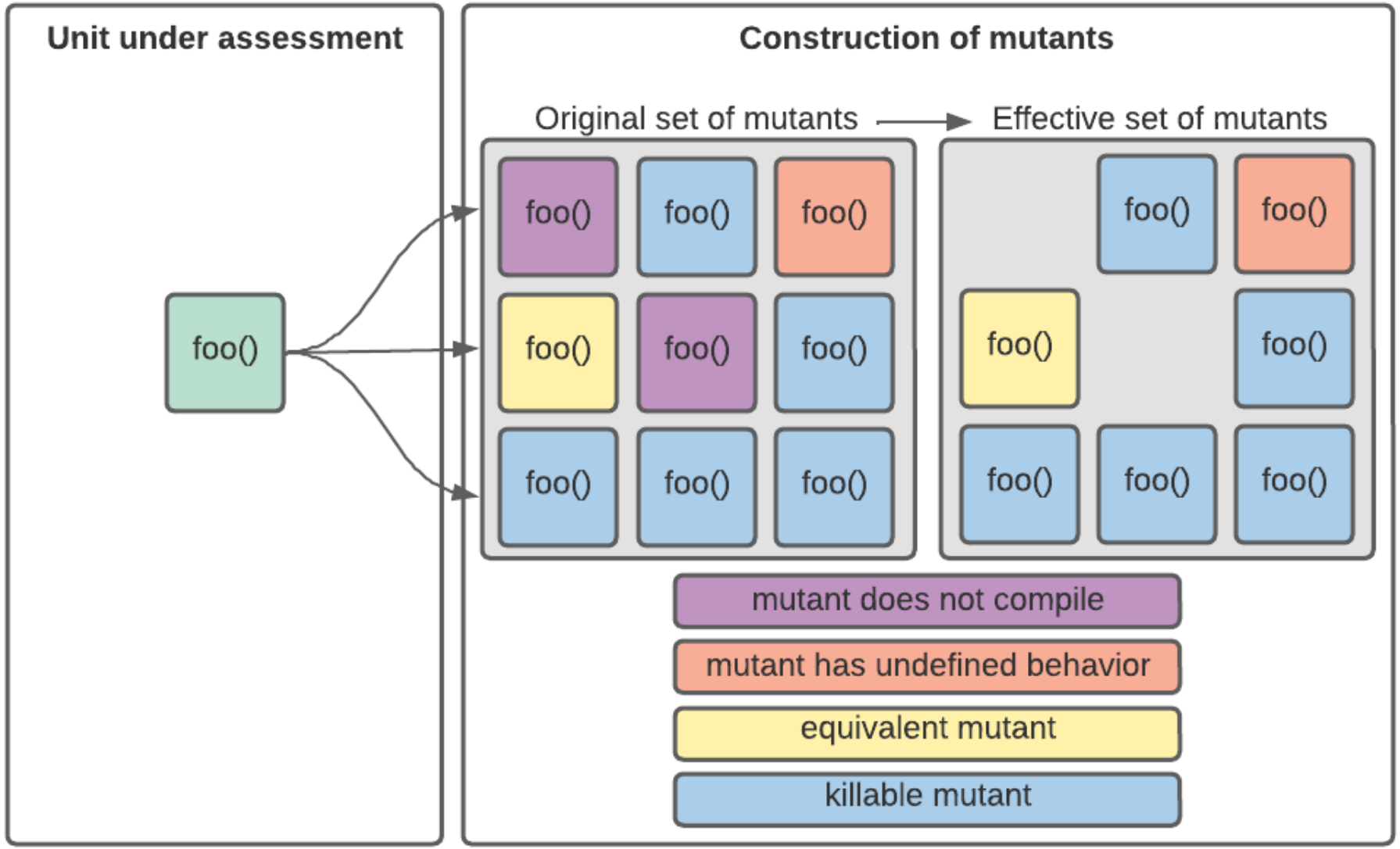
Unit testing & test sufficiency: mutation testing



