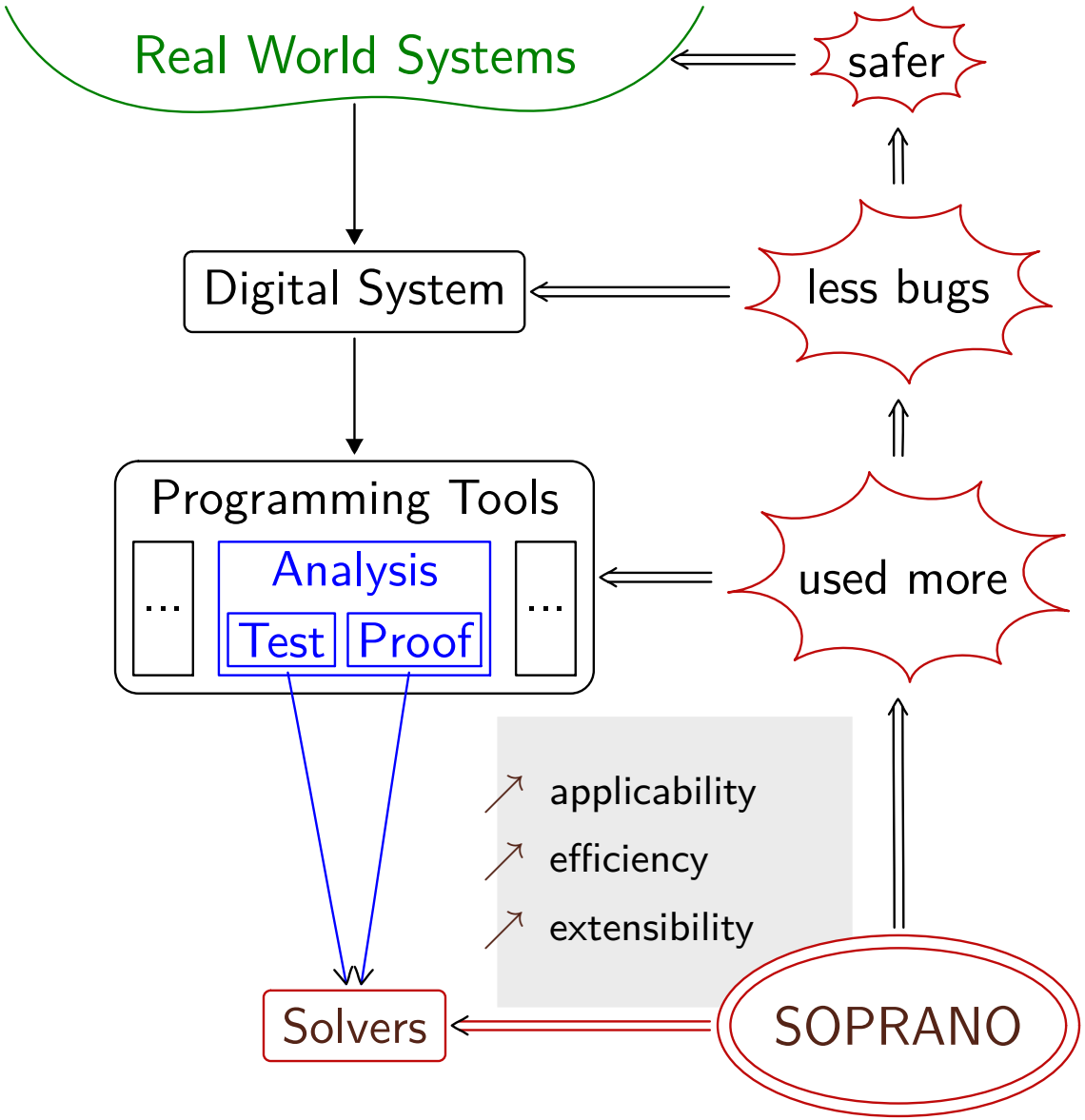
ANR-Project SOPRANO

Revue mi-parcours

4 Octobre

Context


Real World Systems
safer
Digital System
less bugs
Programming Tools
...
Analysis
Test
Proof
...
used more
applicability
efficiency
extensibility
Solvers
SOPRANO

Challenge for SPARK2014

Currently uses SMT solvers:

- ✔ Good handling of arithmetic (integers, bitvectors, reals)
- ✔ Good handling of axioms
- ✔ Reasonably fast
- ✔ Agreed semantics between all provers (SMTLIB)

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- ✘ Many properties involving x/y, $x \times y$, x^y, $x \bmod y$, $x \operatorname{rem} y$
- ✘ Most properties involving floating-point values
- ✘ Properties involving conversions between types (integers $\leftrightarrow$ bitvectors, integers $\leftrightarrow$ reals, integers $\leftrightarrow$ floats)

Interesting and Simple Real Examples

(AdaCore)

```
1  procedure User_Rule_7 (X, Y, Z, A : Float;
                          Res         : out Boolean)
3  begin
      pragma Assume (Z ≥ 0.0);
5     pragma Assume (X ≥ Y);
      pragma Assume (Y ≥ Z);
7     pragma Assume (X > Z);
      pragma Assume (A ≥ 1.0);
9     Res := (X − Y) / (X − Z) ≤ A;
      pragma Assert (Res);       −− valid
11 end User_Rule_7;
```

✔ 25/28 examples are now solved!

