UNIVERSITAT DE BARCELONA

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GURETRUCK

FV Time Manager powered by Formally Verified Time Library

EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

Bosch i Gimpera
UNIVERSITAT DE BARCELONA

DOCTORATS INDUSTRIALS
talent alliance!

Generalitat de Catalunya


WELCOME

THE REGULATIONS ARE LOCALLY STRICTLY STIPULATED BUT:

- Driving data is corrupted;
- Legal enforcement software flawed;
- Certain legal texts at the best ambiguous;
- And possibly not consistent or coherent.

Could logic be of any help?

Mathematical logic can check laws with clear-cut ontologies for

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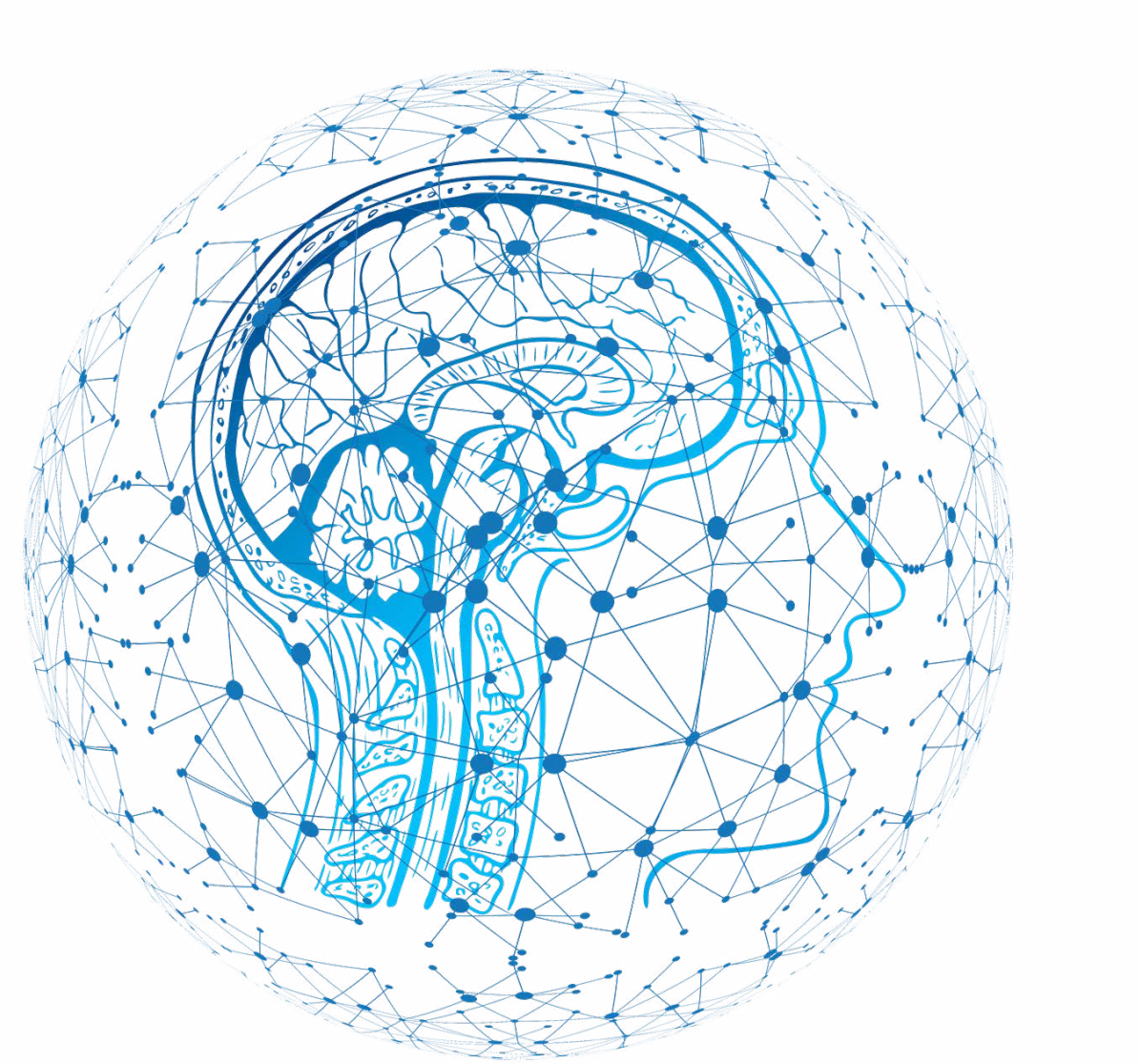
- Consistency;
- Tractability;
- Meeting physics constraints;
- Certificate that software meets the specification.

OUTLINE OF MY TALK:



OUTLINE OF MY TALK:

- Intro

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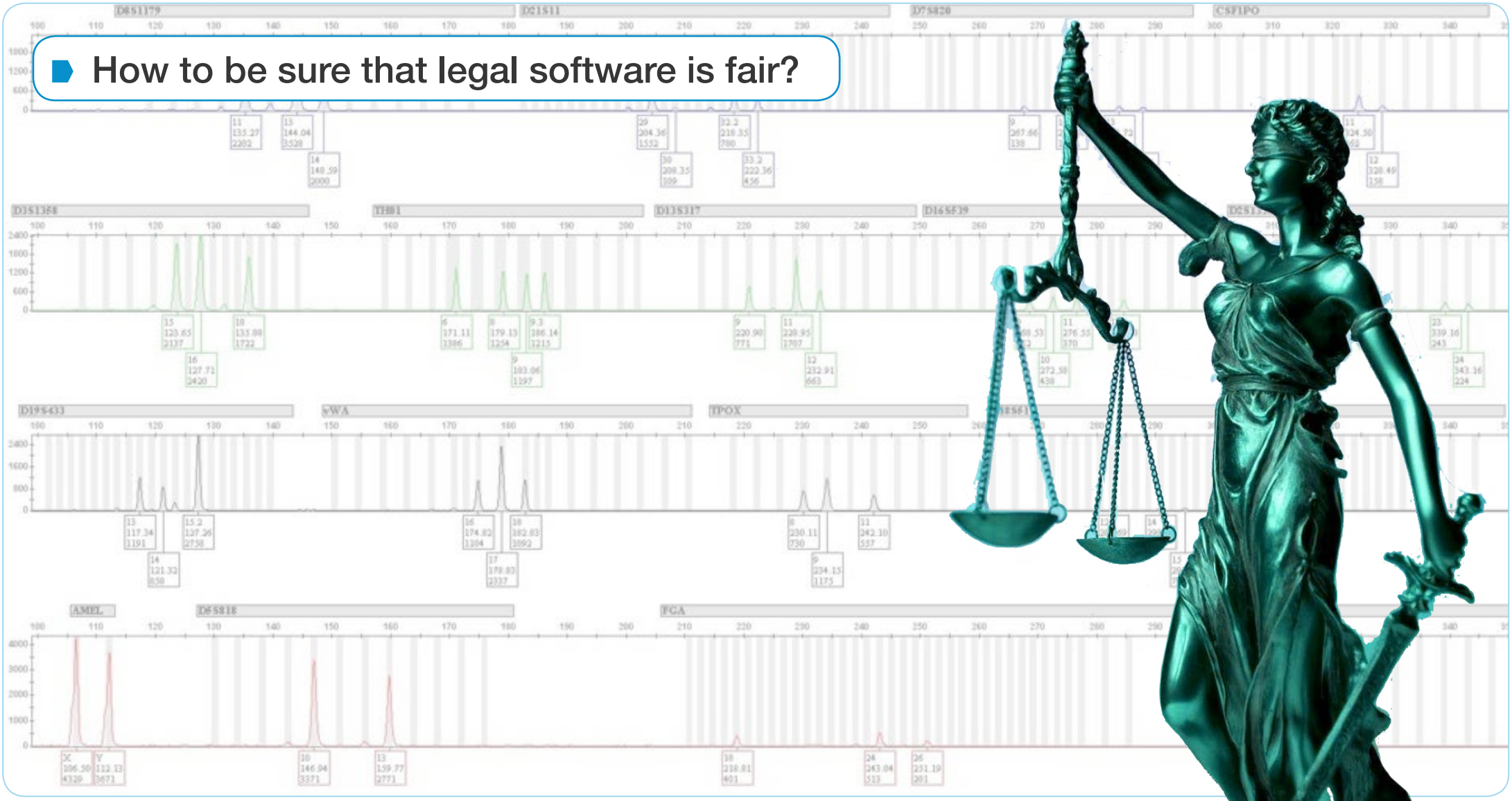
  Formally Verified Time Library
- The future ahead of us


Critical software should be error-free!