Unit testing & test sufficiency: mutation testing



Unit testing & test sufficiency: mutation testing



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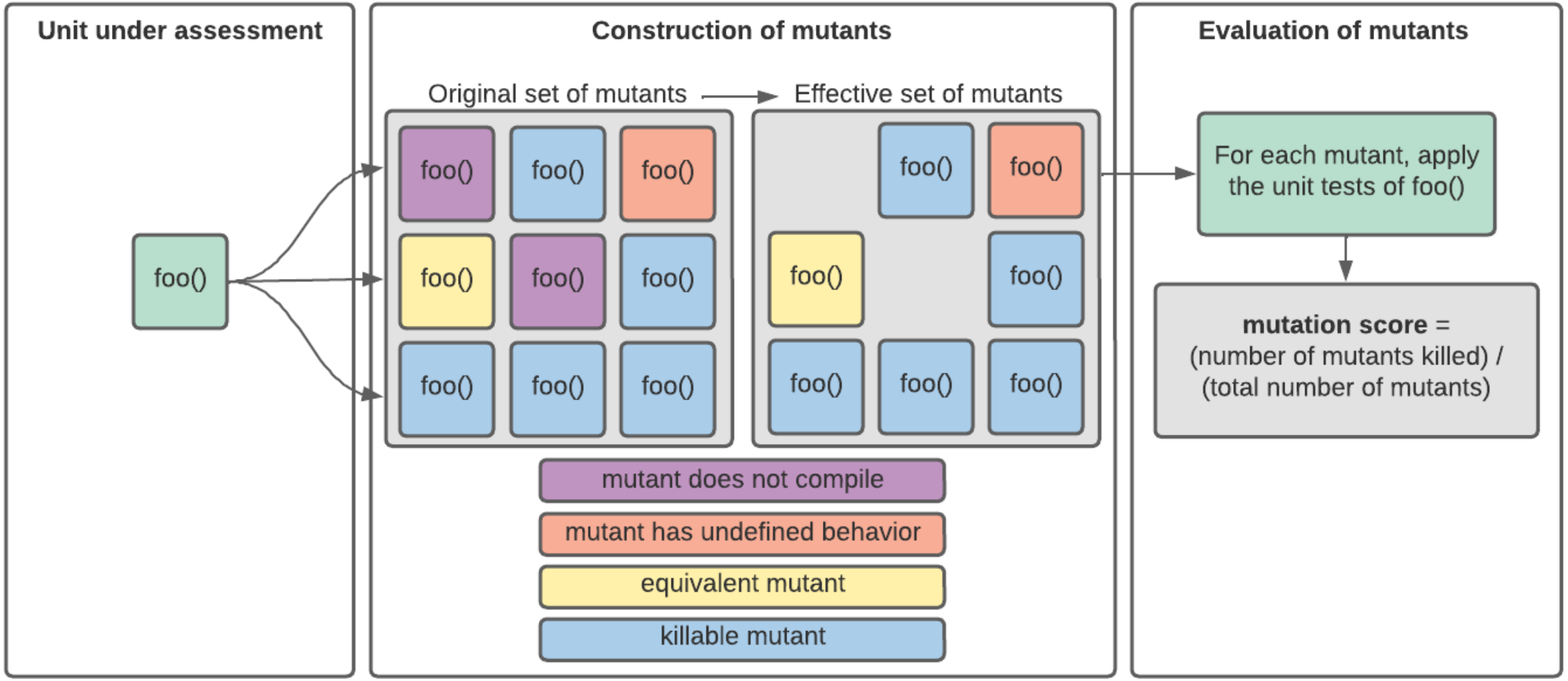

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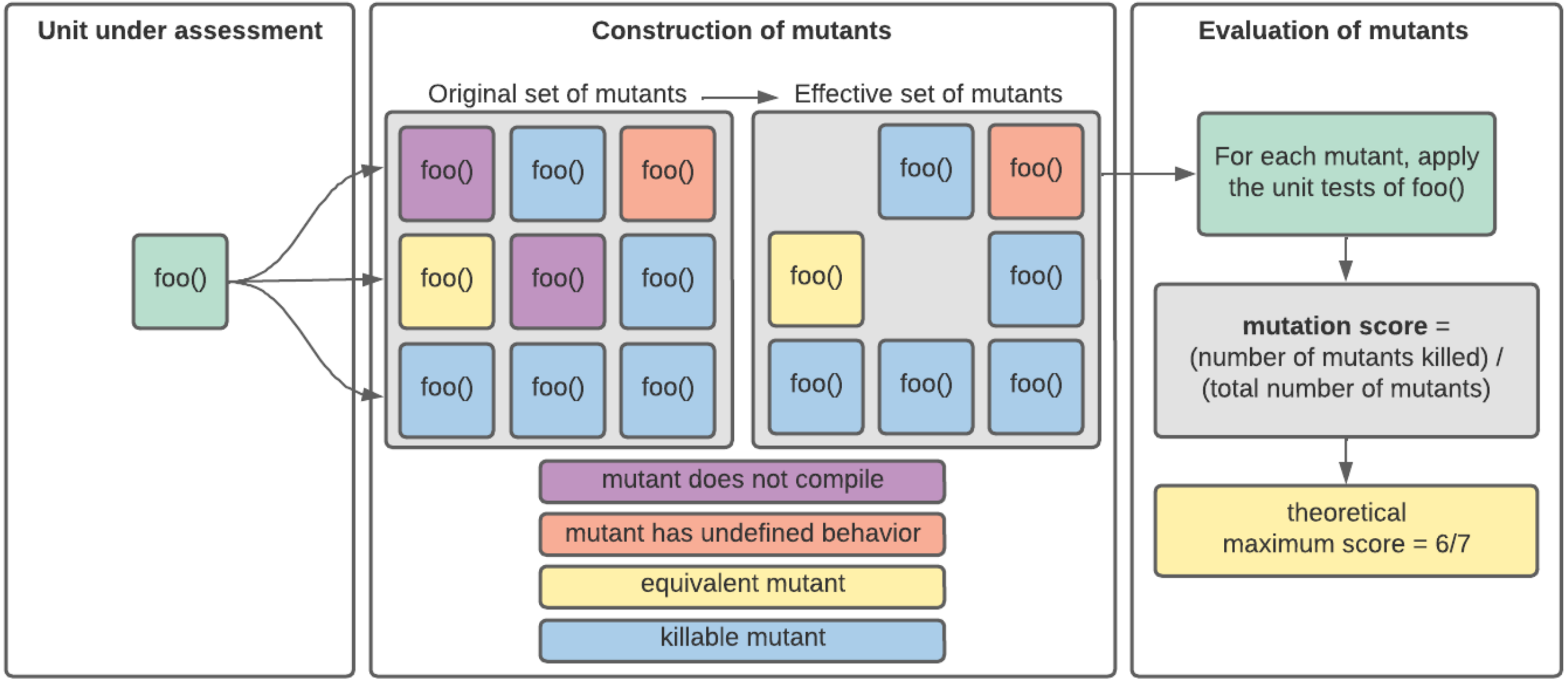

