Isabelle_C: A Generic Front-End of C11 Supported in Isabelle/PIDE

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Isabelle Workshop @ IJCAR 2020, Paris, France

OVERVIEW

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- DEMO: Semantic Backends: CLean, AutoCorres

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/* @ requires n>= 0 && \valid(t+0..n-&)
   @ requires \forall integer k,l; 0 <= k <= l < n ==> t[k] <= t[l];
   @ ensures \result <==> (\exists integer k; 0 <= k < n && t[k] == x);
   @ assigns \nothing;  */

int linearsearch(int x, int t[], int n) {
    int i = 0;
    /*@ loop invariant 0 <= i <= n;
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      @ loop assigns i;
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    while (i < n) {
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struct Handle {
    obj_t obj;
    invariant(obj->handles[this] && closed(obj))
};

struct Data {
    bool handles[Handle*];

    invariant(forall(Handle *h; closed(h) ==> handles[h] <==> h->obj == this)))

    invariant(old(closed(this)) && !closed(this) ==> !exists(Handle *h; handles[h]))

    invariant(is_thread(owner(this)) || old(handles) == handles ||
              inv2(owner(this)))
};
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  - the execution model (sequential ? sequentially consistent? concurrent?)
  - the data-types (arithmetic ? union-types ? floats ? …)
  - the memory and architecture model (global ? local ? physical ? byte-level layout ? …)

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  - either implicit in the VCG algorithm
  - or explicit in the “background theory”

    (VCC(1) : 300 axioms …)

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  (STEPS, STEP2, VCC 1 - 3, Daphne, SAL-Annotations, why, Frama-C, …)

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  - Derived VCG,
  - Derived, guaranteed consistent memory model
  - Clear Management of the involved Logical Contexts

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  - … but still no guarantee that the model meets reality ;-)

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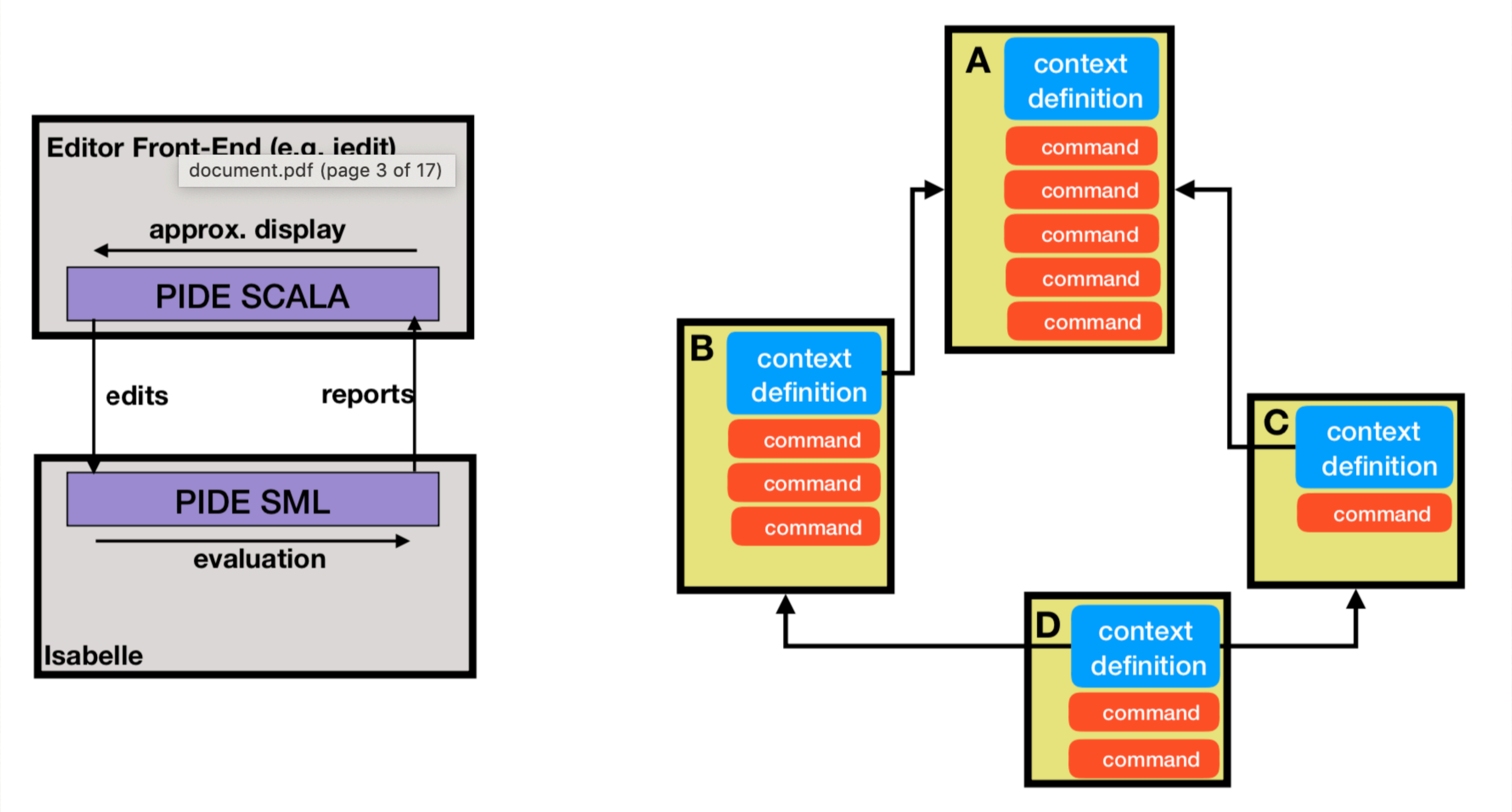

