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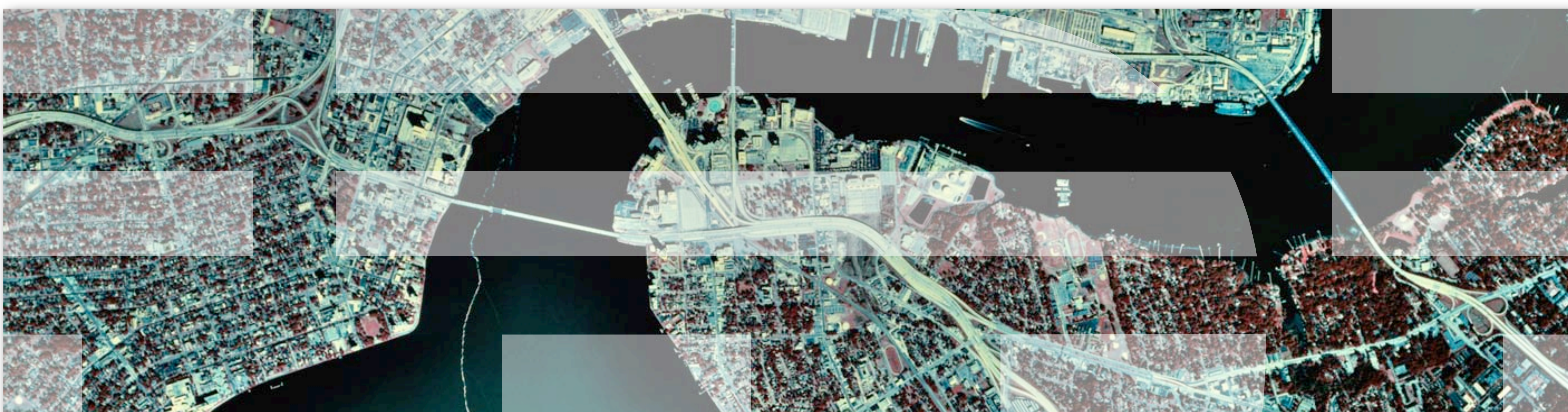
Sal/Svm—A Language and Virtual Machine for Computing with Non-Enumerated Sets



Outline

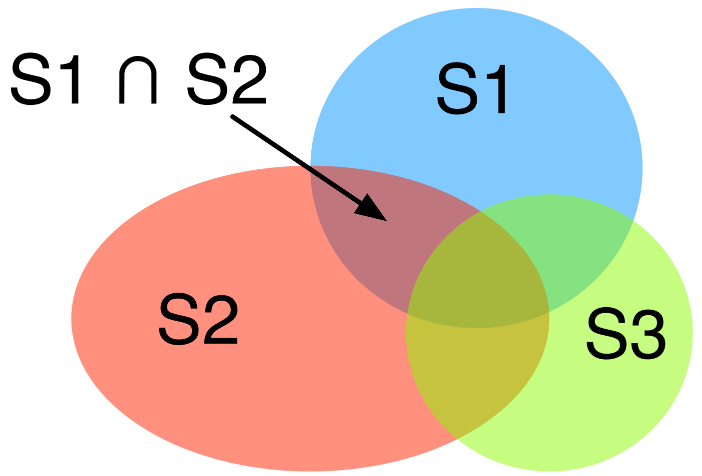
- Background and Example
- Architecture
- Implementation
- Preliminary Evaluation
- Summary

Research Context and Background

- Research context: Hardware architectures for future device technologies
  - Are microprocessors the best way to take advantage of tradeoffs in ⋘20nm CMOS?
- Research problem
  - **Challenge**: Can we represent compute problems independent of algorithms for their solution?
  - **Observation**: Can represent problems using set-theoretic properties their solutions obey
- This talk
  - Platform that represents compute problems using set-theoretic constructs and machine state

Sets and Non-Enumerative Set Representations

- Most people are familiar with these:



, etc.

- Generally, people often think of sets as these:

```
S4 = {1,3,7,9}
S5 = {(1, “science”), (2, “history”)},
```

etc.

- Two main ways of representing sets
  - Enumerated: items in set captured in the representation, e.g., {1, 3, 5, ...}
  - Non-enumerated: properties of the elements captured in representation: e.g. “odd integers”

Sal (Set Assembly Language) and Svm (Set VM)

- Sal/Svm: A Language and Virtual Machine for Computing with Non-Enumerated Sets
  - **Application**: precisely representing compute problem definitions without algorithms
  - Problems specified in an input language (Sal) for describing set relations
  - A virtual machine (Svm) processes the set relations, returning a solution (if requested / possible)

- A simple example: set of odd integers between 0 and 1000 that are not multiples of 3:

① Universe

```
--      The universe
U1       : Integers = <0 ... 1000>

--      The set
S1       = (((v:U1[1] % 3) != 0) &
            ((v:U1[1] % 2) != 0) : U1)
```

③ Boolean predicate

② Set

Sal problem specification / set definition

Svm Output

```
S1 = {1, 5, 7, 11, 13,
17, 19, ...}

(cardinality = 333,
predicate tree size = 11)
```