Domain Specific Approach of CP

$$X_i \in [1;10] \implies X_0 \oplus X_1 \oplus X_2 \oplus X_3 \oplus X_4 \oplus X_5 \oplus X_6 \oplus X_7 \in [8;80]$$

Z3 (SMT): 3s
COLIBRI (CP): 0.1s

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COLIBRI (CP): 0.1s

The Differences between SMT and CP

SMT:

- ✔ Clear design and separation
- ✔ Fast decision procedures with learning
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- ✔ Easy and efficient to mix constraints
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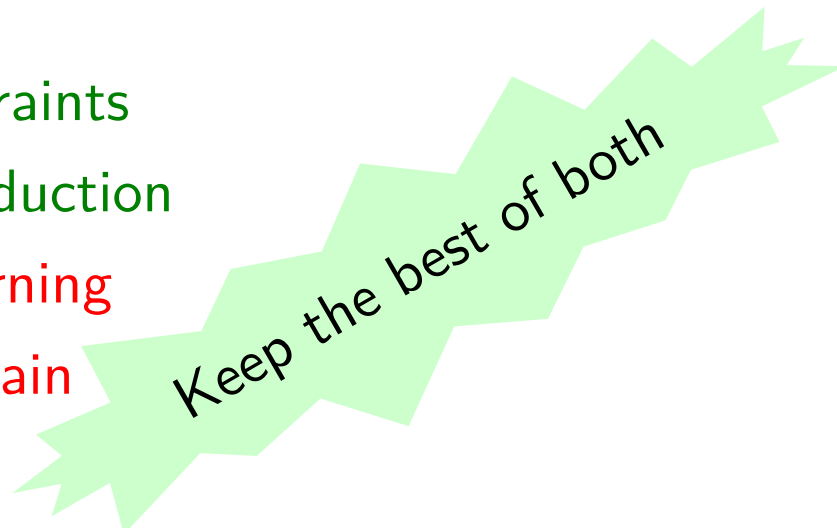

Objectives

- **Obj1:** design a **new collaboration framework for solvers**
- **Obj2:** design **new decision procedures**
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- **Obj4:** ensure **industrial-adequacy**