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  - Semantic Annotations were interpreted "back-end-specific" with logical context, C-scope and C term-context
  - Generic Front-End can create different applications based on symbolic execution, test-generation and interactive and automated proofs

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C2.thy (~/codebox/isabelle_c/C11-FrontEnd/examples/)

```
section‹Some realistic Selection sort with Input and Output›

C‹
#include <stdio.h>

int main()
{
  int array[100], n, c, d, position, swap;

  printf("Enter number of elements\n");
  scanf("%d", &n);

  printf("Enter %d integers\n", n);

  for (c = 0; c < n; c++) scanf("

  for (c = 0; c < (n - 1); c++)
  {
    position = c;
```

```
:: int
C local variable "n"
bound variable
```

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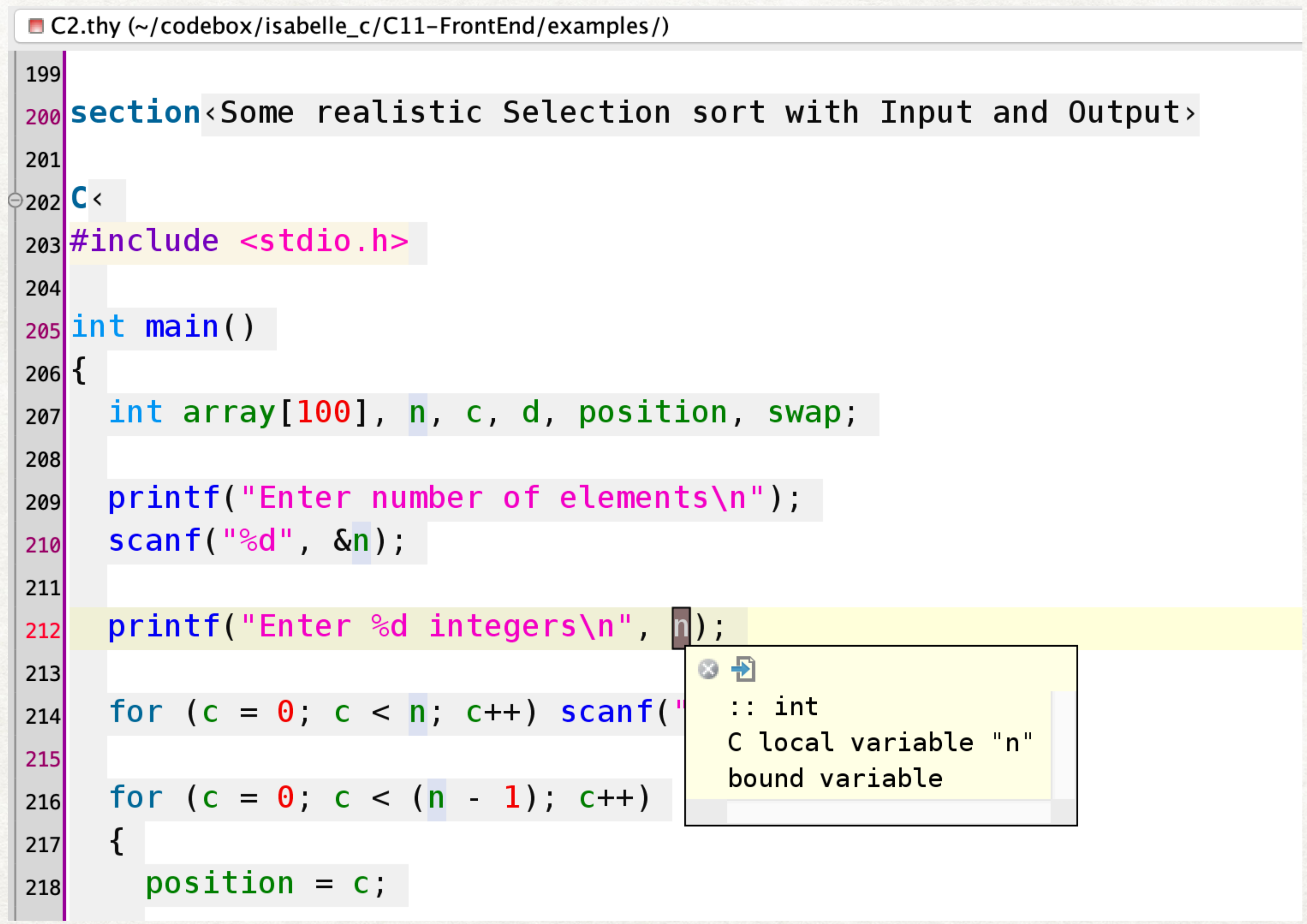