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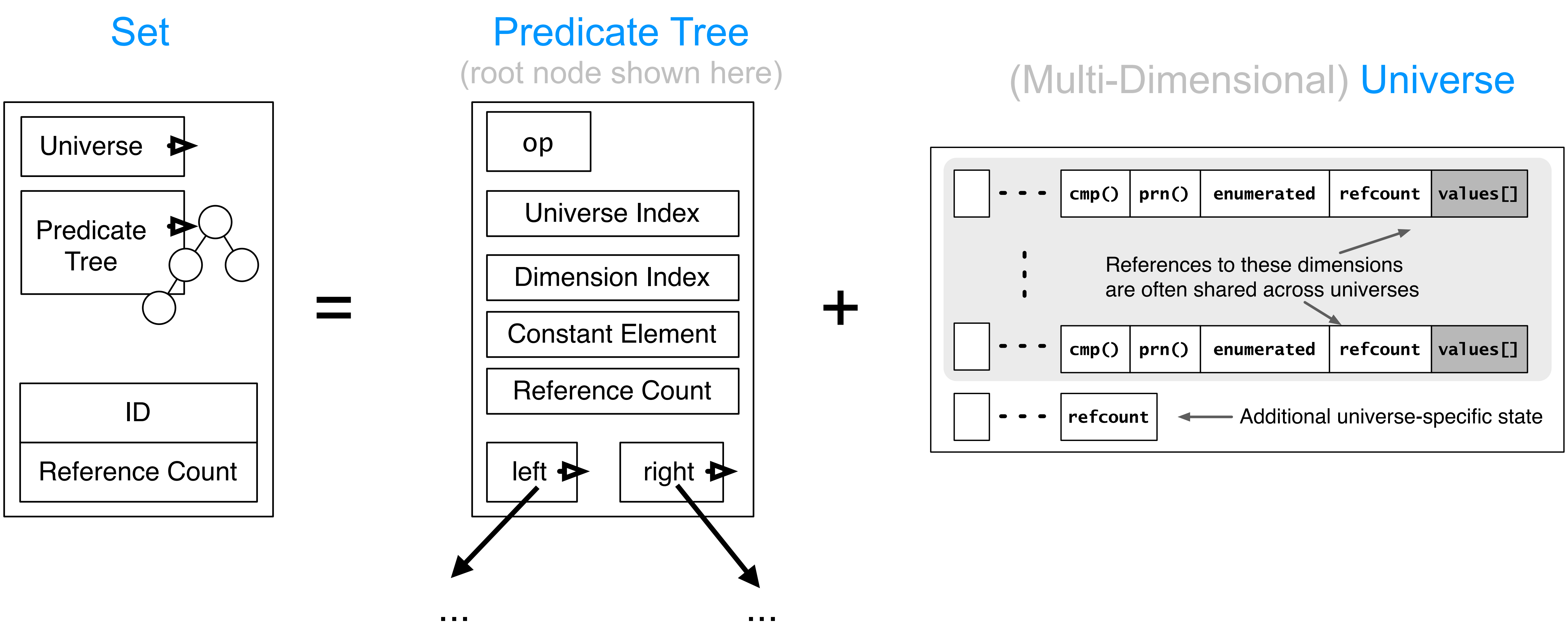
Representation of Sets in Svm