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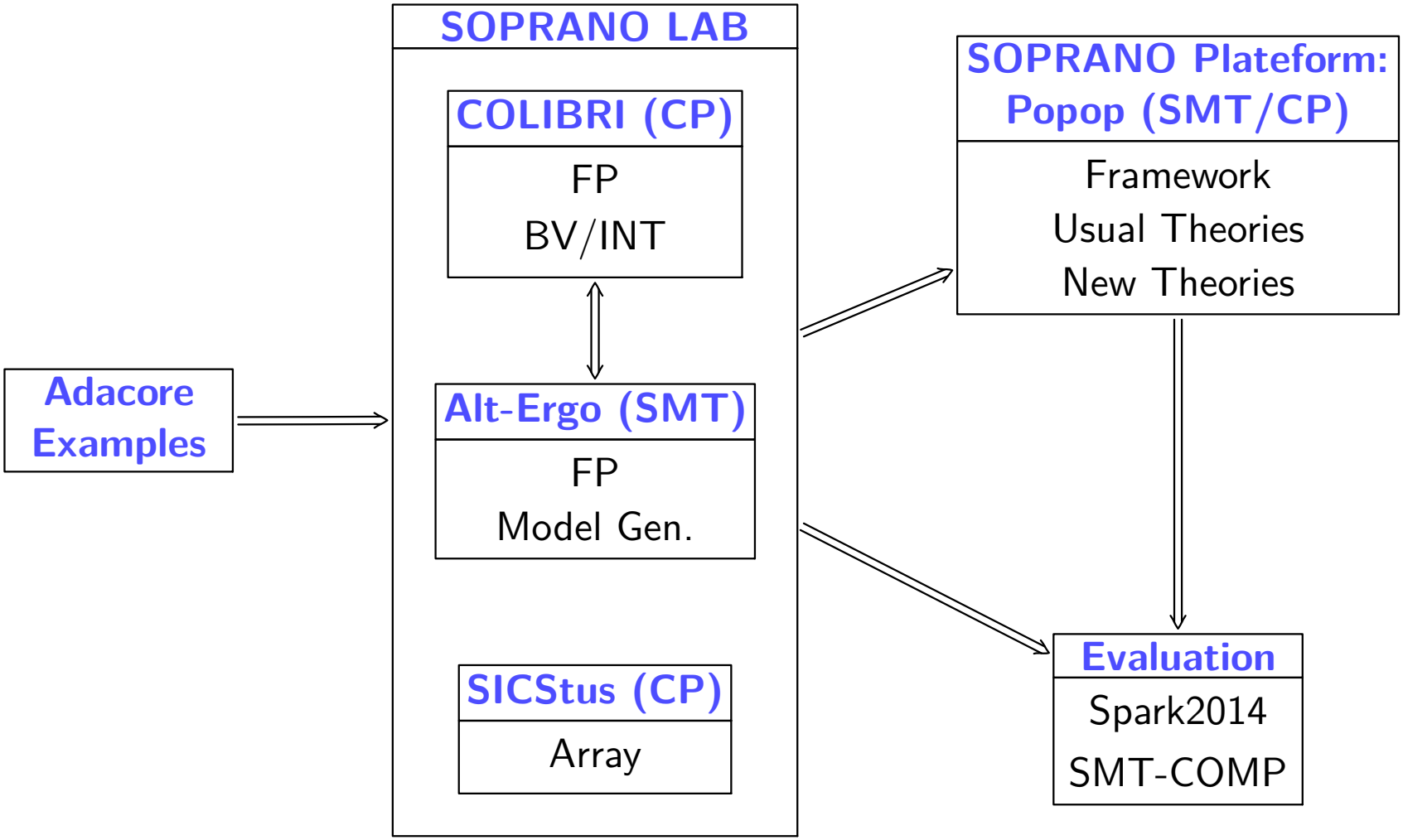
➠ Not yet published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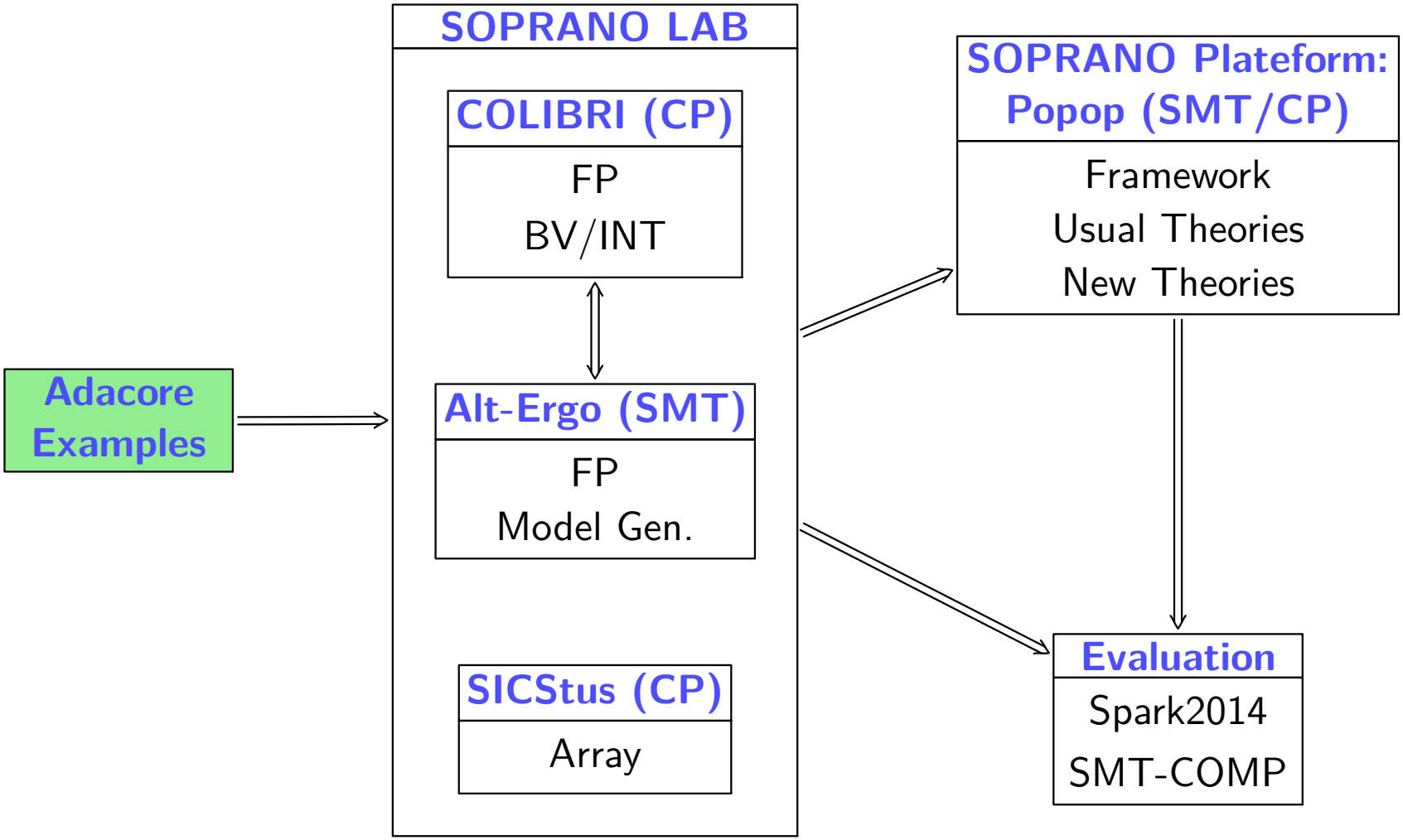
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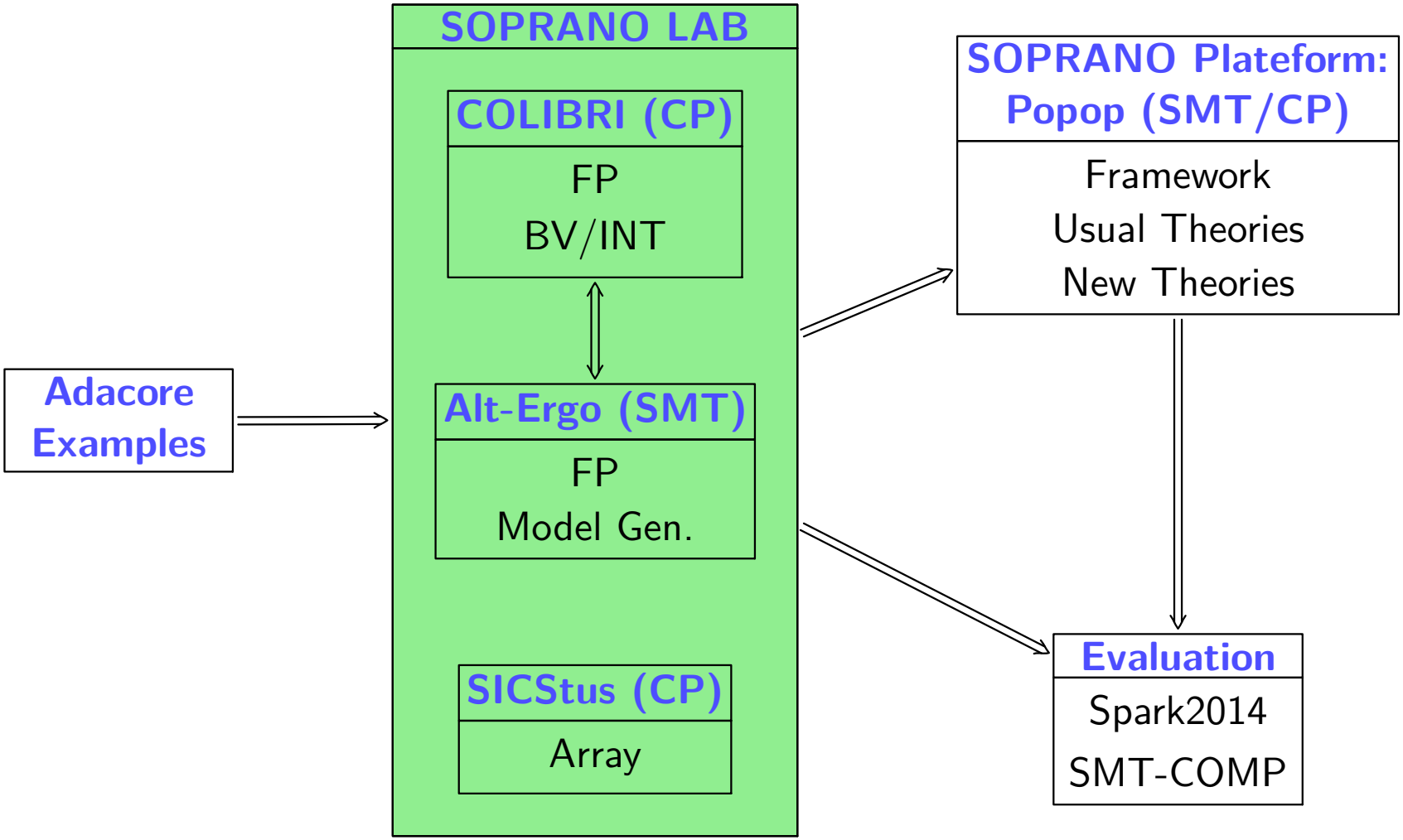
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Floating-Point Arithmetic: Huge Improvements