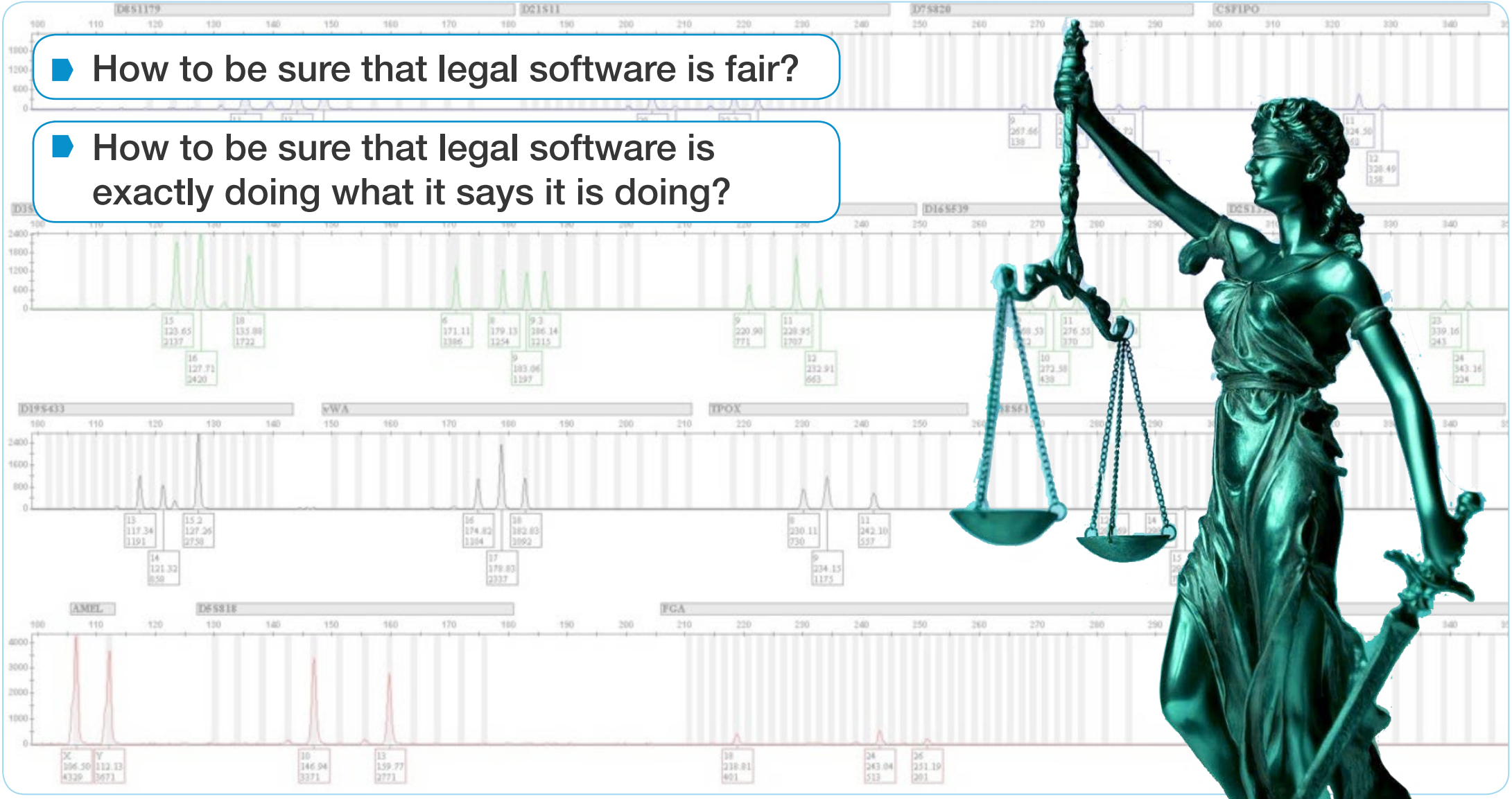
AI in society and law

- How to be sure that legal software is fair?



AI in society and law

- How to be sure that legal software is fair?
- How to be sure that legal software is exactly doing what it says it is doing?



AI in society and law

- How to be sure that legal software is fair?
- How to be sure that legal software is exactly doing what it says it is doing?
- How to provide full legal transparency to legal software without necessarily disclosing the proprietary source code?

IMPERATIVE PARADIGM.

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It is close to the machine and it gives sequential imperative instructions:

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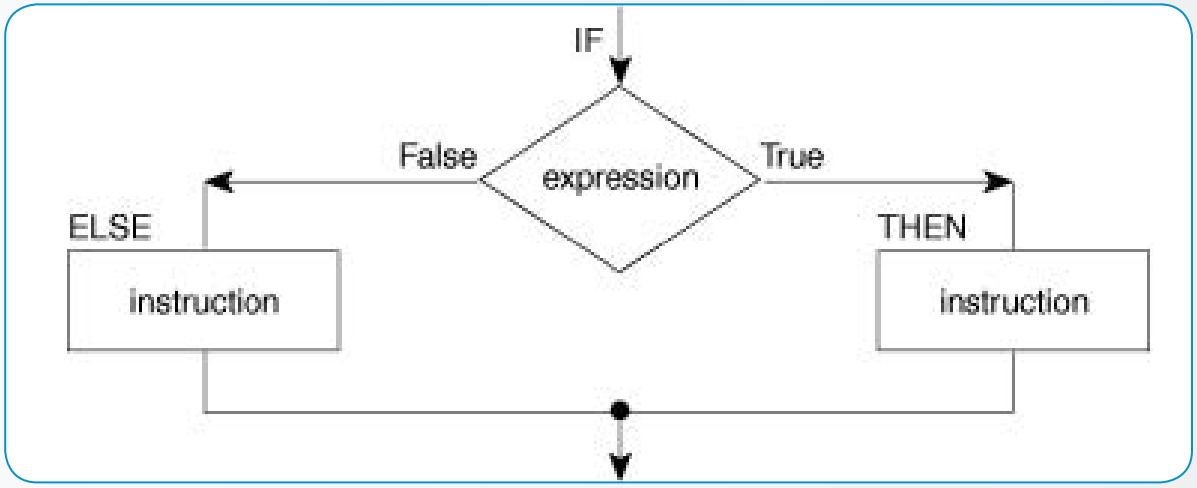
- Etc.



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We do not tell the computer how to operate.

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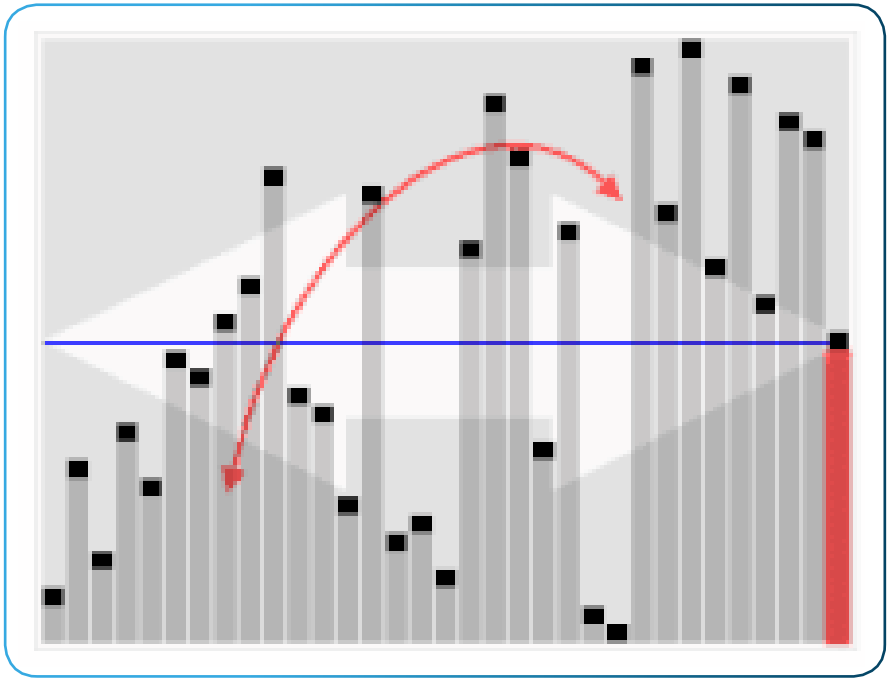
- Advantage: We can easily reason about our programs and prove their correctness.

TEST CASE: SORTING ALGORITHM

- Quicksort is an efficient algorithm which sorts lists of numbers in lexicographical order.