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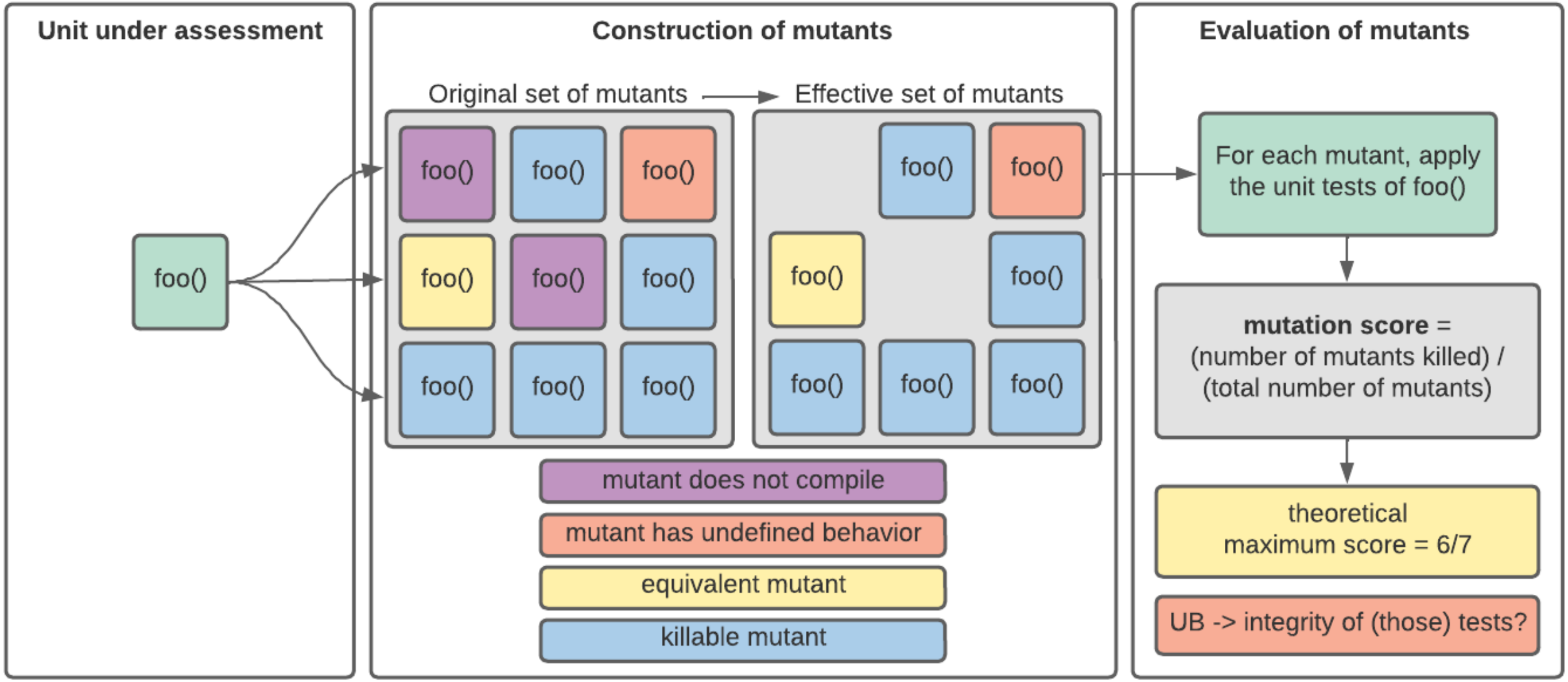