(CEA, Inria, UPSud, OcamlPro)

$$A \leq \frac{X \ominus Y}{X \ominus Z} \leq B \quad \text{with } \ldots$$

$$\sqrt{X^2 \ominus Y^2} \leq X \quad \text{with } \ldots$$

$$\frac{X}{\sqrt{X^2 \oplus Y^2}} \leq 1 \quad \text{with } \ldots$$

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(CEA, UPSud)

- Precise domain propagation
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- Instantiated for many functions
- Linearization of constraints for simplex

Floating-Point Arithmetic: Alt-Ergo

(OCamlPro, UPSud)

Floating-point rounding operator on rational constants

```
1 axiom rounding_operator_1 :
    forall x : real .
3   forall i , j : real .
    forall md : fpa_rounding_mode.
5   forall p,m : int
     [round(m,p,md,x), x in [ i , j ]].
7      i ≤ x ≤ j →
       round(m,p,md,i) ≤ round(m,p,md,x) ≤ round(m,p,md,j)
9
```

(Kailiang Ji, post-doc SOPRANO)

Floating-Point Arithmetic: Recap

Progression of COLIBRI and Alt-Ergo on AdaCore benchmarks:

	Before SOPRANO	Current Results
COLIBRI	18 / 28	25 / 28
Alt-Ergo	2 / 28	19 / 28

Bitvector and Integer Arithmetic

(CEA)

- High-level view of bitvectors
- New propagations for integers $\leftrightarrow$ bitvectors
- Integration in Popop (SOPRANO platform)
- Presentation at *CP meets Verification 2016 Workshop*

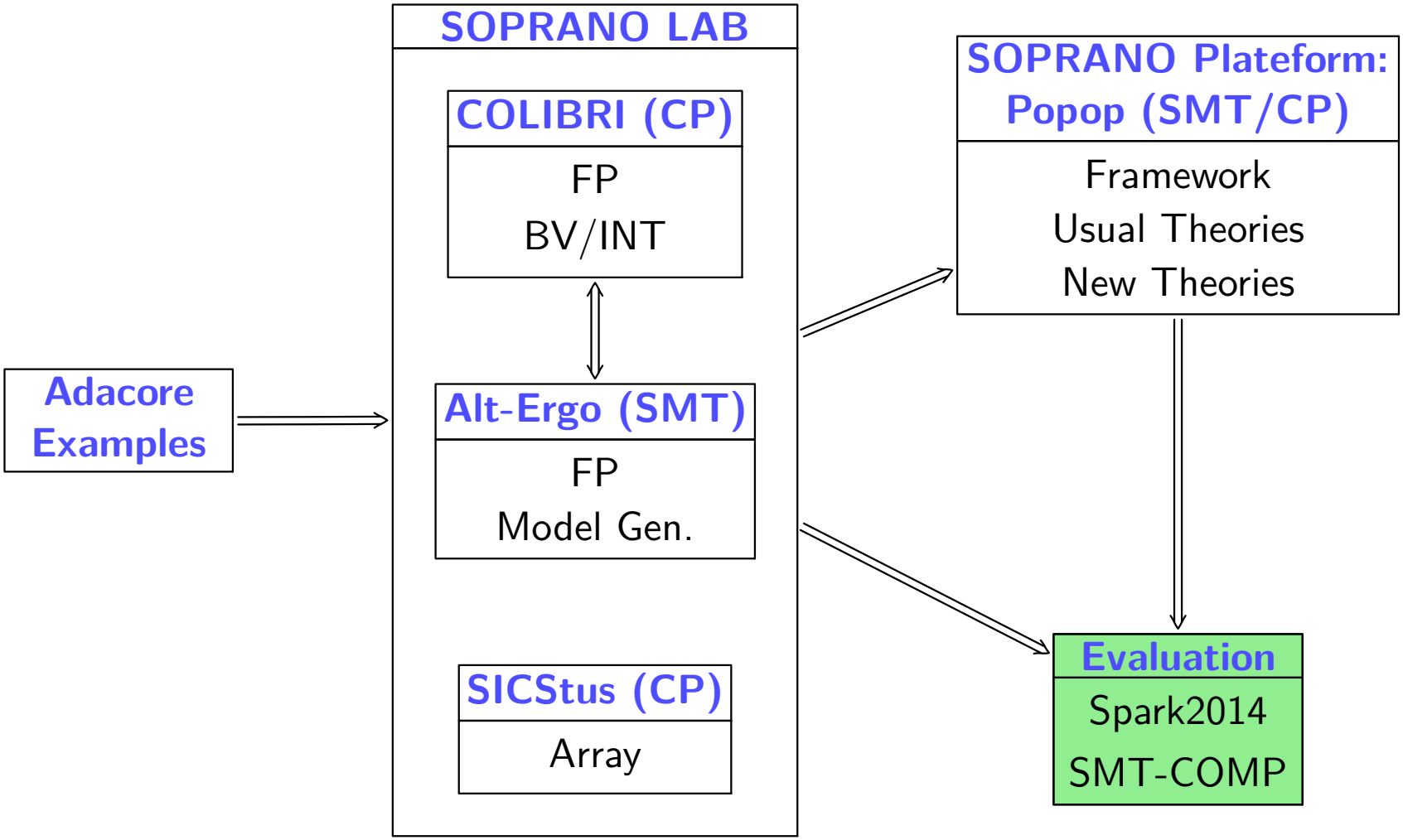
(Zakaria Chihani, post-doc CEA)

Array Theory with CP

(Inria, CEA)

- Large arrays badly handled by SMT solvers
- New domain for arrays
- Propagation and learning
- Integration in SICStus clpfd CP solver