FOR INSTANCE, APPLYING QUICKSORT TO [2,6,1,7] GIVES [1,2,6,7]

IMPERATIVE VS FUNCTIONAL

IMPERATIVE CODE:

```
algorithm quicksort(A, lo, hi) is
    if lo < hi then
        p := partition(A, lo, hi)
        quicksort(A, lo, p)
        quicksort(A, p + 1, hi)

algorithm partition(A, lo, hi) is
    pivot := A[⌊(hi + lo) / 2⌋]
    i := lo - 1
    j := hi + 1
    loop forever
        do
            i := i + 1
        while A[i] < pivot
        do
            j := j - 1
        while A[j] > pivot
        if i ≥ j then
            return j
        swap A[i] with A[j]
```

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```

FUNCTIONAL CODE:

```
algorithm quicksort (l : list) :=
          case l of
            [] -> []
            [a] -> [a]
            (a :: as) -> quicksort [x ∈ l : x ≤ a] ++
                         quicksort [a ∈ l: x > a]
```

DEPENDENT TYPE THEORY CAN REASON ABOUT FUNCTIONAL CODE AND CAN BE USED TO PROVE CORRECTNESS OF THE CODE

VERIFICATION OF FUNCTIONAL CODE

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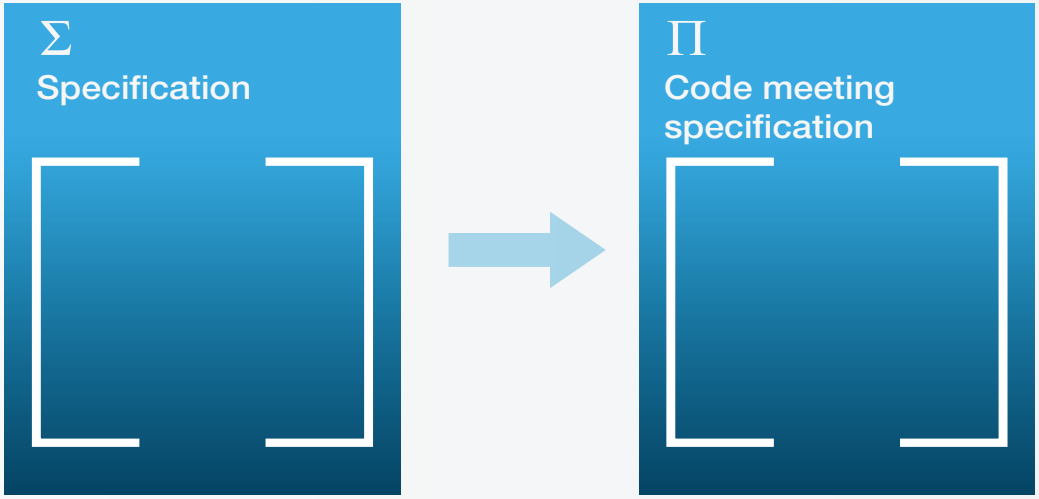

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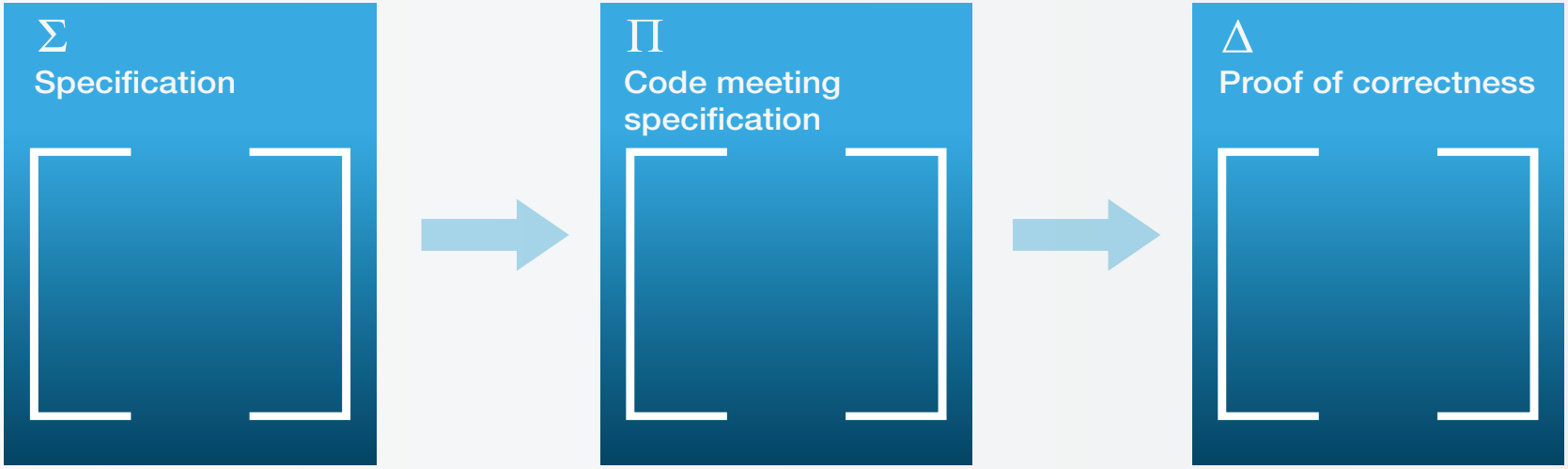

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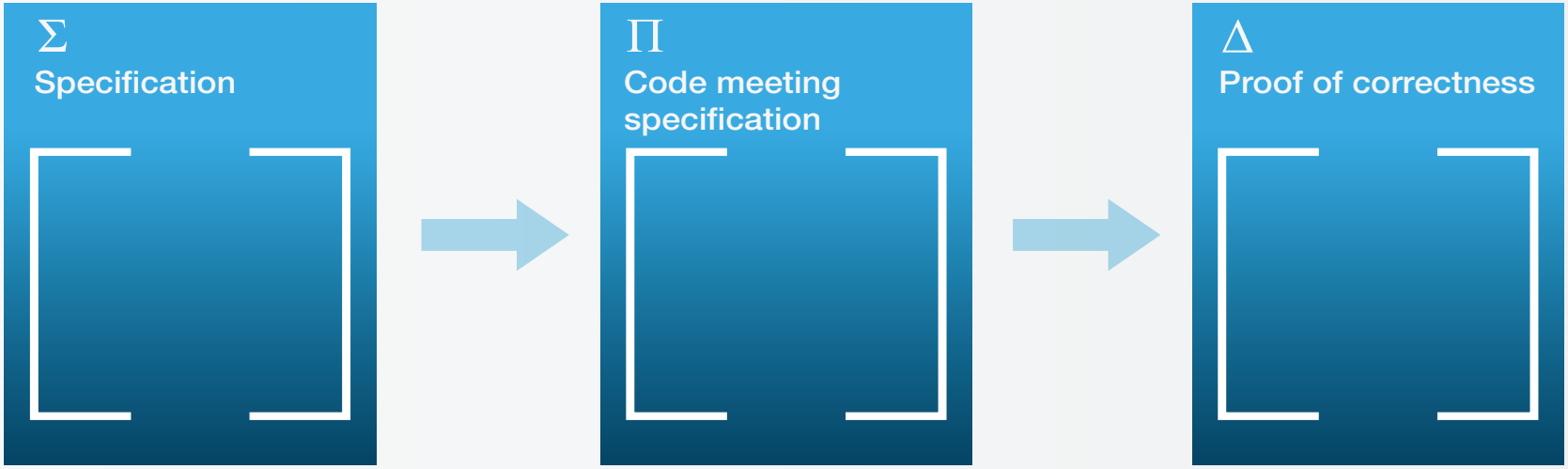