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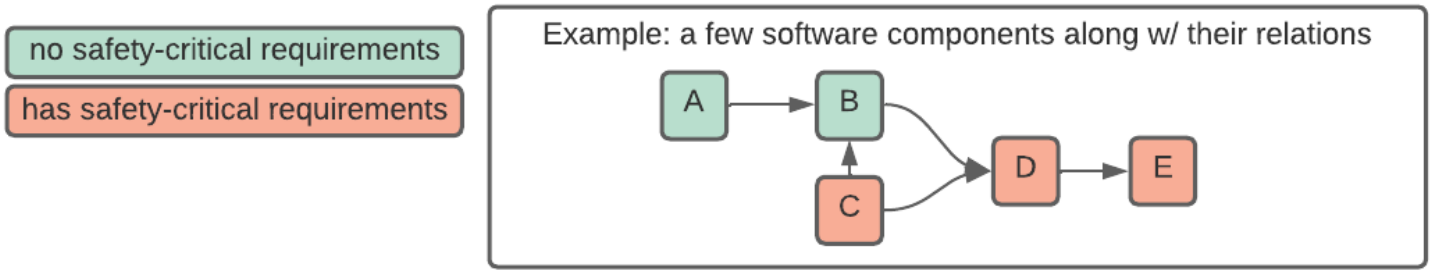

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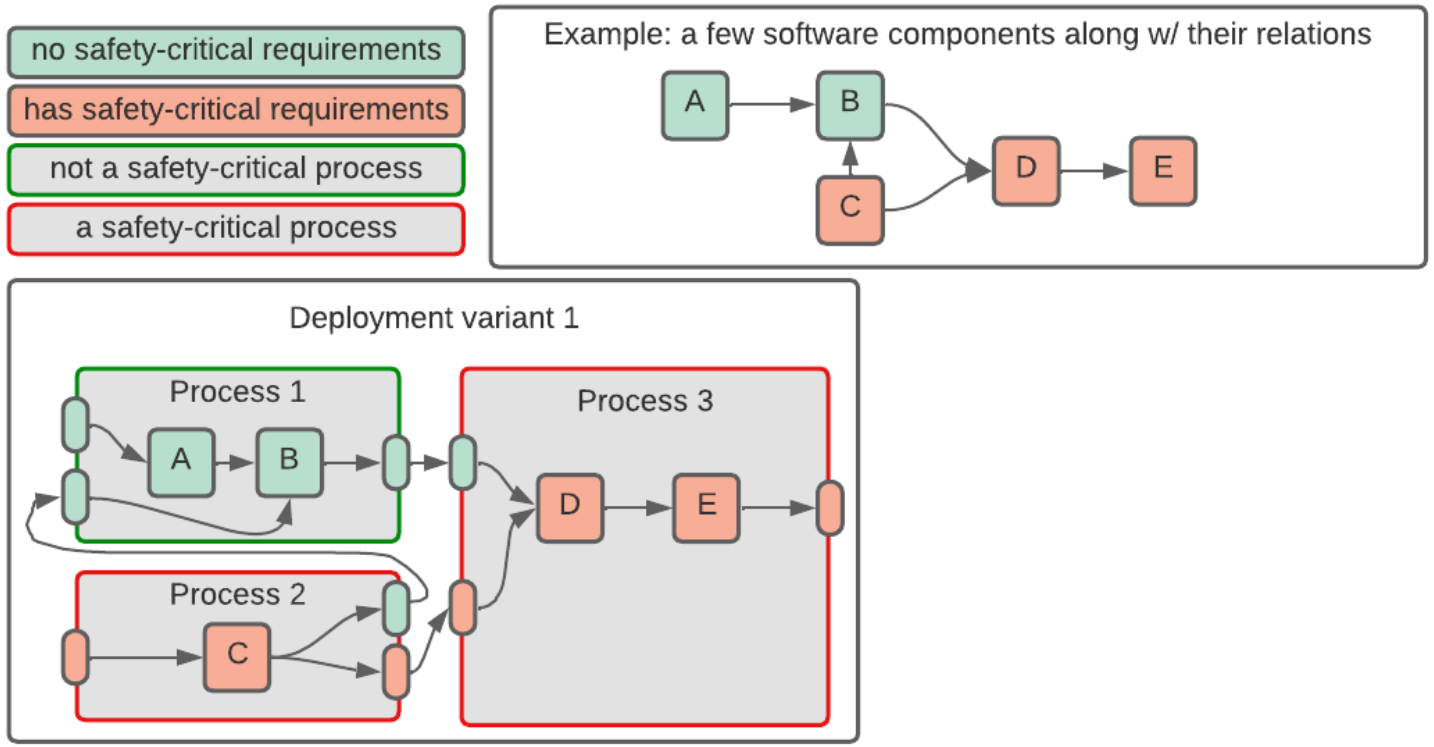