Svm Machine Registers

- Svm virtual machine has three sets of registers that underlie all computation
  - **U** (universe) **registers**: hold the “basis” elements (scalar)
  - **P** (predicate) **registers**: hold Boolean predicate trees (data structures)
  - **S** (set) **registers**: hold information about specific pairings of predicates to universes

```
--      The universe
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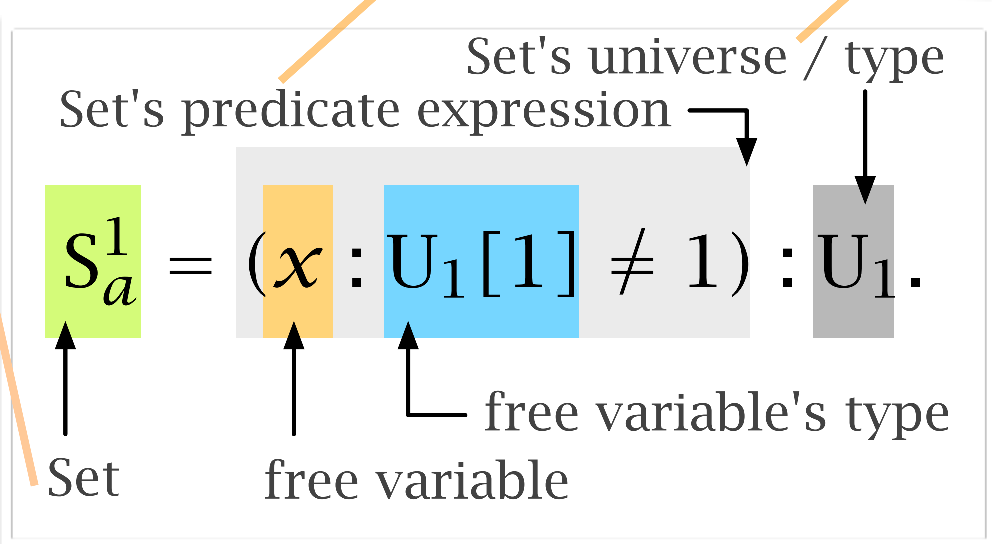
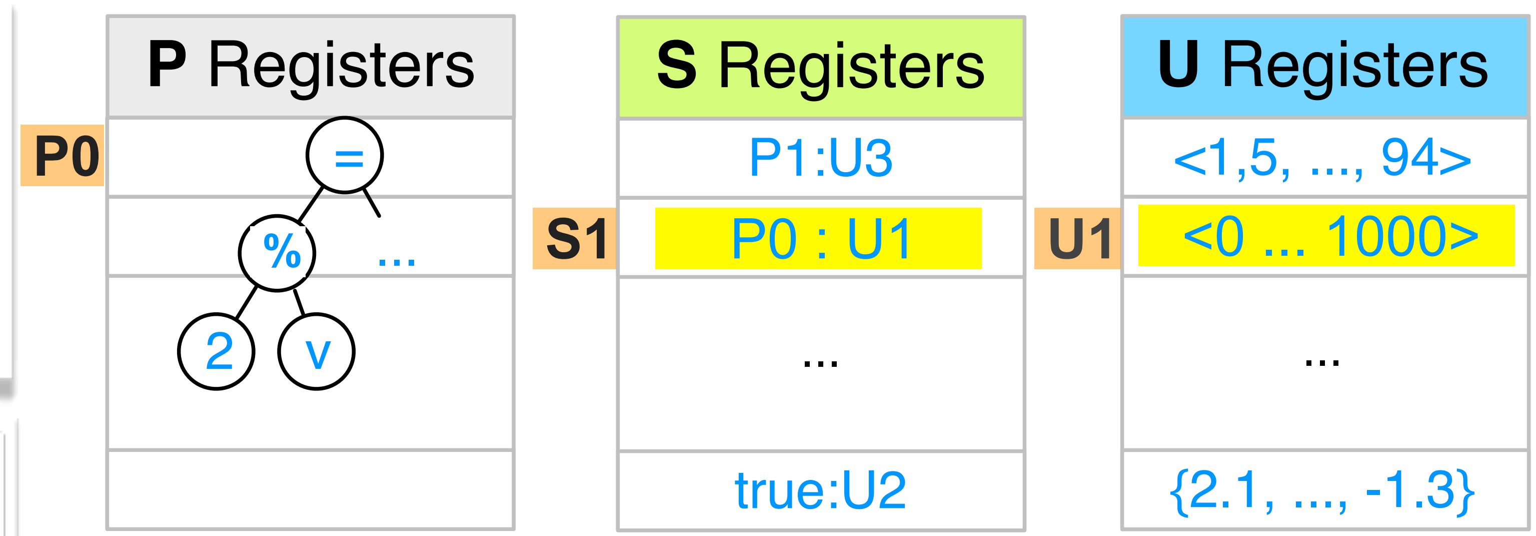
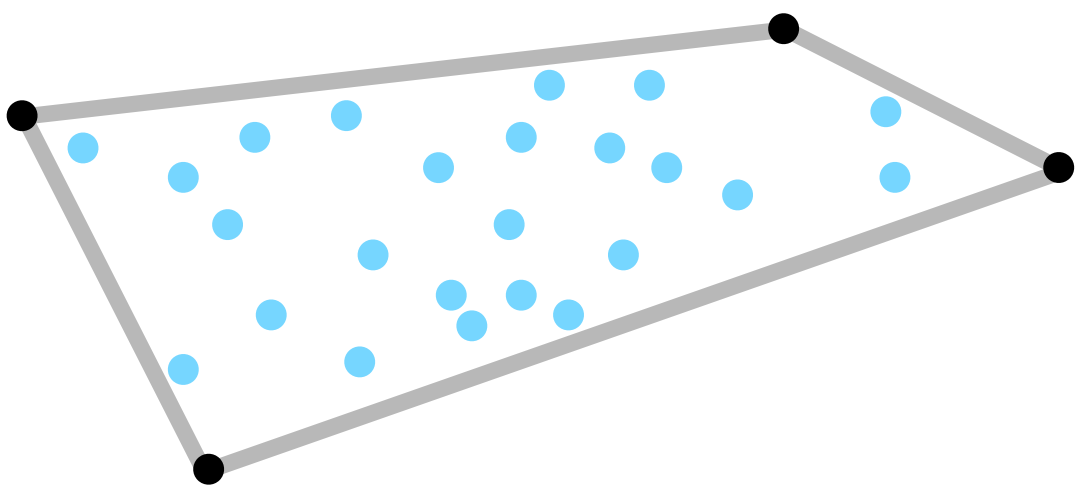




Larger Example: Convex Hull Compute Problem Definition



Definition (Convex Hull). The convex hull, CH(*S*), of a set *S* of points in the plane, is the smallest convex polygon for which each point in *S* is either on the boundary thereof, or in its interior.

- Convex hull computational problem specification in Sal

```
U0      : Integers = <1 … 10 delta 2*iota>
U1      : Integers = <1 … 10 delta (2*iota)+1>
U2      = U0 x U1

P10     = !((qy == py:U2[2]) & (qx == px:U2[1]))
P11     = ((qx*ry – qy*rx) – px:U2[1]*(ry – qy) + py:U2[2]*(rx – qx)) >= 0
P1      = exists qx:U2[1] exists qy:U2[2] forall rx:U2[1] forall ry:U2[2] (P10 & P11)