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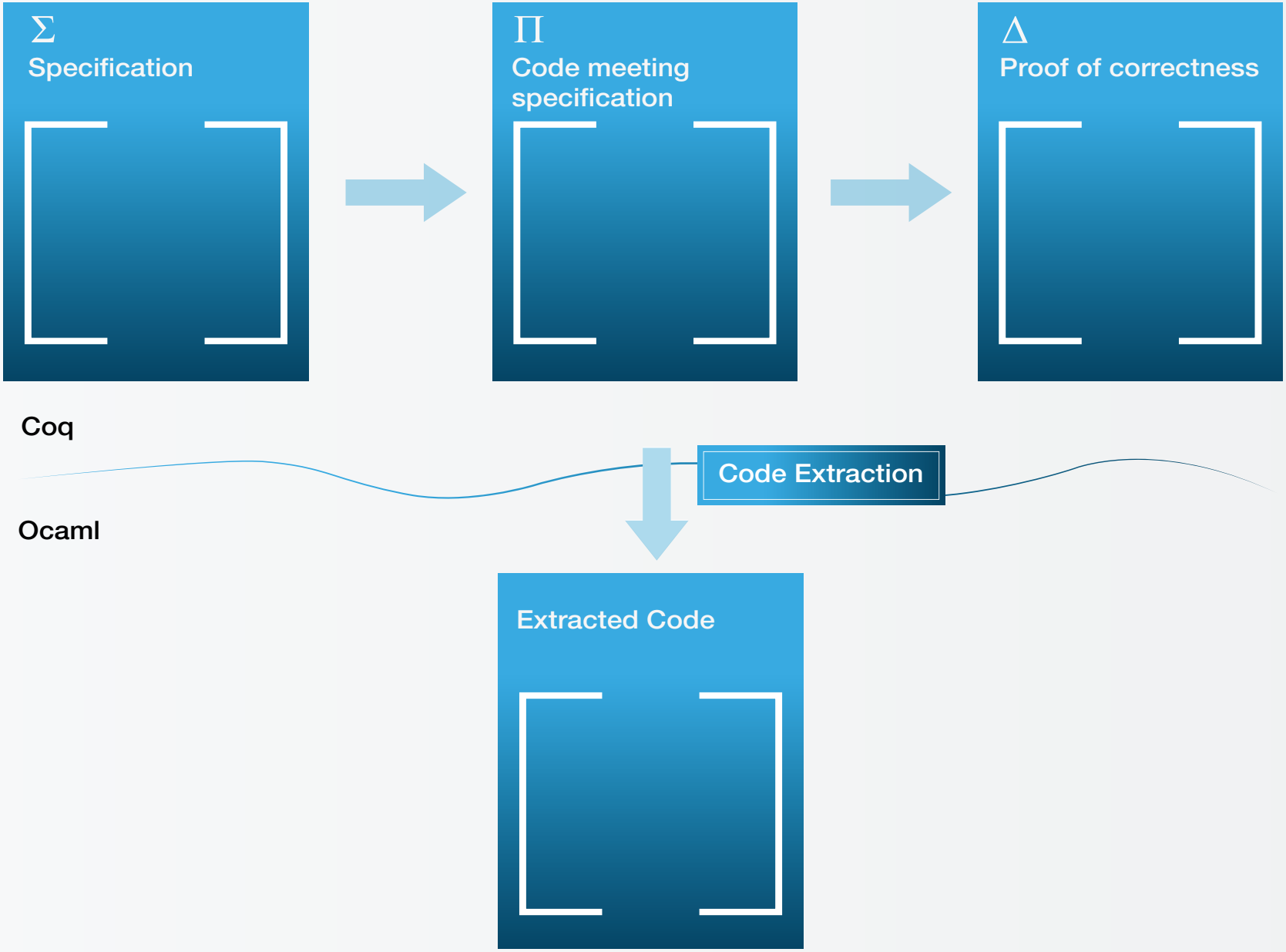

EXAMPLE THEOREMS

```
Lemma leq_trans a b c : a <= b -> b <= c -> a <= c.
Proof. by elim: a b c => [|i IHn] [|b] [|c] //;
      apply: IHn b c. Qed.
```

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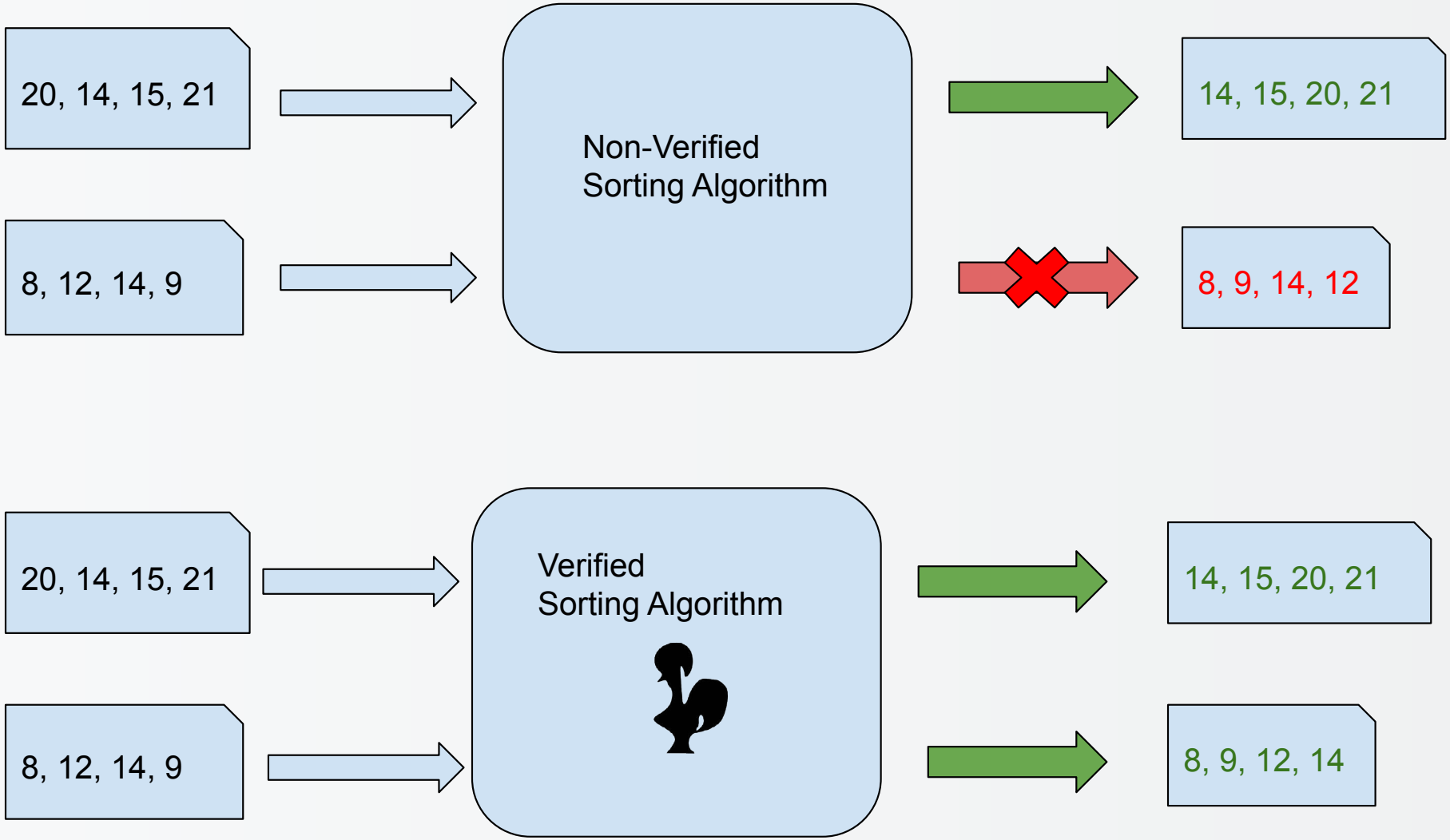
      apply: IHn b c. Qed.
```