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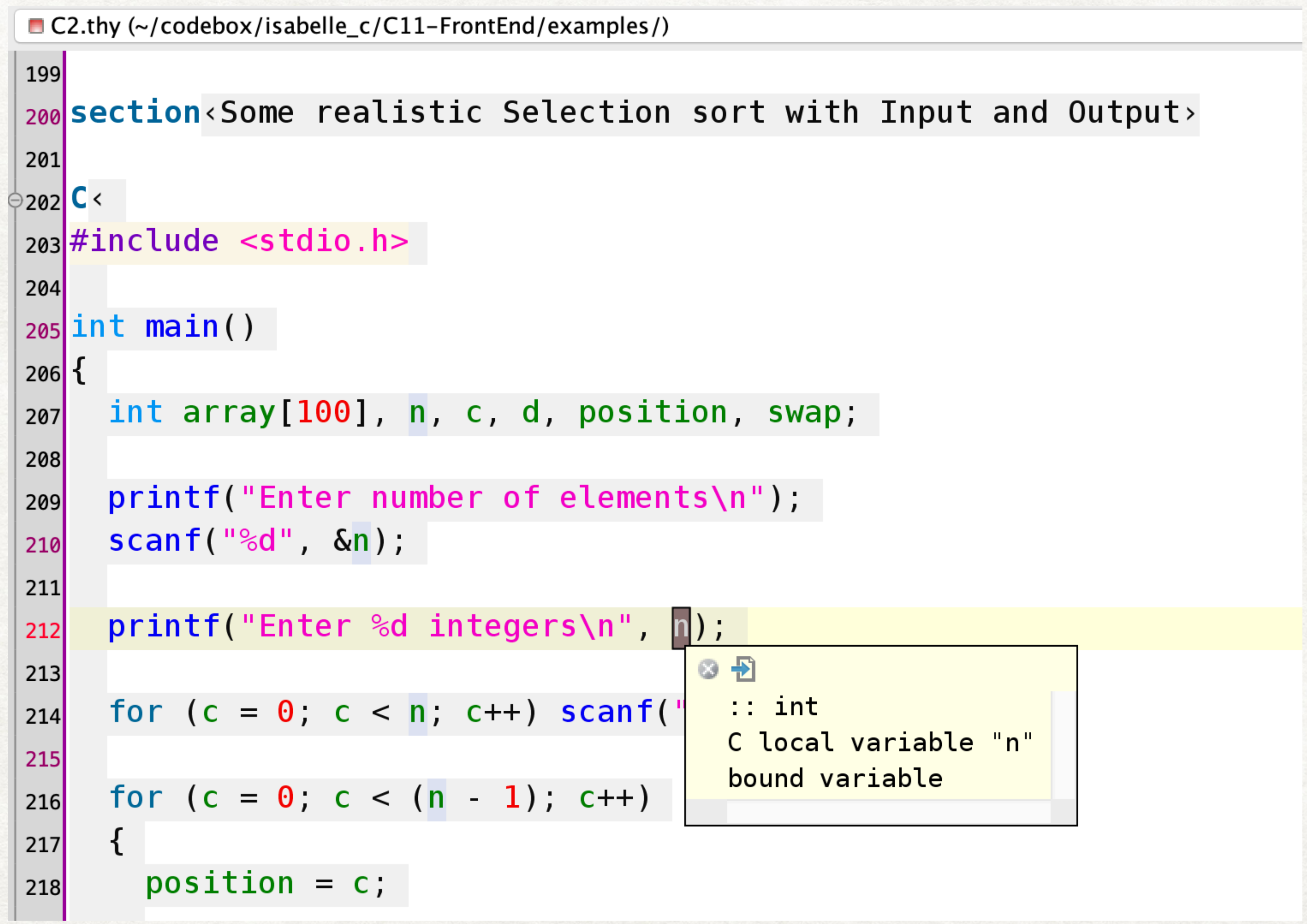