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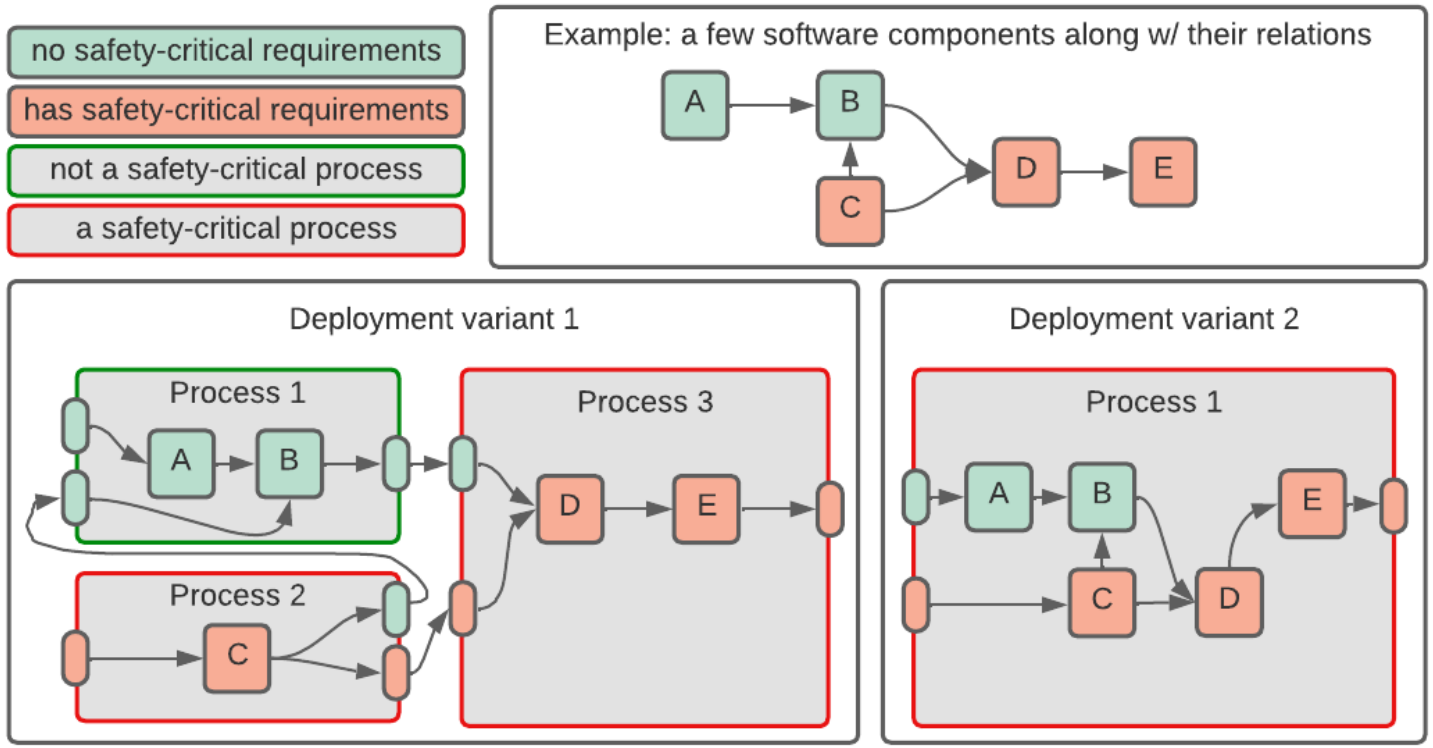