S2      = (P1   : U2)

print   enum S2
```

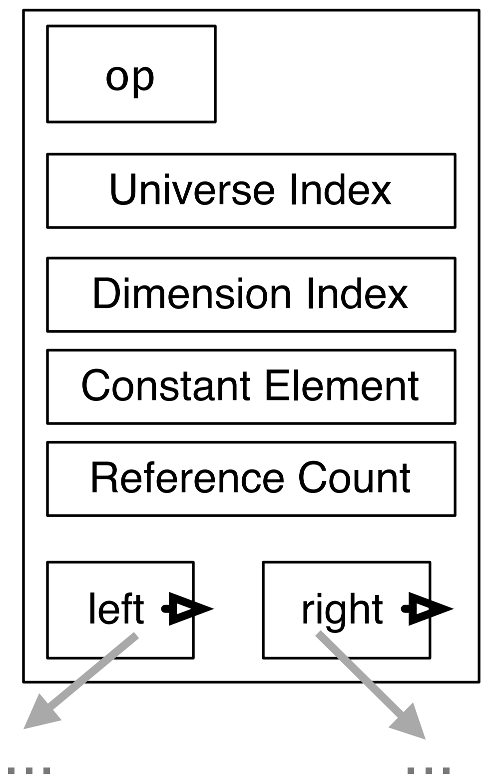
Boolean Predicate Trees

Sal predicate expression