```
Lemma quicksort_correct :
      forall l,
      permutation l (quicksort l)
      /\ is_sorted (quicksort l).
```

THE GOAL


20, 14, 15, 21
8, 12, 14, 9
Non-Verified
Sorting Algorithm
14, 15, 20, 21
8, 9, 14, 12
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Verified
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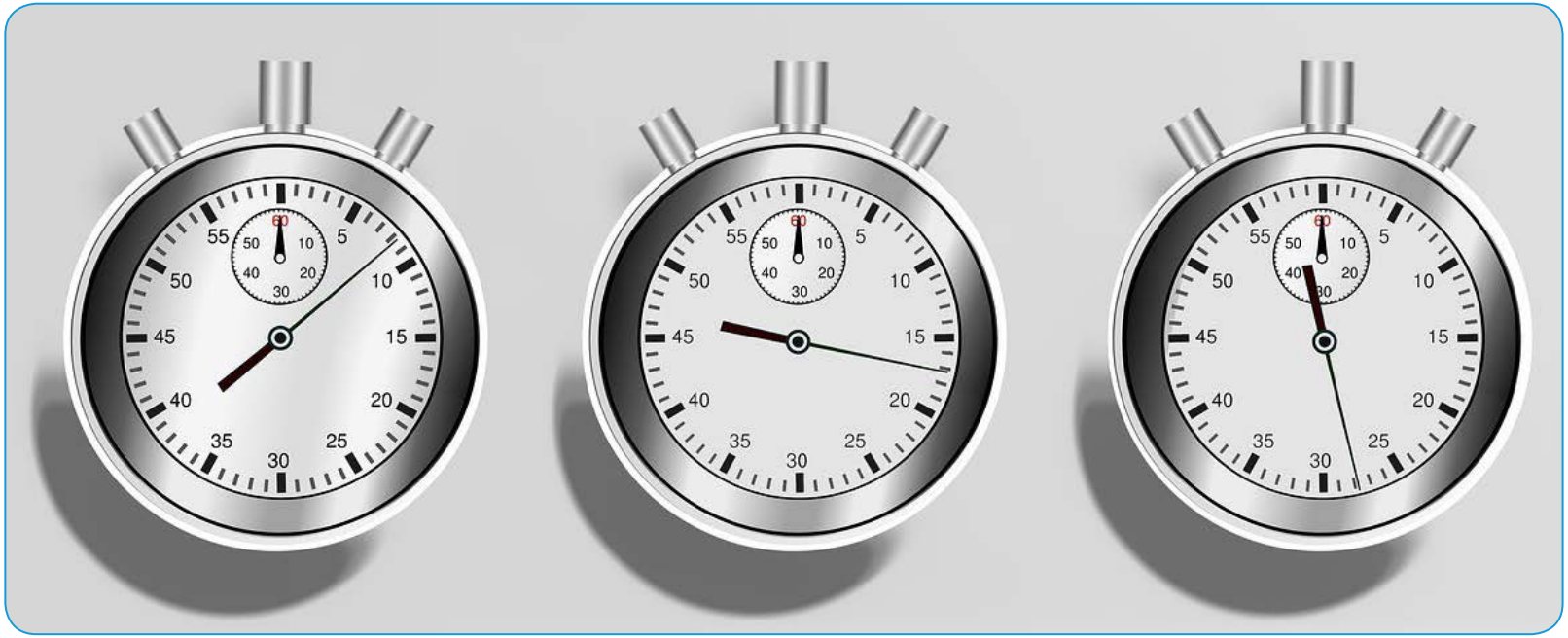
TIME MANAGEMENT IS IMPORTANT



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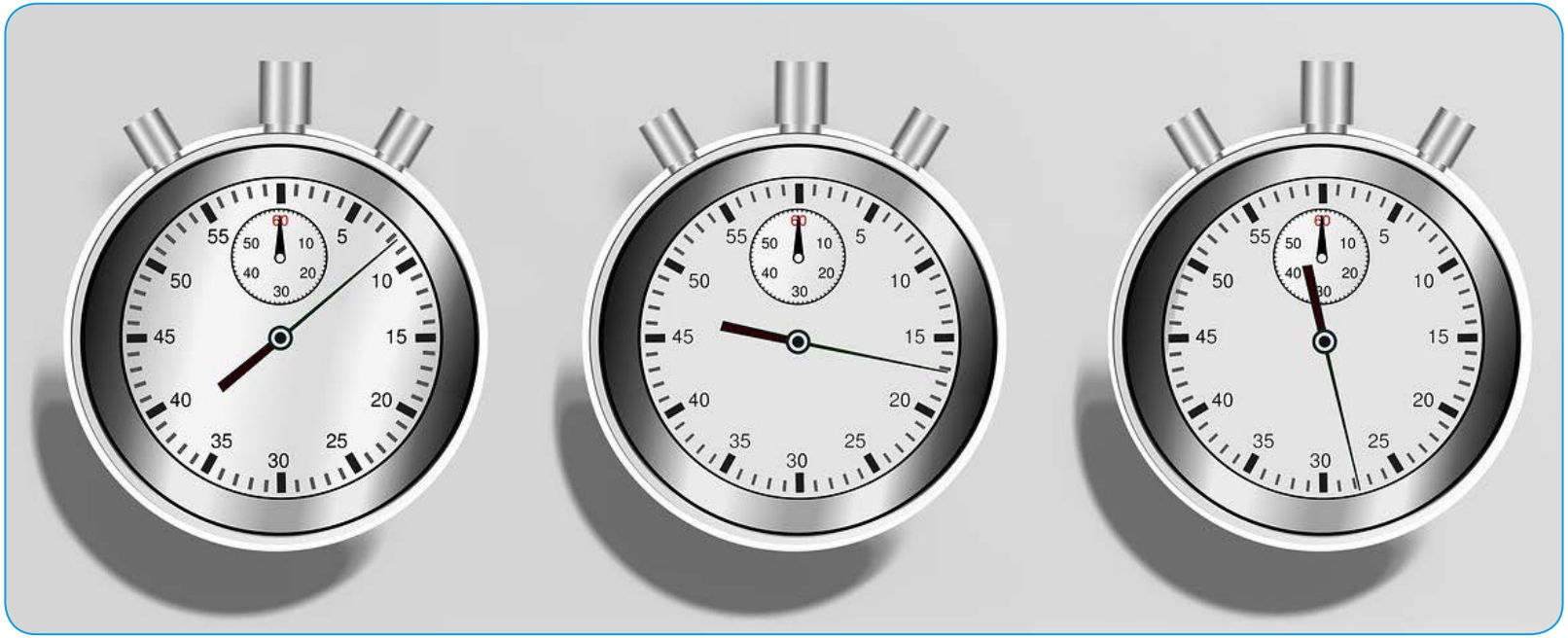

- Time management is a crucial part of many industry projects.

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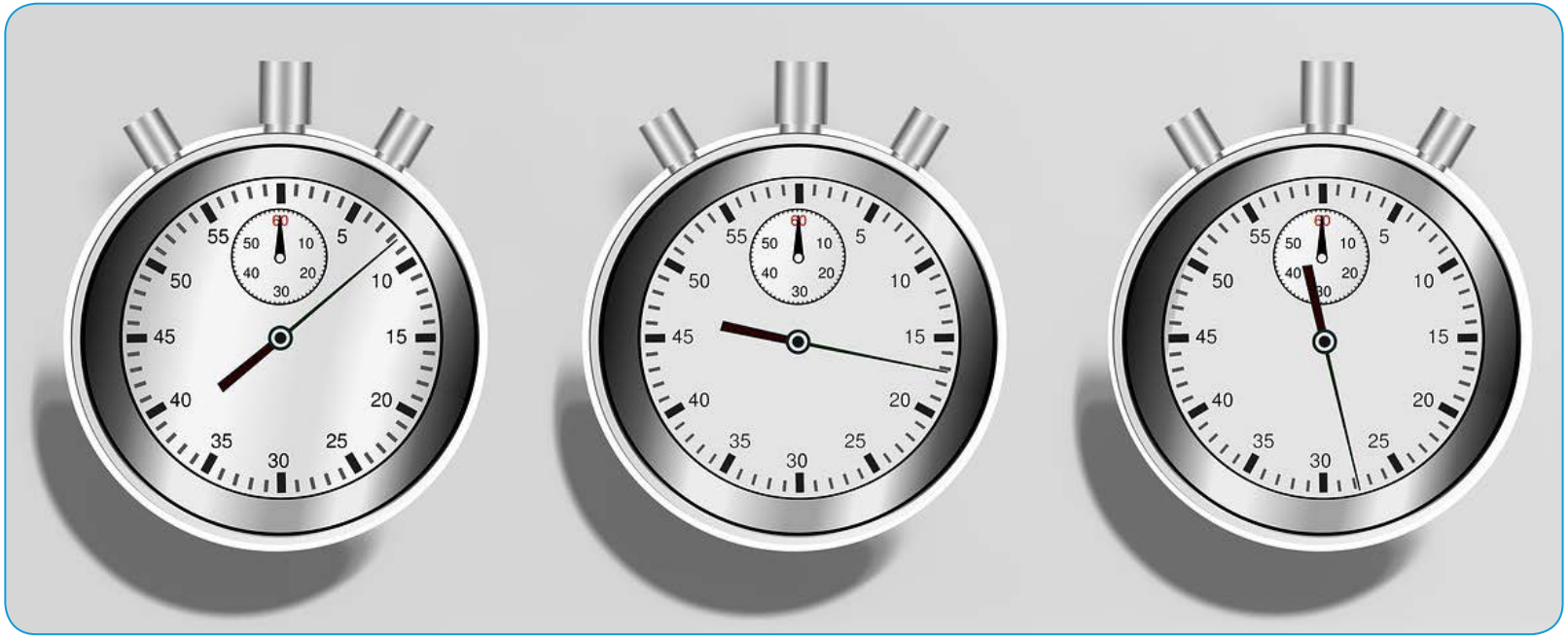

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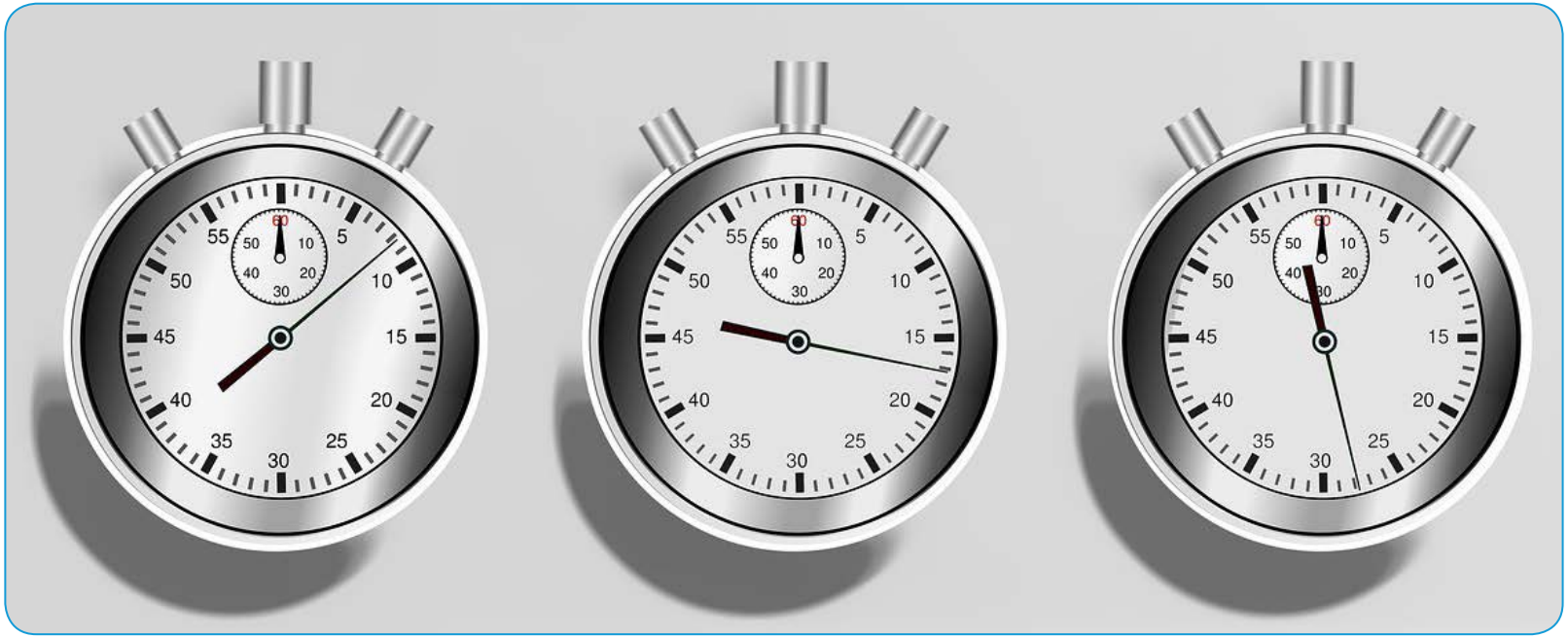

- Time management is a crucial part of many industry projects.
- We have developed our own verified library to be integrated in a bigger project.
- Bigger project: legal software involving time and durations

  for example

  full tachograph software.

SPECIFICATION

- Mathematical definitions
- Blueprint of the running sofware
- Unambiguosly defines sofware intended behaviour