(Quentin Plazar, PhD SOPRANO)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(AdaCore, CEA, UPSud, OCamlPro)

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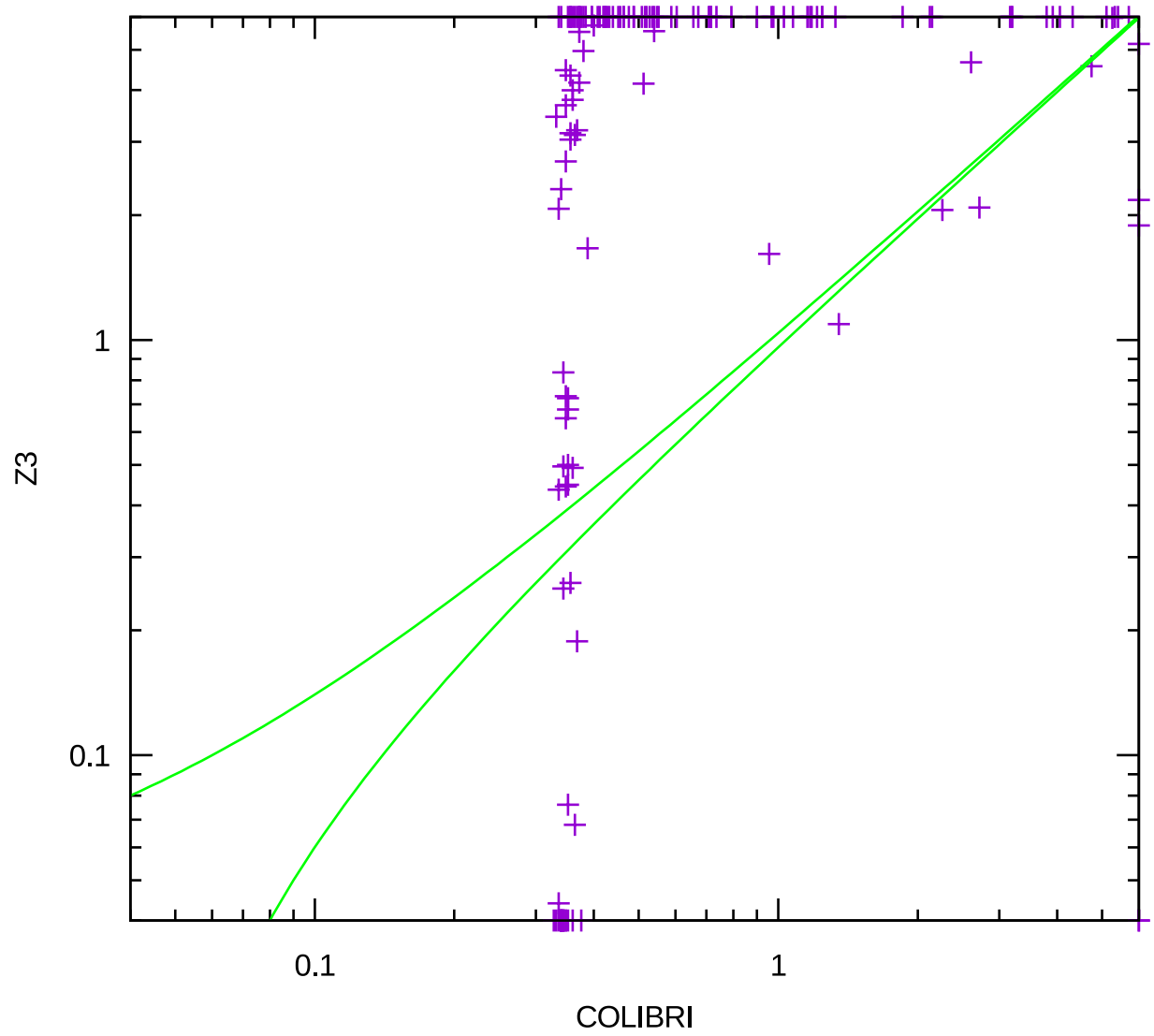
COLIBRI on SMT-COMP FP category

(CEA)



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- Connection from SPARK to COLIBRI and Alt-Ergo