```
P10      = !((qy == py:U2[2]) & (qx == px:U2[1]))
```

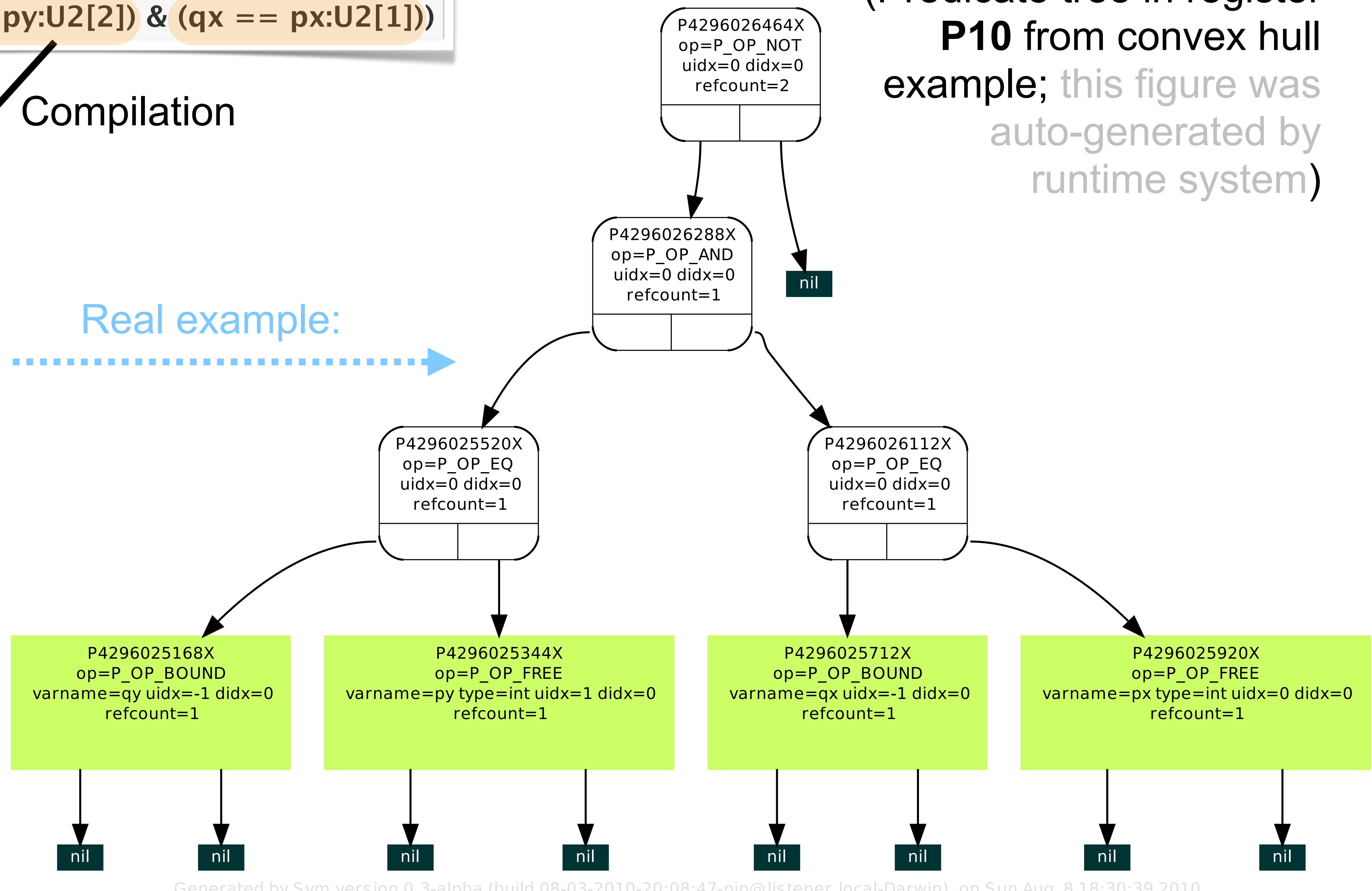
Compilation

Predicate Tree



Real example:

(Predicate tree in register **P10** from convex hull example; this figure was auto-generated by runtime system)



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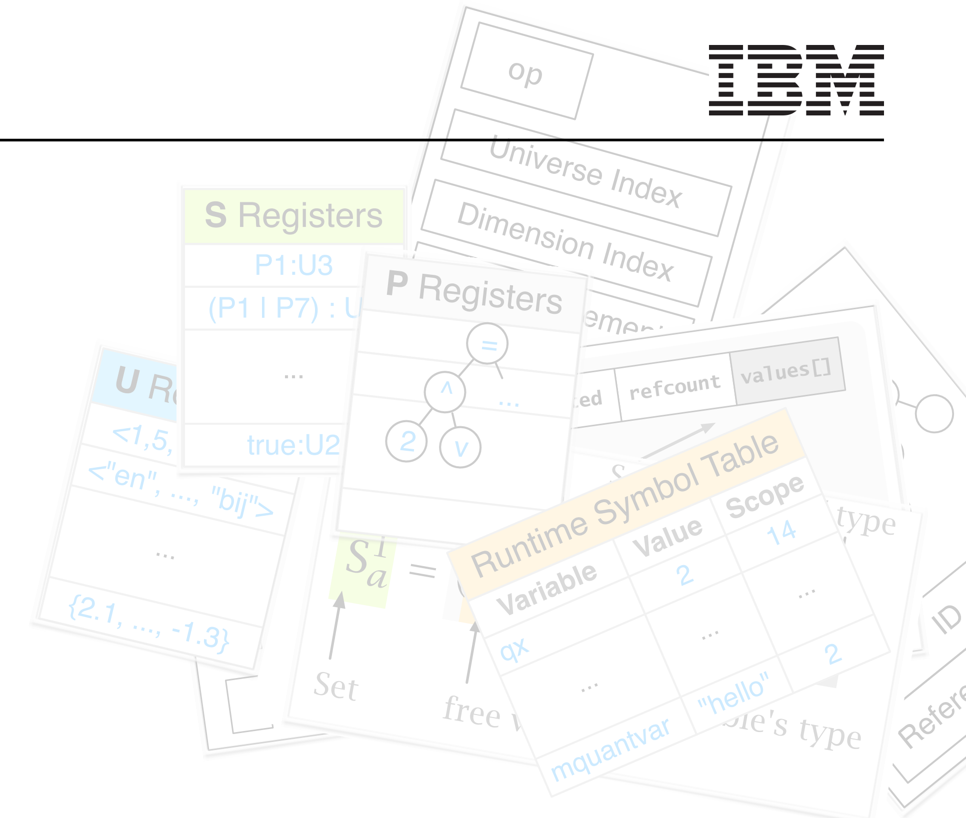
Implementation



- **Svm**
  - Core of runtime system implemented in a library, in ANSI C
  - Library also provides utilities such as rendering machine state (example in previous slide), etc.

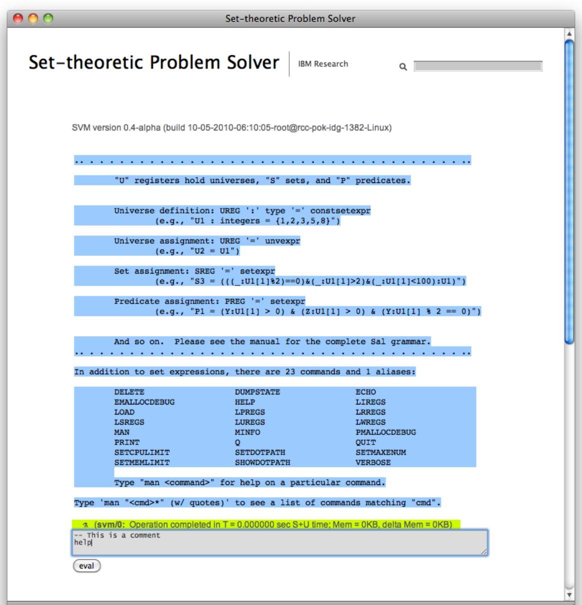
- **Salc**
  - Implemented in C, with YACC-driven parser front-end
  - Takes Sal source assembler and outputs intermediate representation in an ELF container