```
| Rec.WordF n ⇒
| Rec.ArrayF t' n₀ ⇒
  (fix array_of_word n from :=
     match n with
     | O ⇒ Modify (InitSliceWithCapacity n₀) ^(vdst)
     | S n' ⇒
       Declare (go_rec_type t') (λ vt' ⇒
         (array_of_word n' (from + Rec.len t');
          go_of_word t' vt' vsrc from;
          Modify Append ^(vdst, vt')))
     end) n₀ from
| Rec.RecF fs ⇒
  (fix rec_of_word fs vdst from :=
     match fs with
     | [] ⇒ Modify (@SetConst (Struct []) tt) ^(vdst)
     | (_, f) :: fs' ⇒
       Declare (go_rec_type f) (λ vf ⇒
```

SPECIFICATION

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- Unambiguosly defines sofware intended behaviour

- Given a time in format Year- Month- Day- hour : minute : second, obtain the number of seconds elapsed since 1970-01-01-00:00:00 until then
- Mathematical definition:

$$timestamp(T) := |\{t : 1970\text{-}01\text{-}01\text{-}00{:}00{:}00 \leq t < T\}|$$

```
| Rec.WordF n ⇒
| Rec.ArrayF t' n0 ⇒
          Modify Append ^(vdst, vt')))
    end) n0 from
| Rec.RecF fs ⇒
  (fix rec_of_word fs vdst from :=
     match fs with
     | [] ⇒ Modify (@SetConst (Struct []) tt) ^(vdst)
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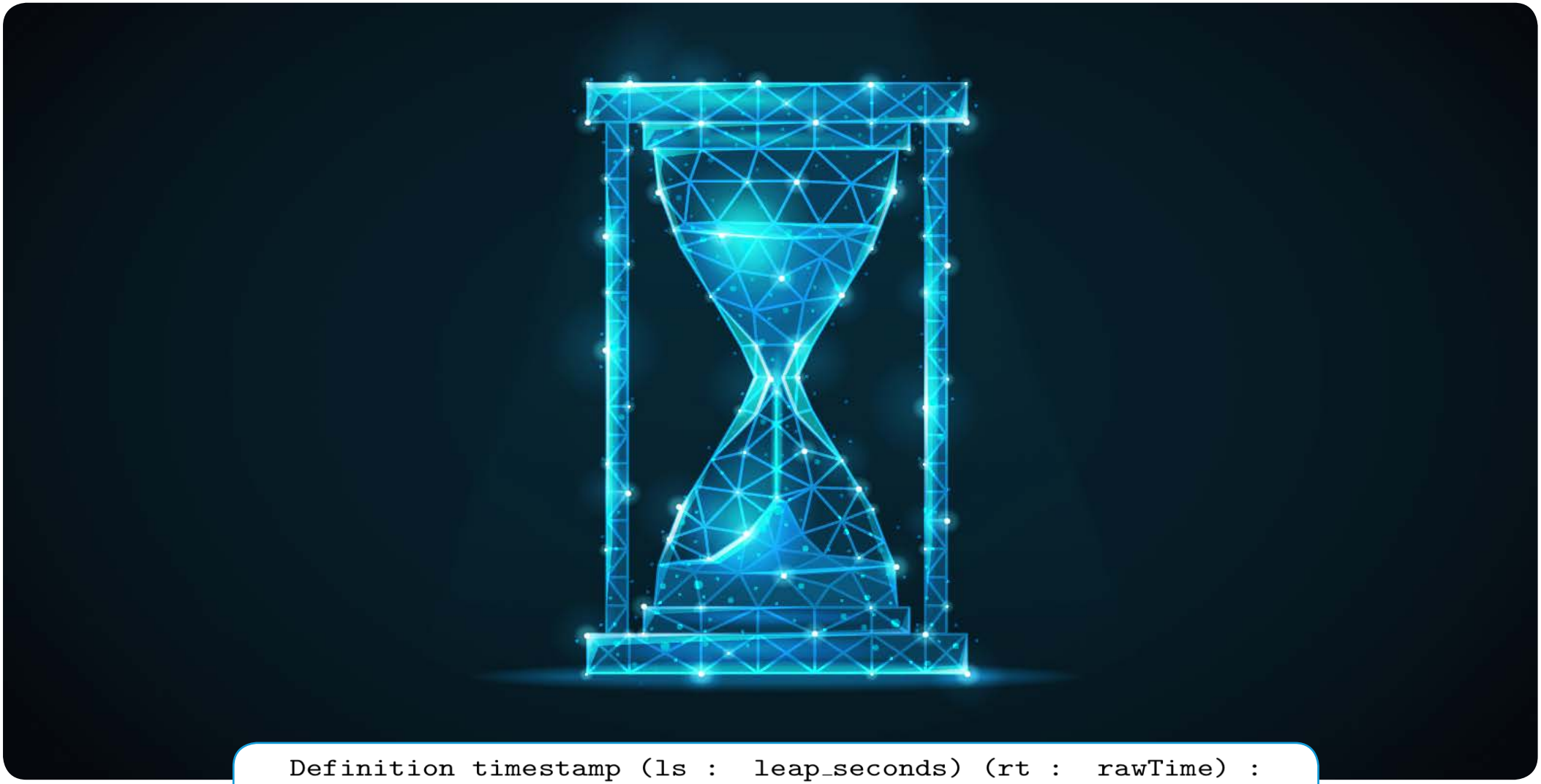
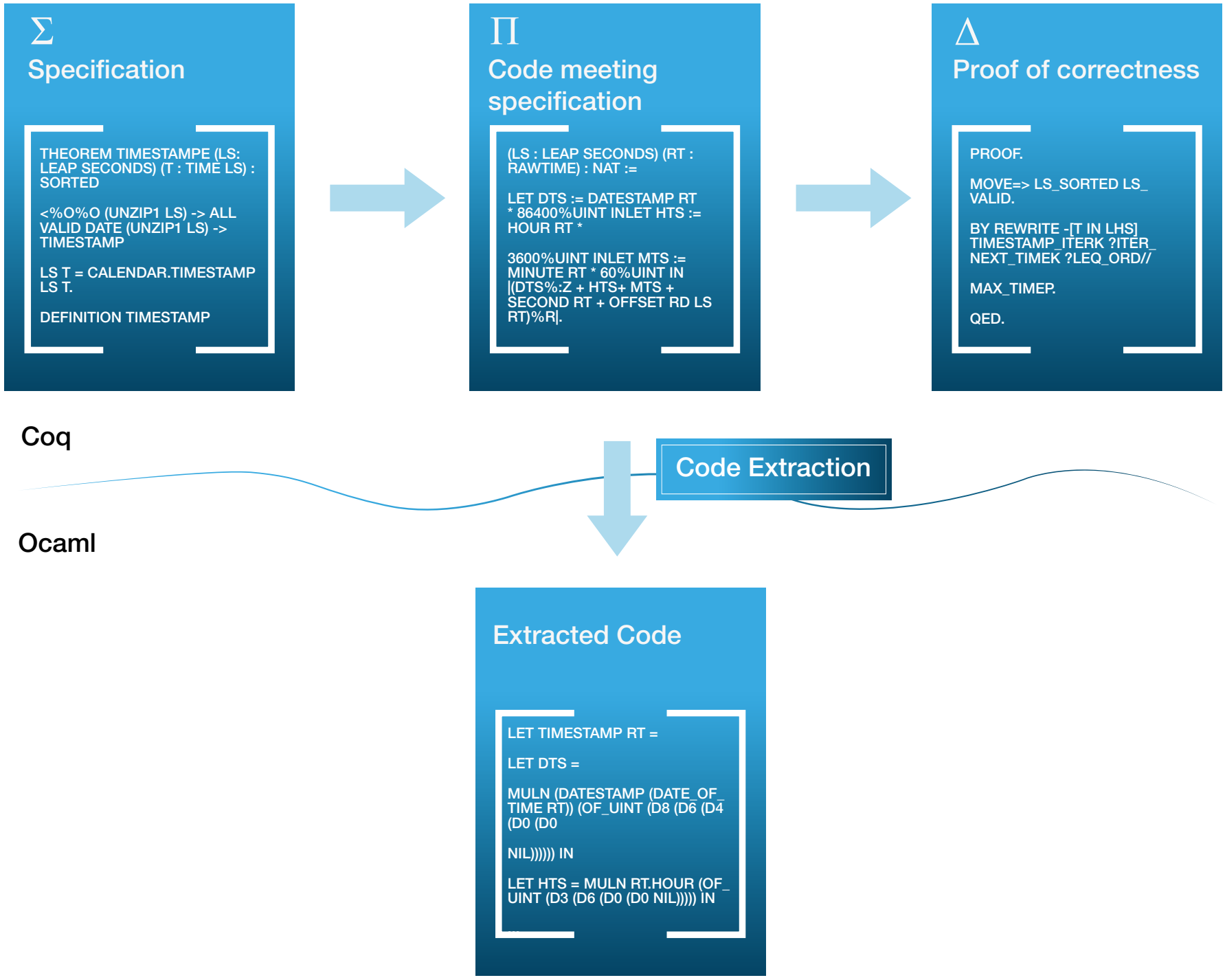
$$timestamp(T) := |\{t : 1970\text{-}01\text{-}01\text{-}00{:}00{:}00 \leq t < T\}|$$