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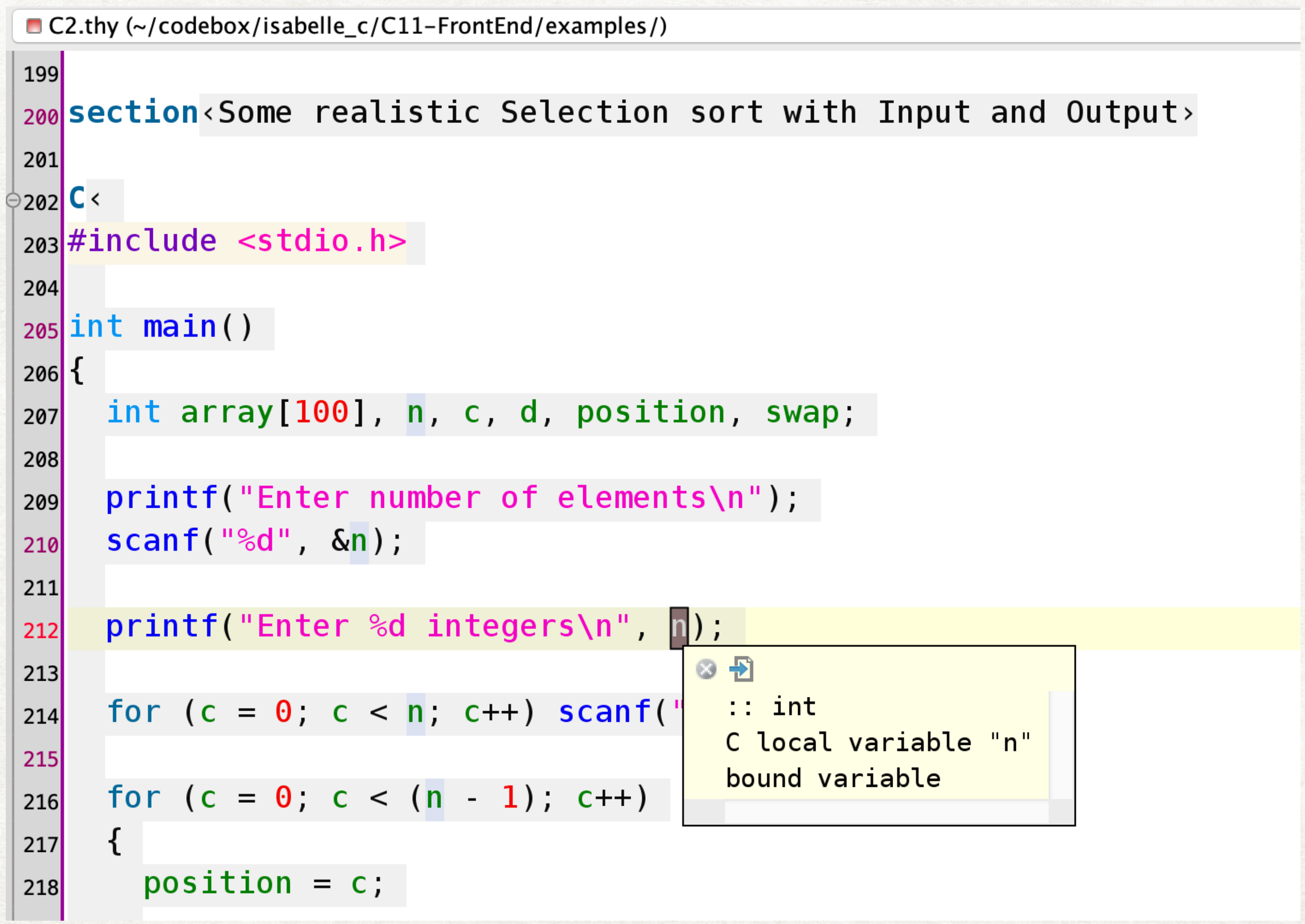