  - A few optimizations implemented, potential for more

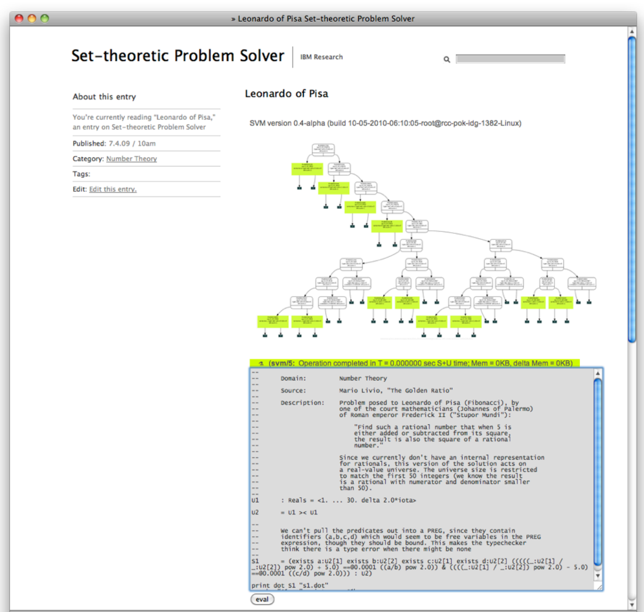
- **Interactive command console**
  - Accepts Sal statements, parses and injects into machine state
  - Interactive help system, commands to probe Svm state, etc.

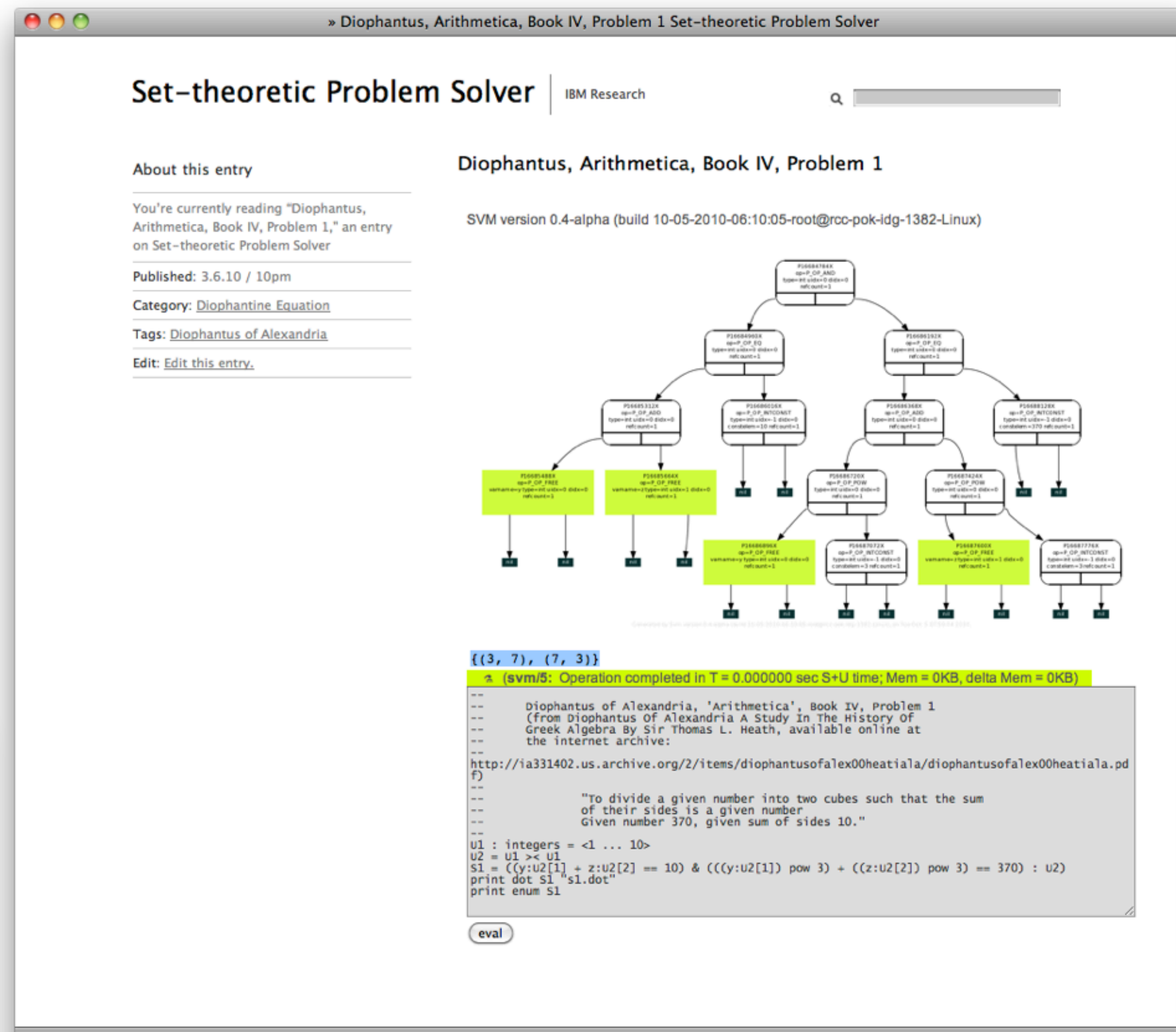
- **Web interface to interactive console on server**
  - Runs interactive command console via web, on server

Internal Demo Site Examples

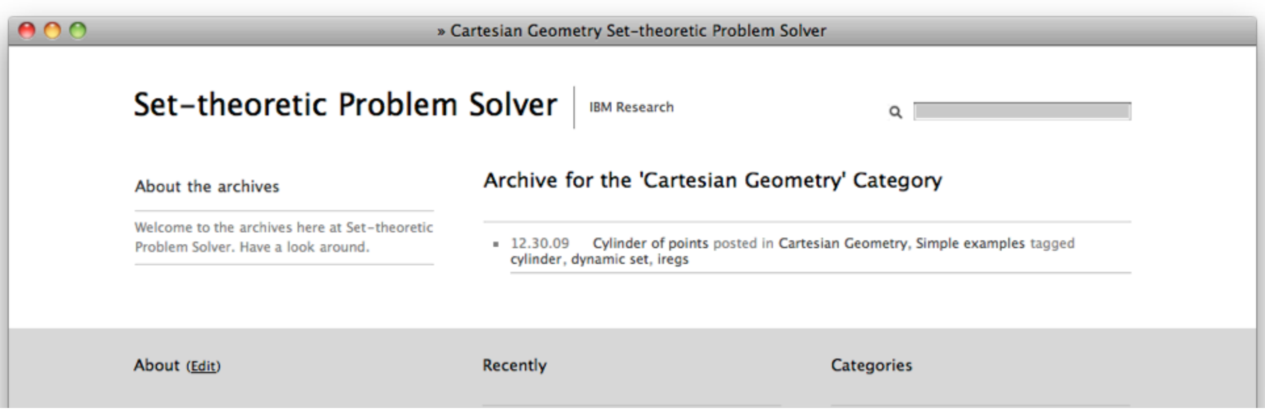
- Interactive interface is embedded in a content-management system
  - Contains examples that can be modified and run via web; users can post comments, questions







- A collection of example problems



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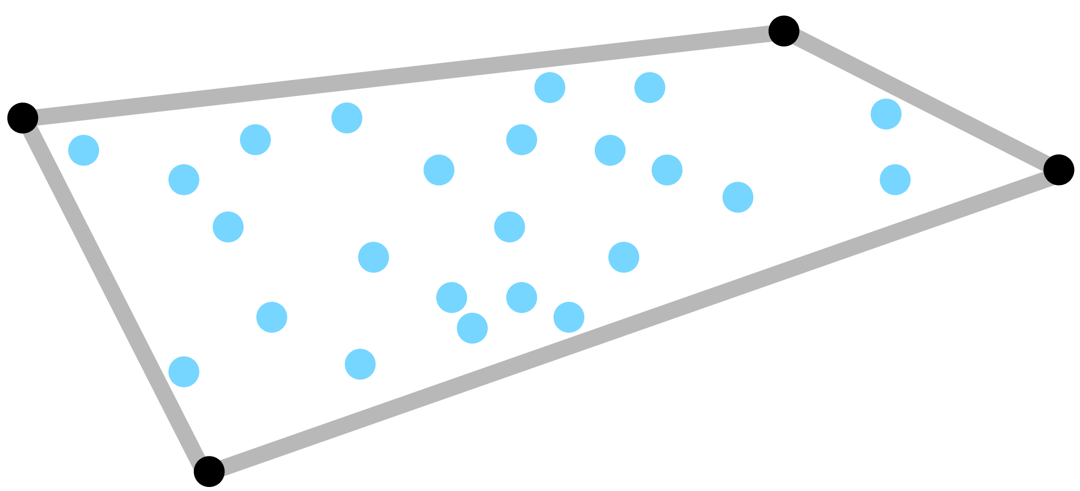