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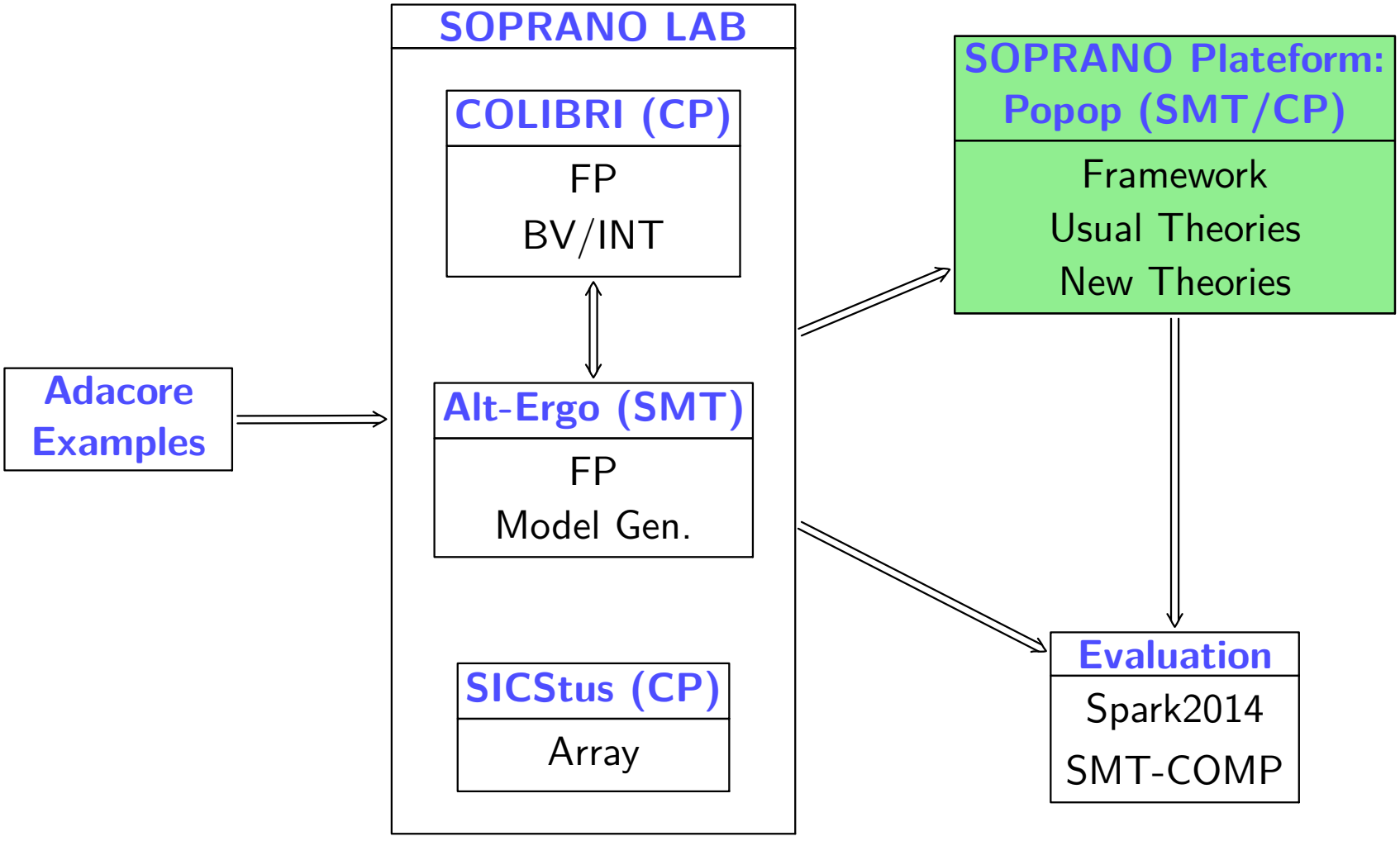
- Connection from SPARK to COLIBRI and Alt-Ergo
- Soon, evaluation directly on SPARK programs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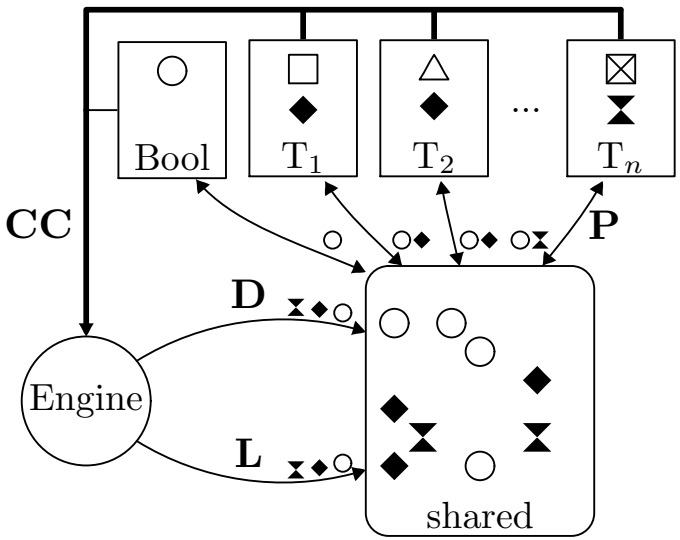
Popop Framework (Implemented)



Engine:

- equivalence class
- semantic values
- pluggable domains
- event loop
- pluggable learning

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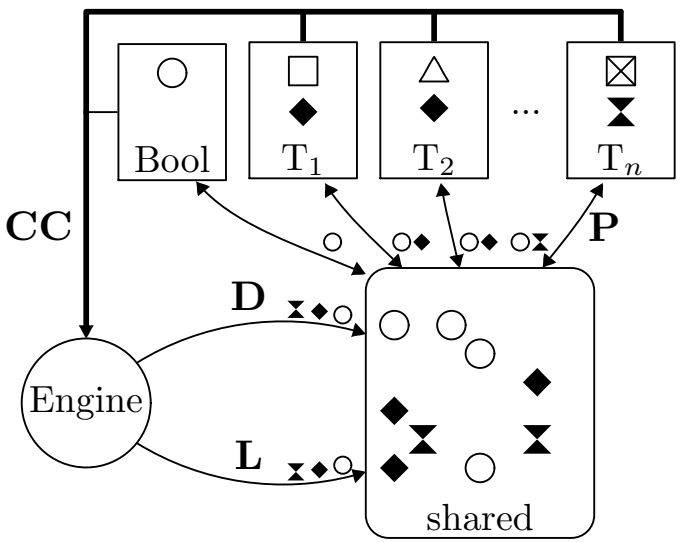