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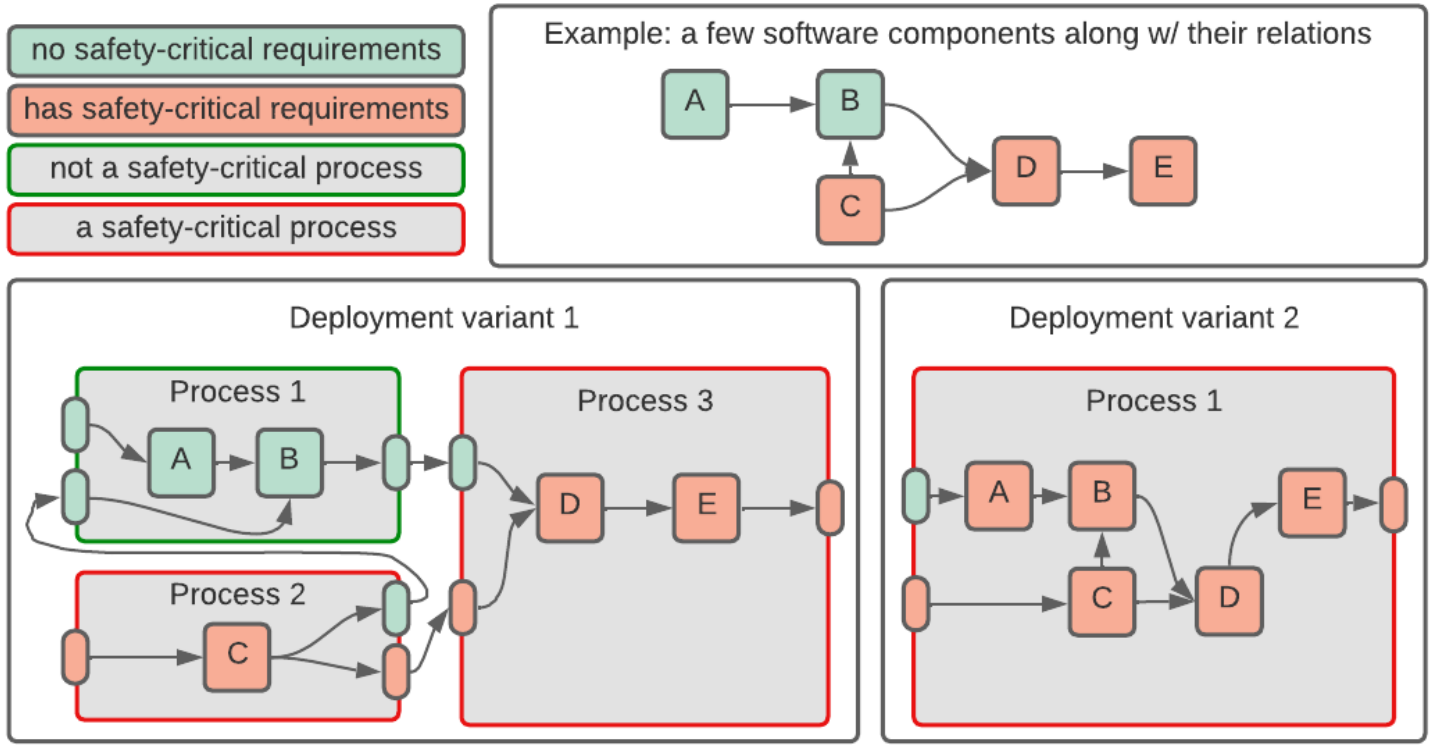