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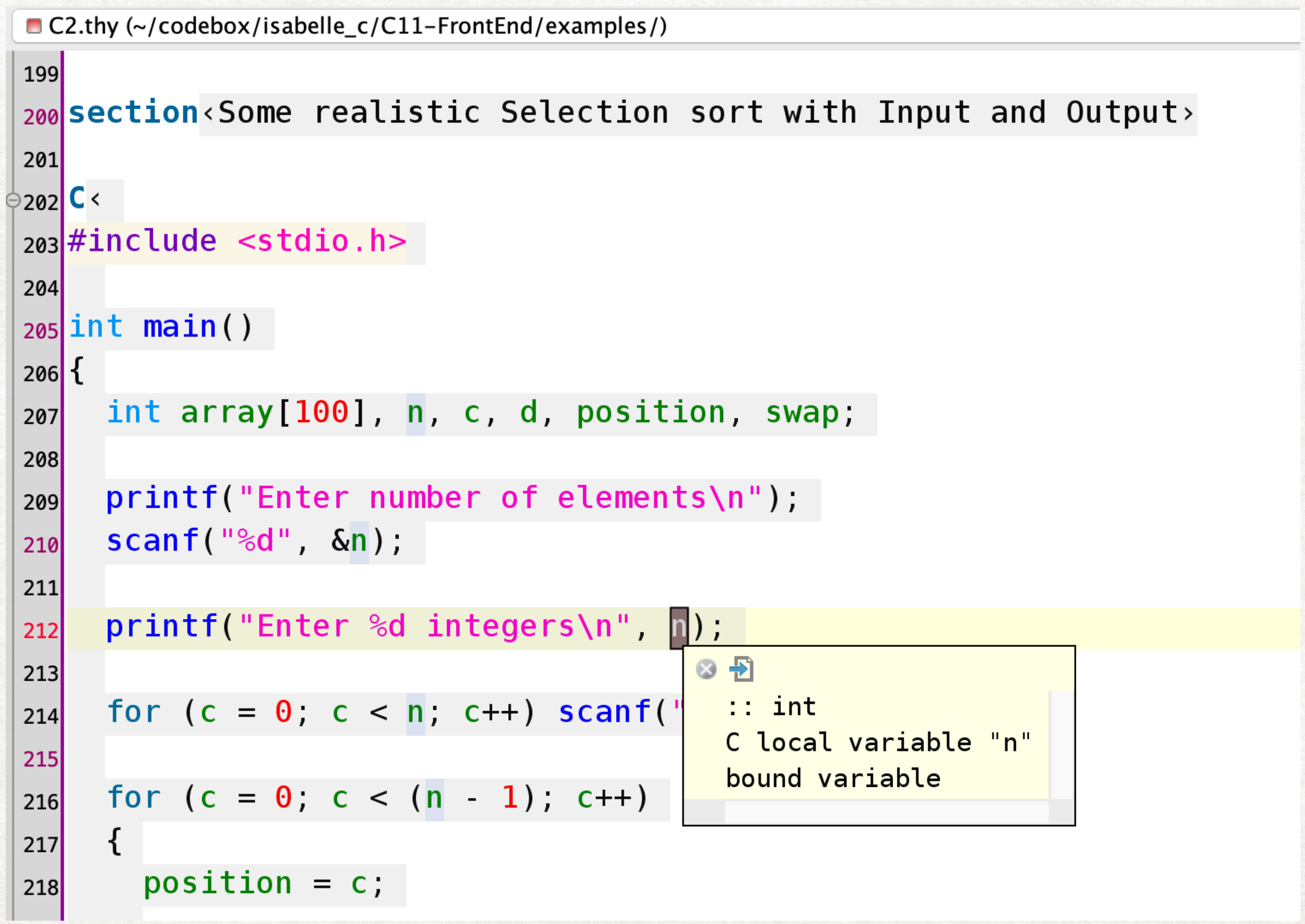
  - Generic, programmable Annotations



DEMO

Isabelle/C and Isabelle/C/AutoCorres

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- AutoCorres [Klein @ al, 2014]
  realistic C model for OS code verification
  used in seL4 project, decent automation support, but complex.