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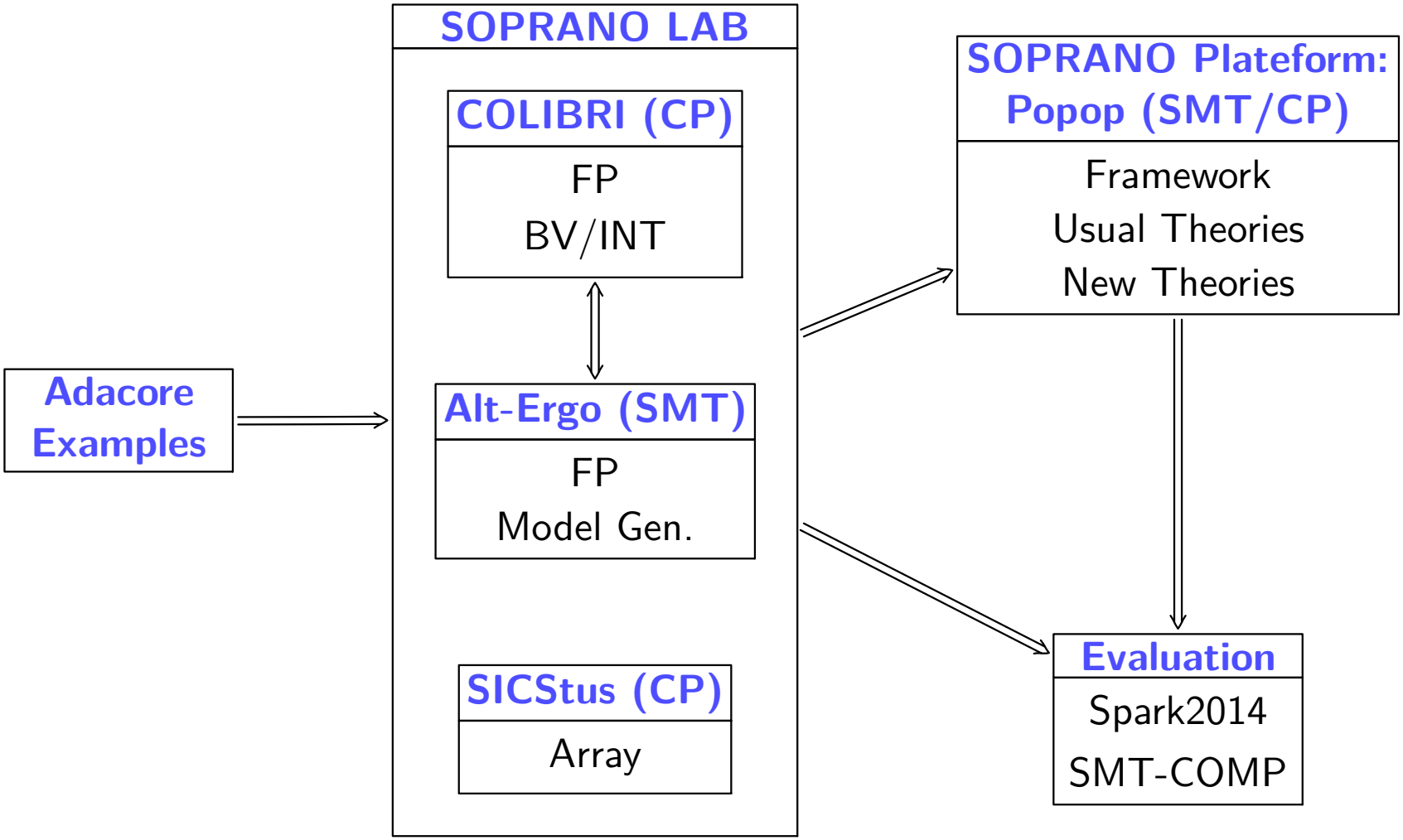
Theories:

- Bool: friendly with other theories
- equalities/disequalities, `ite`
- uninterpreted function
- linear rational arithmetic
- bitvectors (partial)

Popop Framework: Roadmap

Roadmap:

- implementation of learning for bitvector operators
- structures, algebraic datatypes, arrays
- floating-point arithmetic
- non-linear rational arithmetic
- integer linear arithmetic and bitvectors on arithmetic operators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Current releases (CEA, OcamlPro)

OCI open-source:

- Benchmarking framework
- Continuous integration (used daily for Frama-C, maybe Coq)

Ocplib-Simplex open-source:

- Simplex implementation
- Parametric on constants and polynomial

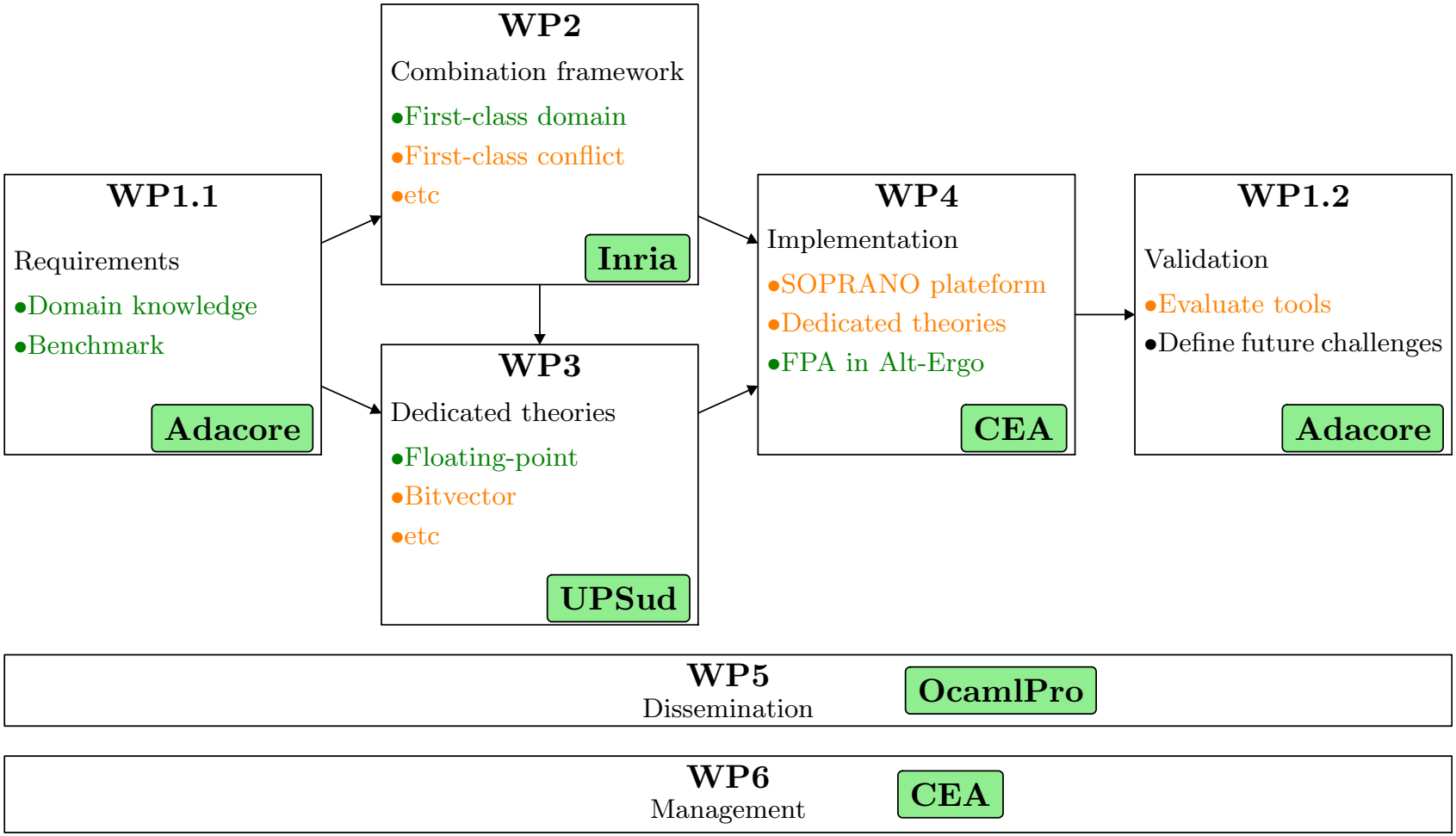
Alt-Ergo: new open-source release with model generation