- Different implementations might correspond to the same specification
- Is not obvious when the implementation satisfies its specification

```
match fs with
| [] ⇒ Modify (@SetConst (Struct []) tt) ~(vdst)
| (_, f) :: fs' ⇒
  Declare (go_rec_type f) (λ vf ⇒
```



```
Definition timestamp (ls :  leap_seconds) (rt :  rawTime) :
nat :=
  let Dts := datestamp rt * 86400%uint in
  let hts := hour rt * 3600%uint in
  let mts := minute rt * 60%uint in
  ⌊(Dts%:Z + hts + mts + second rt + offset_rd ls rt)%R⌋.
```


Σ
Specification
THEOREM TIMESTAMPE (LS: LEAP SECONDS) (T : TIME LS) : SORTED
<%O%O (UNZIP1 LS) -> ALL VALID DATE (UNZIP1 LS) -> TIMESTAMP
LS T = CALENDAR.TIMESTAMP LS T.
DEFINITION TIMESTAMP
Π
Code meeting specification
(LS : LEAP SECONDS) (RT : RAWTIME) : NAT :=
LET DTS := DATESTAMP RT * 86400%UINT INLET HTS := HOUR RT *
3600%UINT INLET MTS := MINUTE RT * 60%UINT IN |(DTS%:Z + HTS+ MTS + SECOND RT + OFFSET RD LS RT)%R|.
Δ
Proof of correctness
PROOF.
MOVE=> LS_SORTED LS_ VALID.
BY REWRITE -[T IN LHS] TIMESTAMP_ITERK ?ITER_ NEXT_TIMEK ?LEQ_ORD//
MAX_TIMEP.
QED.
Coq
Code Extraction
Ocaml
Extracted Code
LET TIMESTAMP RT =
LET DTS =
MULN (DATESTAMP (DATE_OF_ TIME RT)) (OF_UINT (D8 (D6 (D4 (D0 (D0
NIL)))))) IN
LET HTS = MULN RT.HOUR (OF_ UINT (D3 (D6 (D0 (D0 NIL))))) IN

TIME LIBRARY FUNCTIONALITY

Time Library is formally verified with an ample functionality:

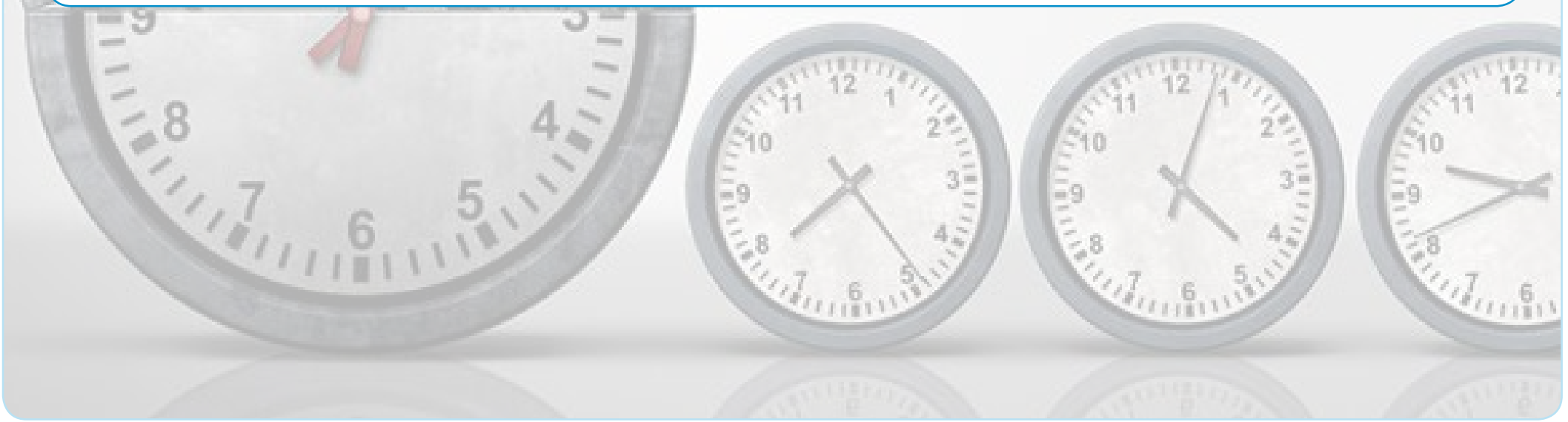
- Conversion functions (4);
- Shift functions (6);
- Add functions (6);
- Auxiliary functions (174).

TIME LIBRARY PROGRAMMING STATISTICS

Some statistics about the library and corresponding extraction:

- Estimated programming hours 30.000 = 41 formal months;
- Nr of lines of Coq code and proofs= 4114 (4821 incl. extraction directives);
- Nr of lemmata/theorems = 190 (278 incl. extraction directives);
- Nr of lines of extracted code = 1363 (down from an earlier (±) 100 MB)

A particularly hard function to deal with was yoe_of_doe



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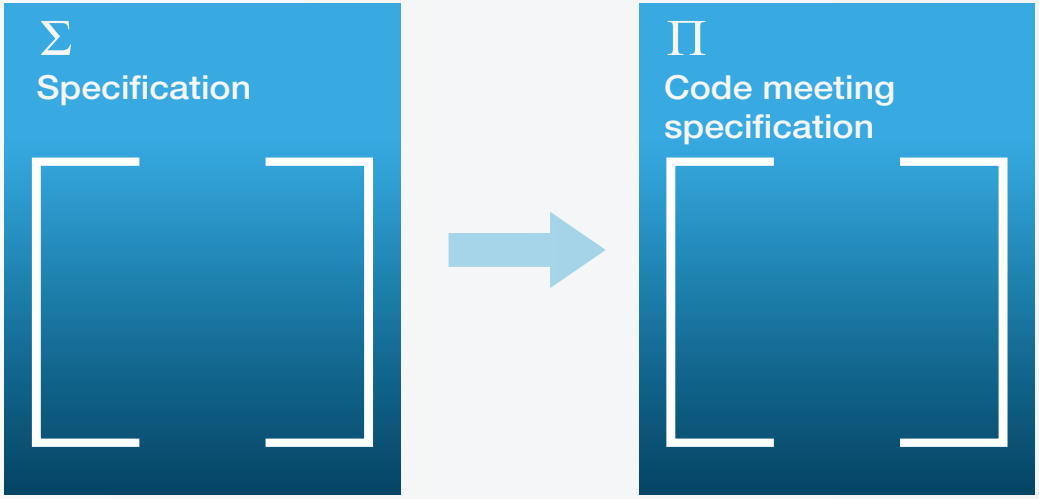