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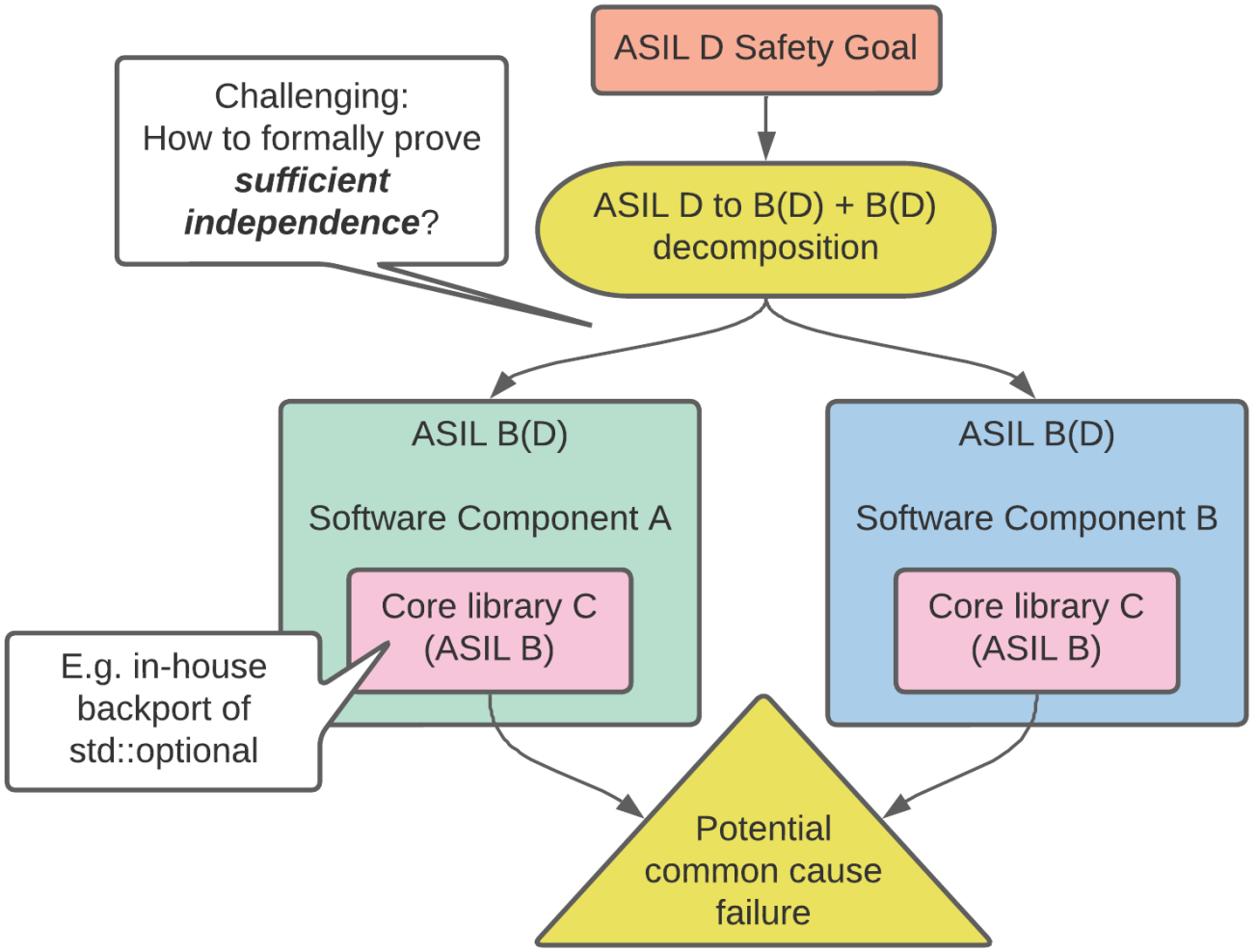
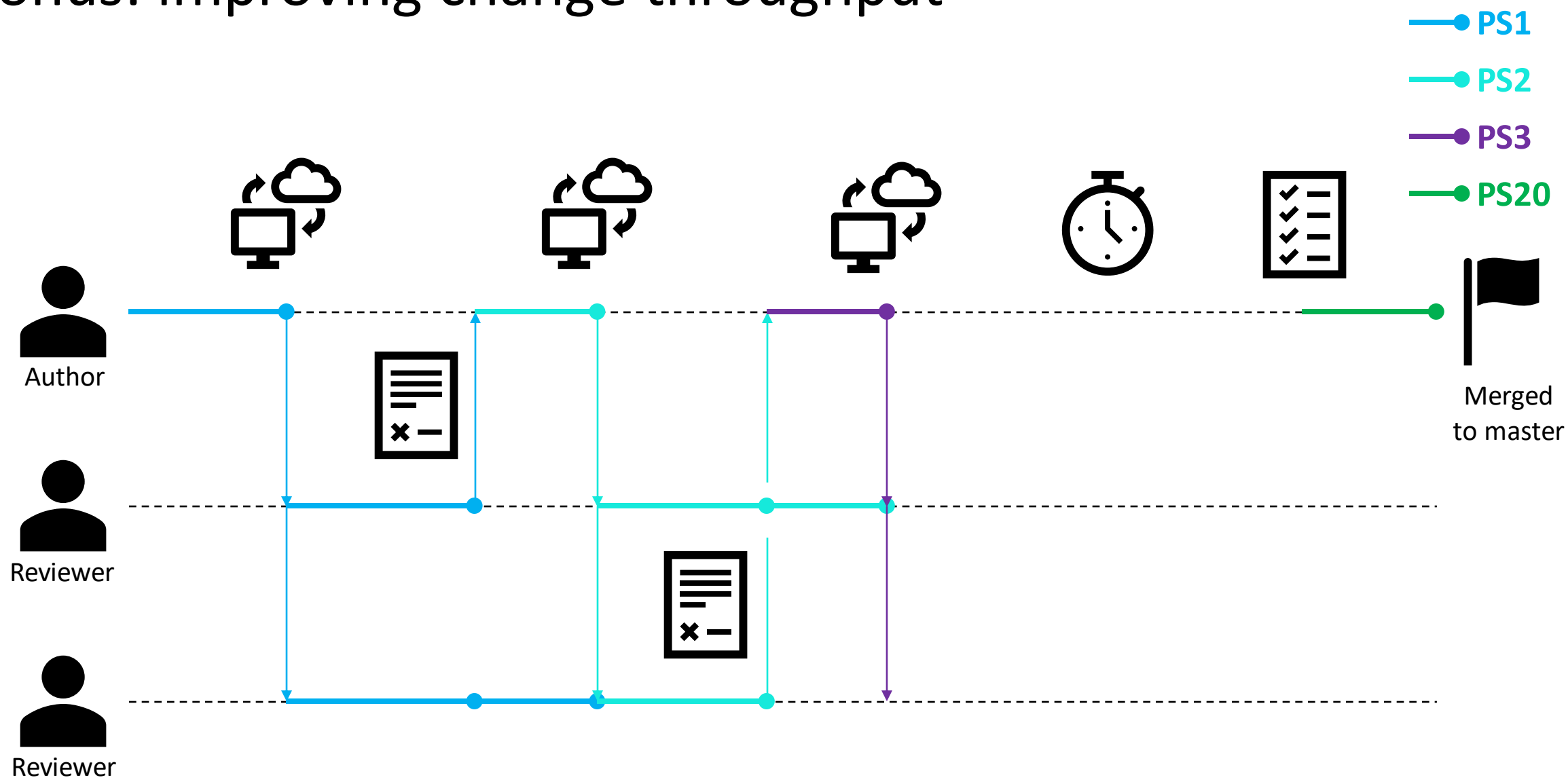
- ✓ Repository uniformity facilitates safety culture
  - ✓ E.g.: within reasonable limits, consolidate coding requirements on safety- and non-safety-critical code
  - ✓ Additional pro: facilitates robustness towards higher-level safety and deployment architectural changes