COLIBRI Freeware

Dissemination

- Chaired *CP meets Verification 2016 Workshop*
- Publications in preparation:
  - Semantic triggers and applications in Alt-Ergo
  - Real behavior of floating point (techniques used in COLIBRI)
  - Quadruple domain representation tackling bitvector theory
  - CP meets SMT: MCSAT generalization

Workflow


WP2
Combination framework
•First-class domain
•First-class conflict
•etc
Inria
WP1.1
Requirements
•Domain knowledge
•Benchmark
Adacore
WP3
Dedicated theories
•Floating-point
•Bitvector
•etc
UPSud
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CEA
WP1.2
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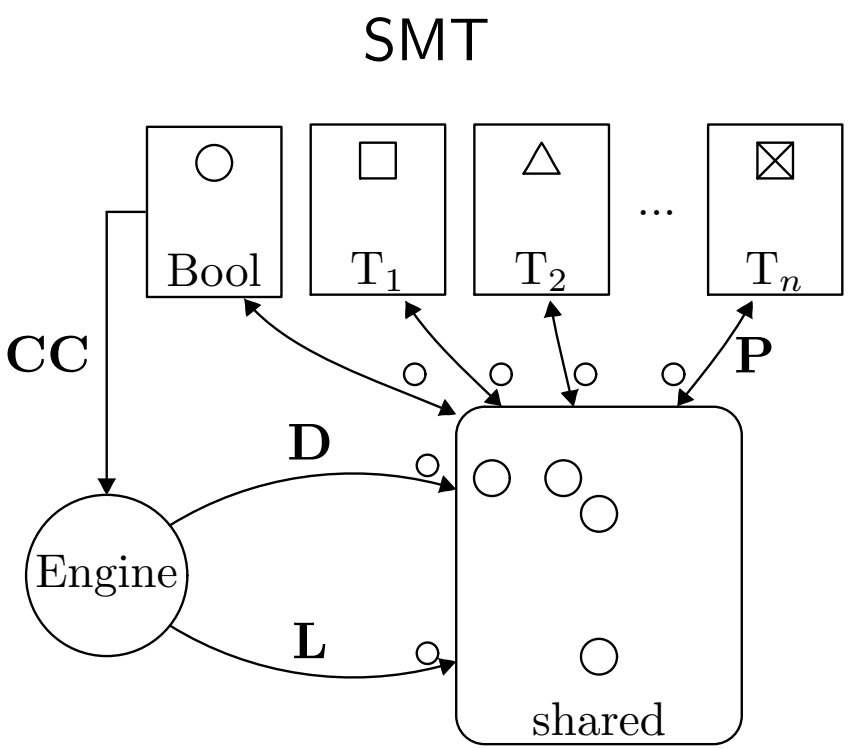
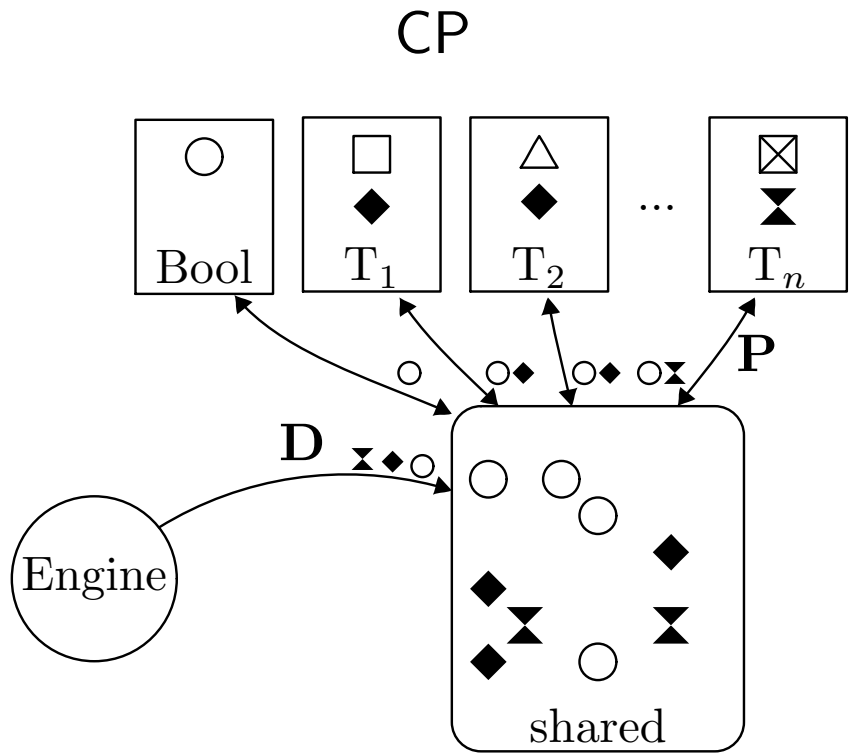
•Define future challenges
Adacore
WP5
Dissemination
OcamlPro
WP6
Management
CEA

The Problems





Floating-Point Arithmetic: Monotonic functions

(CEA, UPSud)

Theorem

Let $D, E \subset \mathcal{R}$, $f : D \mapsto E$ *and* $f^{-1} : E \mapsto D$ *such that*

- $\forall x : D,\ f^{-1}(f(x)) = x$
- f *increasing*

We have

- $\forall x \in D,\ o(y) \in E,\ o(f(x)) < o(y) \implies o(x) \leq o(f^{-1}(o(y)))$
- $\forall x \in D,\ y \in E,\ o(f(x)) < o(f(y)) \implies x < y$

Instantiated for many functions in COLIBRI's DBM