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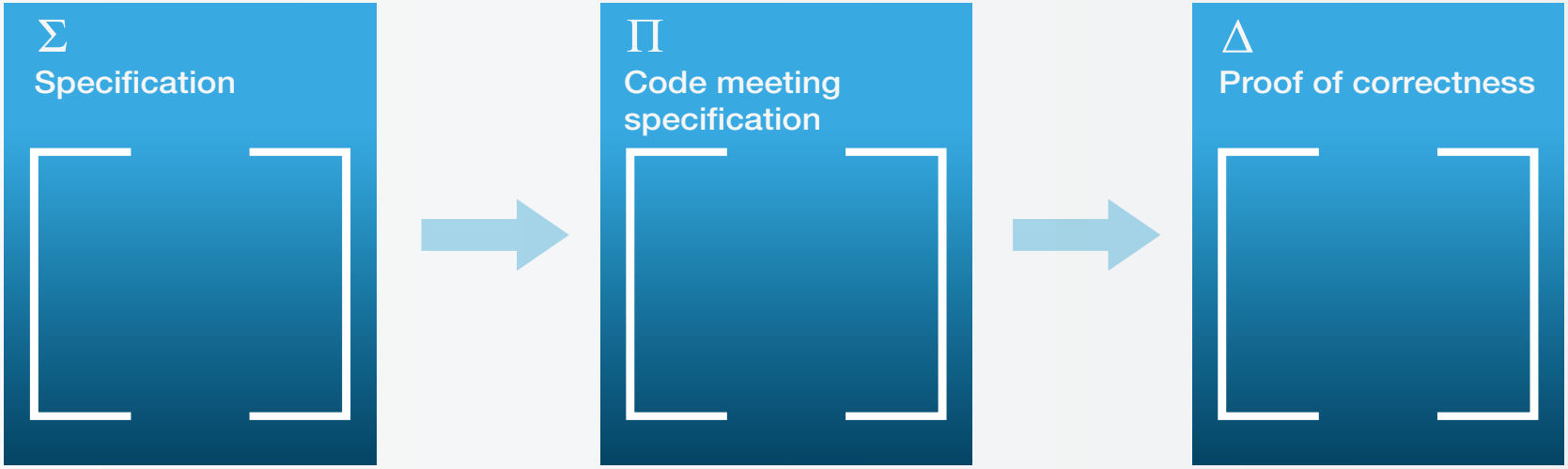

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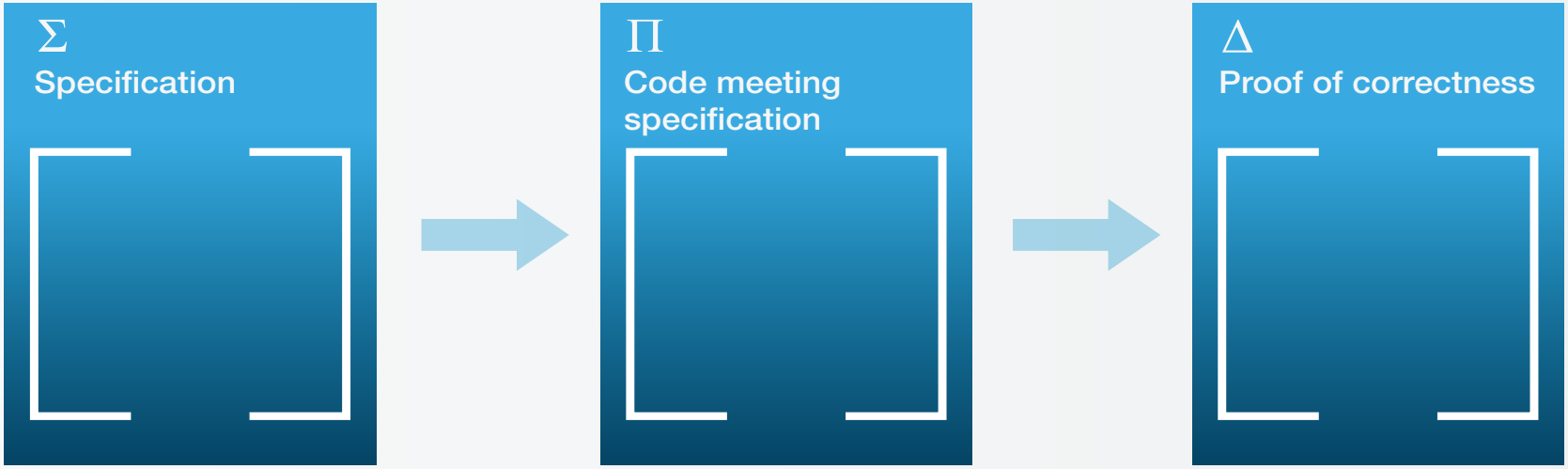

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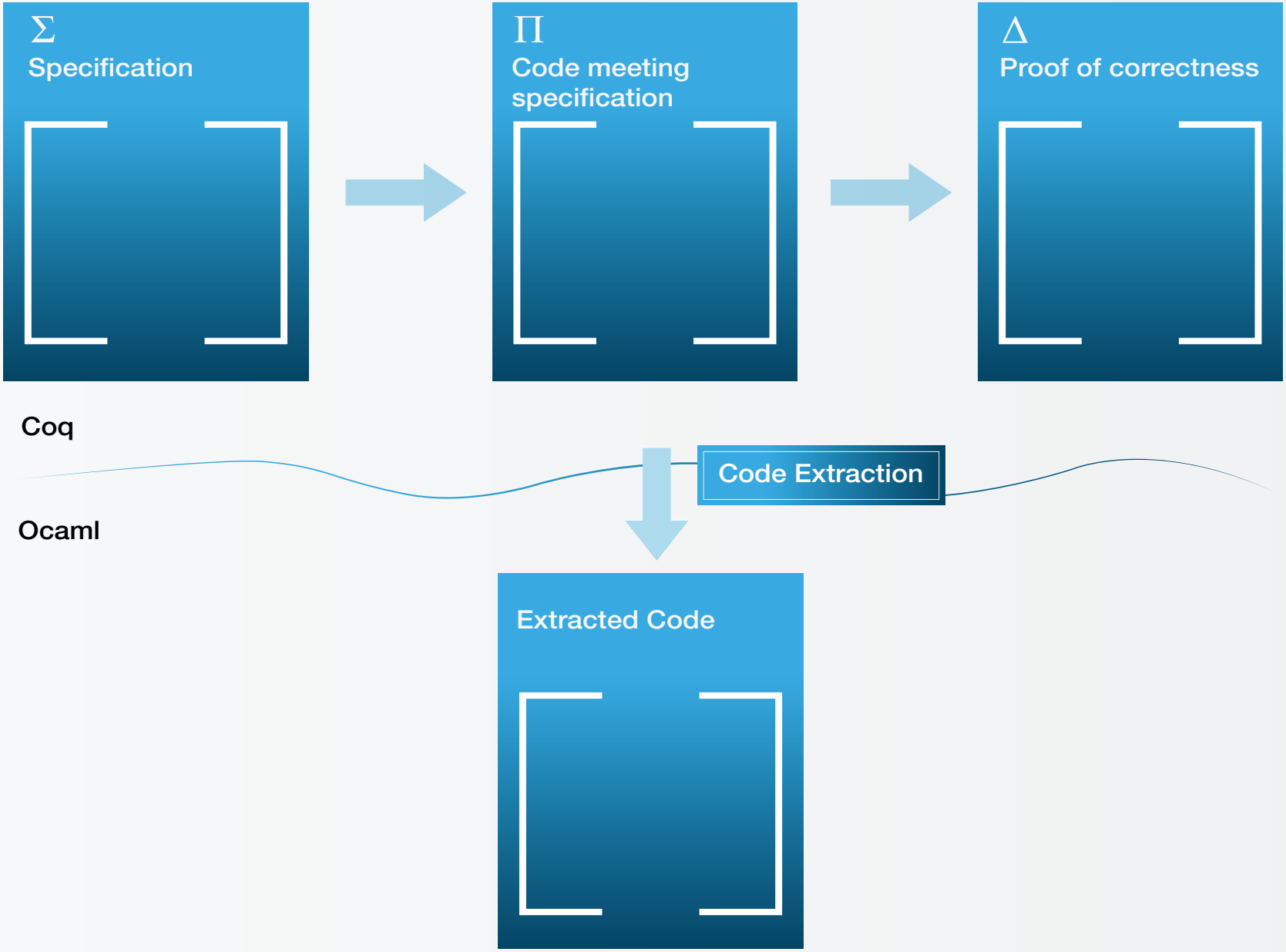


THANK YOU!