Safety vs software engineering: perceived contradictions

- ✓ Common cause failures vs code re-use



Bonus: improving change throughput



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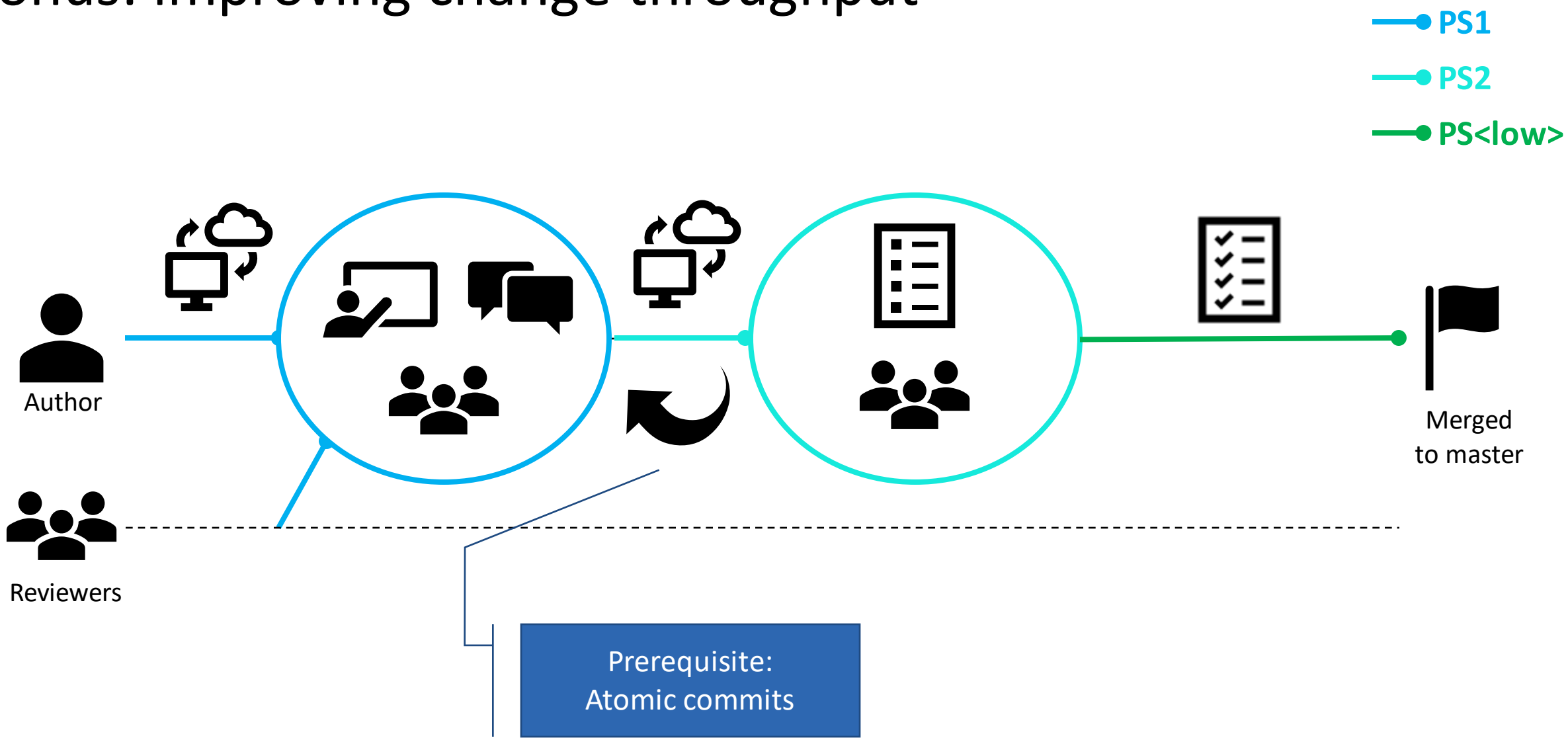

A few other interesting topics (out of scope today)

- ✓ How to handle debug-only code
- ✓ Error-handling guidelines on a unit/library level
- ✓ Floating point guidelines (**difficult**)
- ✓ Software architecture and fault handling on architectural elements' boundaries