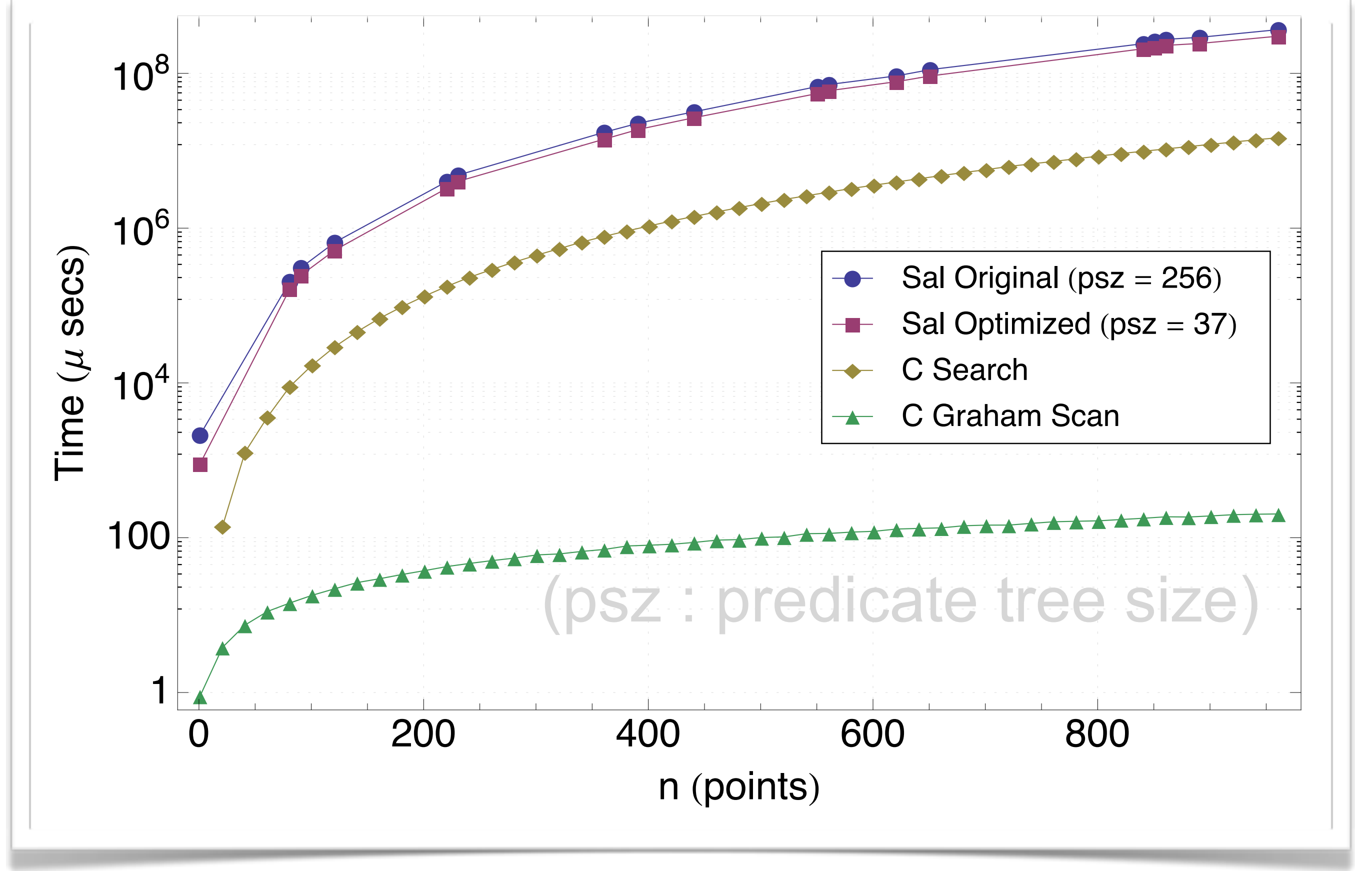
Preliminary Performance Evaluation: Convex Hull Problem

Recall: given set of points in plane, compute "points on the hull" (black points below)





- Evaluation setup
  - All cases: compiler: **gcc 4.2.1**, -O3; CPU: **2.8GHz Intel® Core™ i7**; OS: **MacOS® 10.6.3**
- Svm is within ~20× of optimized C code implementing same enumeration algorithm
  - Sal problem specification is significantly simpler (~11 lines) than C algorithm implementation
- Orders of magnitude slower than (provably) optimum algorithm (Graham's Scan)
  - Paper provides a counterexample where Sal/Svm and C search can be more energy-efficient

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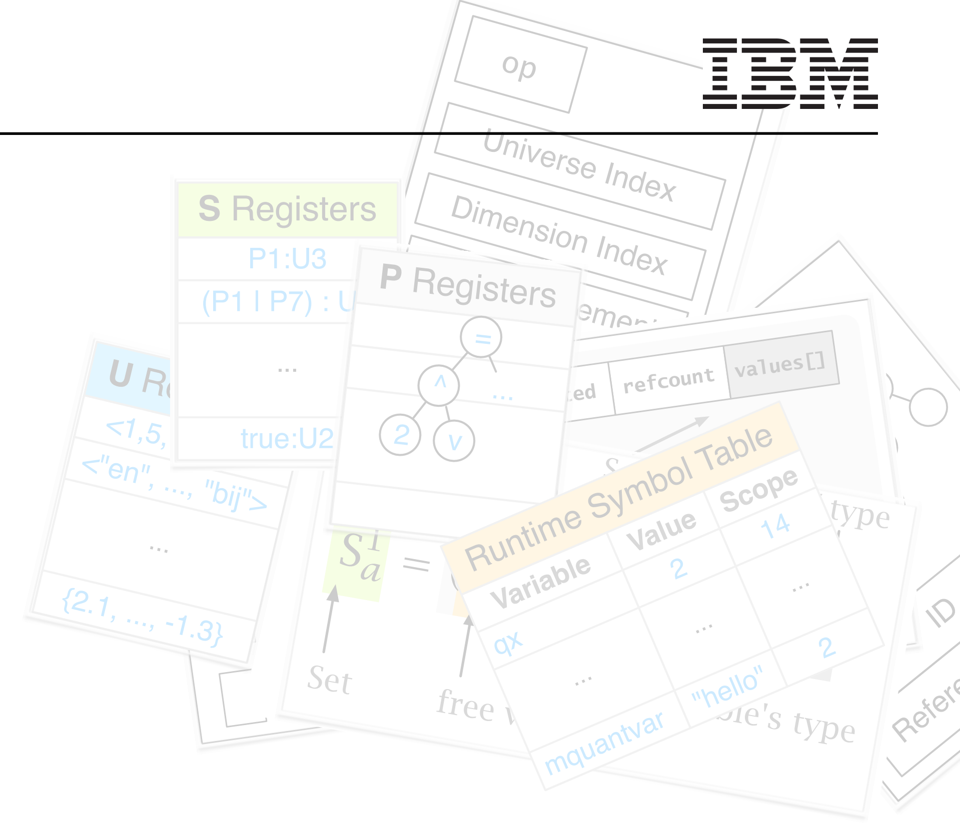
Summary and Ongoing Work



- Summary: Research context
  - Architectures for future devices and device technologies

- Summary: Sal/Svm
  - A framework for specifying computational problems using set-theoretic constructs
  - Enables leaving algorithm choice undefined, to pick best hardware-dependent tradeoff

- Ongoing: Integrating Sal-based problem definitions in high-level languages
  - Ongoing work to use Sal problem definition as part of type structure in a high-level language
  - Specification of “arithmetic imprecision” in computation problems

- Availability
  - Currently available to users inside IBM Research
  - Working to make interactive web version available to general public in coming months