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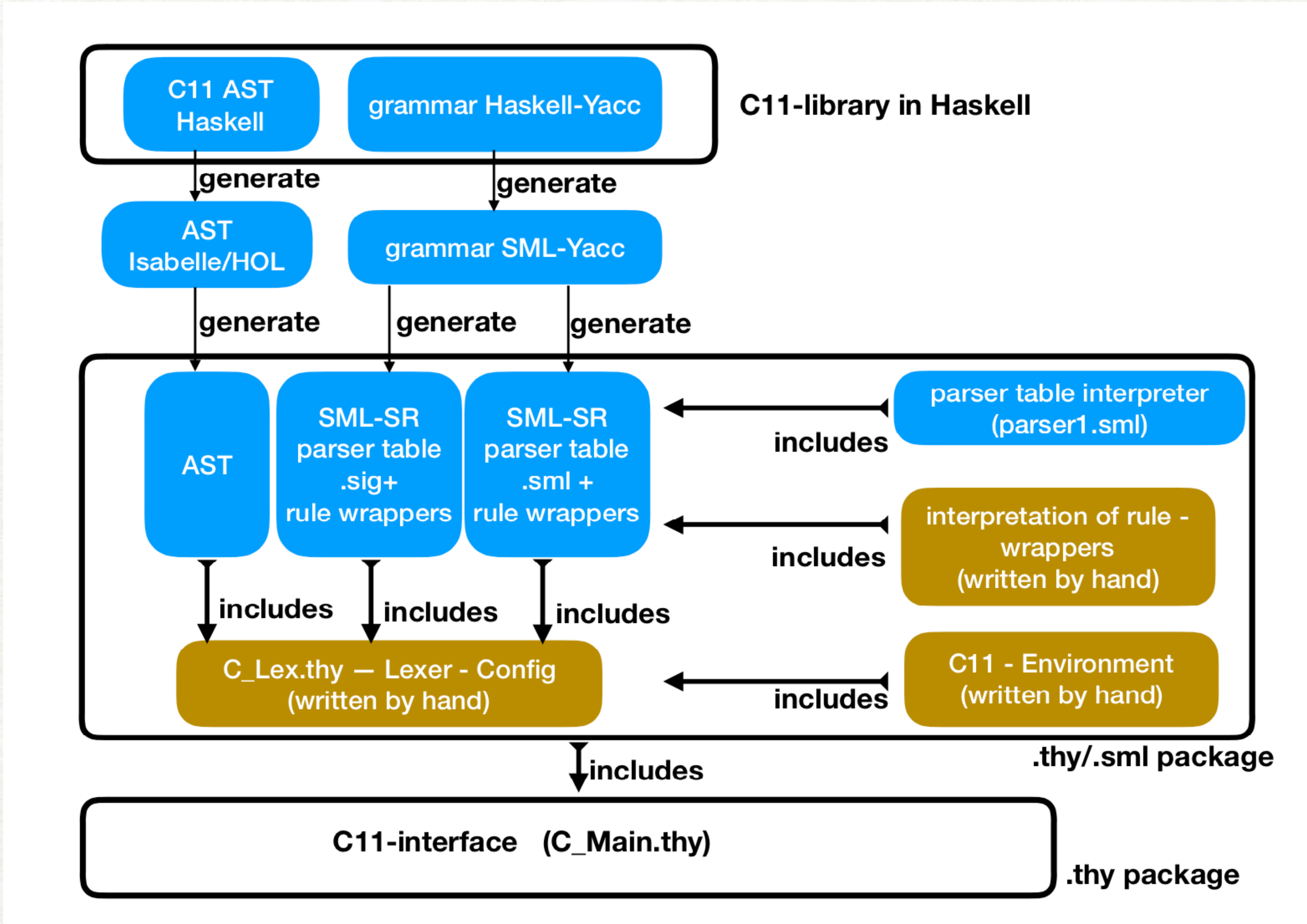
- Construction by Compiler-Generators
  (and not general-purpose, inner-syntax "Early-Parser" for λ-terms)

- Efficient parsing, and Intellisense

- Generic Scope-Analysis

- parses entire seL4 sources (26 kLoC in 1s)

- markup in 20 s



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- … comprising in Isabelle/C an environment env and the stack of S-R- AST's

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int sum1(int a)
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  while (a < 10)
    /*@ @ INV: ‹…›
        @ highlight */
    { a = a + 1; }
  return a;
}›
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                          @ C1  ‹//* C2 ‹int _;››   \
                          @ C1⇓ ‹//* C2 ‹int _;››     ››
    @ C ‹//* C2 ‹int _;›                              ›
      ≃setup ‹@{C_def ⇑ (* bottom-up *)  C1  }›
      ≃setup ‹@{C_def ⇓ (* top-down  *) "C1⇓"}›
*/›
```

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  - (direct recursive) function calls

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- Example in Isabelle/C/Clean

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```
theory Prime imports Isabelle_C_Clean.Backend
                    — ‹Clean back-end is now on›
begin
C ‹
//@ definition ‹primeHOL (p :: nat) =                    \
          (1 < p ∧ (∀ n ∈ {2..<p}. ¬ n dvd p))›
#   define SQRT_UINT_MAX 65536
unsigned int k = 0;
unsigned int primeC(unsigned int n) {
//@ preClean  ‹C‹n› ≤ UINT_MAX›
//@ postClean ‹C‹primeC(n)› ≠ 0 ⟷ primeHOL C‹n››
    if (n < 2) return 0;
    for (unsigned i = 2; i < SQRT_UINT_MAX
                         && i * i <= n; i++) {
      if (n % i == 0) return 0;
      k++;
    }
    return 1;
}›
```

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- C command generates for prime_{HOL}, SQRT_UINT_MAX, prime_{C_pre}, prime_{C_post}, and prime_C a monadic Clean presentation

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- C command generates for $\text{prime}_{\text{HOL}}$, SQRT_UINT_MAX, $\text{prime}_{\text{C\_pre}}$, $\text{prime}_{\text{C\_post}}$, and prime_{C} a monadic Clean presentation

- definitions in the logical context **σ**

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```
"isPrime_core n ≡
     ifC (λσ. n < 2) then (return↘result_value_update↙ (λσ. False))
                          else skipSE fi;-
     i_update :==L (λσ. 2) ;-
     whileC (λσ. (hd∘i)σ < SQRT_UINT_MAX ∧ (hd∘i)σ * (hd∘i)σ ≤ n)
     do
        (ifC (λσ. n mod (hd ∘ i) σ = 0)
         then (return↘result_value_update↙ (λσ. False))
         else skipSE fi ;-
        i_update :==L (λσ. (hd ∘ i) σ + 1))
     od ;-
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```

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```

```
"isPrime n ≡ blockC push_local_isPrime_state
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- Hoare-Triple over Monad:

```
 "⦃λσ.   ▷ σ ∧ isPrime_pre (n)(σ) ∧ σ = σpre ⦄
    isPrime n
  ⦃λr σ. ▷ σ ∧ isPrime_post(n) (σpre)(σ)(r) ⦄"
```

HOOKING UP BACKENDS

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- Example in Isabelle/C/AutoCorres

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```
theorem (in primeC) primeC'_correct:
  ‹⦃ λ _. n ≤ UINT_MAX ⦄ primeC' n
   ⦃ λ primeC' _. primeC' ≠ 0 ⟷ primeHOL n ⦄!›
proof (rule validNF_assume_pre)
 assume 1: ‹n ≤ UINT_MAX›
 have   2: ‹n = 0 ∨ n = 1 ∨ n > 1› by linarith
 show ?thesis
  proof (insert 2, elim disjE)
   assume ‹n = 0›
   then show ?thesis
        by (clarsimp simp: primeC'_def, wp, auto)
  next
```

DEMO

Isabelle/C and Isabelle/C/AutoCorres

CONCLUSION

- Isabelle/C : a generic Front-End for C providing general IDE support
- Technology can construct other parsers (C18, Javascript, Rust,...)
- Follows idea of "Isabelle as Eclipse" and Integrated Documents
- Instantiatable with various semantic interpretations of C, and derived, conservative libraries in HOL
- Platform for verification "back-ends" in Test and Proof
- Strong mechanism for plugin-separation as well as plugin-collaboration

Abstract

We report on an integration of a novel C11 Frontend into Isabelle/HOL enabling different semantic backends (AutoCorres, Securify, IMP2, Clean, . . .). We discuss the challenges of a Generic Framework ranging from IDE to Proof-Support, and show how a small semantic backend can be hooked into our Framework enabling both deductive program verification as well as program-based Test-Generation.

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